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INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1887.

PUBLISHED BY THE INSTITUTION,

10 VICTORIA CHAMBERS, LONDON, S.W.

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CORRECTIONS.

Page 228, line 24, for "In 1881 he had modified *them* by" read "In 1881 he had modified *that type of engine* by." And in line 28, for "Engines of this type" read "Engines of this *modified* type."

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

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PAST-PRESIDENTS.

George Stephenson, 1847-48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849-53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854-55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856-57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858-59, 1867-68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869.

Robert Napier, 1863-65. (*Deceased* 1876.)

John Ramsbottom, 1870-71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872-73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, D.C.L., F.R.S., 1874-75.

Thomas Hawksley, F.R.S., 1876-77.

John Robinson, 1878-79.

Edward A. Cowper, 1880-81.

Percy G. B. Westmacott, 1882-83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885-86.

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Institution of Mechanical Engineers.

OFFICERS.

1887.

PRESIDENT.

Edward H. Carbutt, ... London.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, D.C.L., F.R.S., ... London.
Thomas Hawksley, F.R.S., ... London.
Jeremiah Head, ... Middlesbrough.
John Ramsbottom, ... Alderley Edge.
John Robinson, ... Manchester.
Percy G. B. Westmacott, ... Newcastle-on-Tyne.

VICE-PRESIDENTS.

Daniel Adamson, ... Manchester.
Charles Cochrane, ... Stourbridge.
David Greig, ... Leeds.
Arthur Paget, ... Loughborough.
Richard Peacock, M.P., ... Manchester.
Joseph Tomlinson, Jun., ... London.

MEMBERS OF COUNCIL.

William Anderson, ... London.
Benjamin A. Dobson, ... Bolton.
Sir James N. Douglass, F.R.S., ... London.
Samuel W. Johnson, ... Derby.
Alexander B. W. Kennedy, F.R.S., ... London.
William Laird, ... Birkenhead.
Edward B. Marten, ... Stourbridge.
Edward P. Martin, ... Dowlais.
R. Price-Williams, ... London.
Sir James Ramsden, ... Barrow-in-Furness.
E. Windsor Richards, ... Middlesbrough.
T. Hurry Riches, ... Cardiff.
Benjamin Walker, ... Leeds.
J. Hartley Wicksteed, ... Leeds.
Thomas W. Worsdell, ... Gateshead.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 10 *Victoria Chambers, London, S.W.*

[Telegraphic address:—*Mech, London.*]

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Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1887.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., F.R.S., Royal Arsenal, Woolwich.

1878. Crawford and Balcarres, The Right Hon. the Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1883. Kennedy, Alexander Blackie William, F.R.S., Professor of Engineering, University College, Gower Street, London, W.C.; and 3 Prince's Street, Westminster, S.W.

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1883. Trasenster, Jean Louis, Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

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1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, Manager, Messrs. Oswald Mordaunt and Co., Southampton.

1878. Adcock, Francis Louis, Government Land Surveyor, Post Office, Kimberley, Griqualand West, Cape Colony: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, care of Mrs. W. Hudson, Middleton Hall, Pickering.

1883. Allam, Edwin Clerk, Normanhurst, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Wild, Albert Works, Penistone Road, Sheffield.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

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1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of W. Cuningham, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1876. Allport, Charles James, 11 Euston Square, London, N.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, Temple Sheen, East Sheen, London, S.W.

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent; Lesney House, Erith, S. O., Kent; and 3 Whitehall Place, London, S.W. [3695.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Millwright, London.* 1731.]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool; and 176 Upper Parliament Street, Liverpool.

1874. Archer, David, Oldbury Railway-Carriage and Wagon Co., Oldbury, near Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford [*Armer, Hallford, Dartford.*]; and 13 Clifton Road, Brockley, London, S.E.

1887. Armit, Thomas Napier, Dundee Salvage Co., 23 Panmure Street, Dundee. [*Armit, Dundee.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

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1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1887. Arrol, William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, Managing Engineer, Argentine Government Marine Workshops, Buenos Aires, Argentine Republic.

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and 215 Plymouth Grove, Manchester. [*Thomas Ashbury, Manchester.*]

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]

1875. Atkinson, Edward (*Life Member*), Simond's Steel and Iron Forging Works, Acre Street, New Road, Wandsworth Road, London, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley. [*Bagshaw, Batley.*]

1865. Bailey, John, 41 Rue des Vieillards, Boulogne-sur-mer, France.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

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1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; 22 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollockshields, Glasgow. [*Glacis, Glasgow.*]

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1887. Baker, William James, Town Hall Chambers, 72 New Market Street, Bradford.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.

1887. Barningham, James, 27 Corporation Street, Manchester.

1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.

1878. Barr, James, care of William McConnell, 45 Oakshaw Street, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Outside Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1887. Barringer, Herbert, Assistant Superintendent Engineer, Messrs. Scrutton Sons and Co., 9 Gracechurch Street, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

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1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.

1887. Bate, Charles McGuire, Captain R.E., Railway Depôt, Royal Arsenal, Woolwich.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Queen Chambers, 88 Colmore Row, Birmingham; and Heald Bank, Langham Road, Bowdon, Cheshire.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Engineer, Strand and North Docks Engineering Works, Swansea.

1875. Beckwith, John Henry, Manager, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, 94 St. Mary's Street, Cardiff.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Consulato Brittanico, Spezia, Italy; and care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 6 Wetherby Terrace, Earl's Court, South Kensington, London, S.W.

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1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1887. Bennetts, Edward John, Nine Reefs Mine, Colar Road Station, Mysore, India: (or care of W. Francis Bennetts, Roskear, Camborne.)

1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]

1887. Bertram, William, Messrs. George and William Bertram, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 8 Canynge Square, Clifton, Bristol.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1887. Binnie, Alexander Richardson, Town Hall, Bradford.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

1875. Bisset, William Harvey, Board of Trade Office, Falmouth; and Erin Lodge, Green Bank, Falmouth.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Barrow Ship Building Works, Barrow-in-Furness.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Bocquet, William, North Western Railway, Lahore, India.

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1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley; and Hunningley, near Barnsley.

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1884. Bourne, James Johnstone, 3 St. Nicholas Buildings, Newcastle-on-Tyne.

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.

1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.

1869. Boyd, William, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne. [*Wall, Newcastle-on-Tyne; Wall, Cardiff.*]

1884. Boyer, Robert Skeffington, 8 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1878. Bradley, Frederick Augustus, Eldorado, Butler County, Kansas, United States.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich; and Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1883. Bricknell, Augustus Lea, 56 Arlington Road, Brixton, London, S.W.

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1887. Brier, Henry, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.; and Connaught Mansions, Victoria Street, Westminster, S.W.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Teilo Tin-Plate Works, Pontardulais, R.S.O., Glamorganshire.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, South Indian Railway, Cuddalore, Madras Presidency, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Stabilimento Armstrong, Pozzuoli, near Naples, Italy: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1884. Brown, Oswald, 2 Victoria Mansions, Victoria Street, Westminster, S.W. [*Acqua, London.*]

1887. Browne, Frederick John, 69 Lombard Street, London, E.C.

1874. Browne, Tomyns Reginald, District Locomotive Superintendent, East Indian Railway, Asansol, Bengal, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 8 Champion Park, Denmark Hill, London, S.E.

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1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1873. Buckley, Robert Burton, Executive Engineer, with Supreme Government of India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, 7 Penypound, Abergavenny.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes and Co., 90 Cannon Street, London, E.C.)

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, Mining Engineer of the Government Coal Mines, Warora, Central Provinces, India; and Neville Cottage, Clifton Road, Newcastle-on-Tyne.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rio Tinto Mines, Huelva, Spain.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1877. Burgess, James Fletcher, 14 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

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1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Engineer to the Corporation of Oxford, Corporation Water Works, Oxford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1884. Butcher, Joseph John, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1887. Caiger, Emery John, Messrs. W. J. Helmore and Co., 23 St. Mary Axe, London, E.C.

1886. Cambridge, Henry, Messrs. Jacobs and Cambridge, Bute Docks, Cardiff.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java: (or care of R. Campbell, Slamat Cottage, Mount Vernon, Glasgow.)

1882. Campos, Raphael Martinez, 598 General Lavalle, Buenos Aires, Argentine Republic.

1885. Capito, Charles Alfred Adolph, Messrs. Capito and Hardt, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.; and 7 Nygade, Copenhagen. [*Capito Hardt, London.*]

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Madras Presidency State Railways, Guntakal Junction, Madras Presidency, India: (or care of Rev. J. H. Cardew, 1 Spring Grove Villas, Cheltenham.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1887. Carlyle, Thomas, Inspector of Ordnance Machinery, Royal Artillery, Singapore: (or 72 Glyndon Road, Plumstead.)

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

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1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead. [*Wardale, Gateshead.*]

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, La Compañia Unida, Guanajuato, Mexico: (or care of H. M. Carter, 1 Gresham Buildings, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1883. Cawley, George, "Industries" Office, 70 Market Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, 52 Amwell Street, Claremont Square, London, E.C.

1884. Chamberlain, John, Assistant Engineer, Gas Light and Coke Co.'s Tar and Liquor Works, Beckton, London, E.

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham. [*Chatwin, Birmingham.*]

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

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1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1880. Churchward, George Dundas, Locomotive Superintendent, China Railway Company, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln. [*Claytons, Lincoln.*]

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W. [*Cleminson, London.* 3046.]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, 42 Newcomen Street, Redcar.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

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1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bradford.
1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)
1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.
1886. Coles, Robert, White Hall, Foleshill, Coventry.
1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.
1884. Collenette, Ralph, Egerton Iron Works, Chester.
1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.
1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.
1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.
1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.
1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.
1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]
1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.
1874. Cooper, William, Neptune Foundry, Hull. [*Cooperco, Hull.*]
1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne
1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]
1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.
1884. Corder, George Alexander, Chief Engineer, Chinese Naval Service, China; care of Commissioner of Customs, Shanghai, China.
1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 30 Walbrook, London, E.C. [*Stothert, Cornes, London.*]
1848. Corry, Edward, 9 New Broad Street, London, E.C.
1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)
1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.
1875. Cottrill, Robert Nivin, Beehive Works, Bolton. [*Beehive, Bolton.*]
1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.
1868. Coulson, William, High Coniscliffe, Darlington.

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1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and Palace Chambers, 9 Bridge Street, Westminster, London, S.W.

1882. Courtney, William McDougall, care of Frank S. Courtney, Palace Chambers, 9 Bridge Street, Westminster, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1870. Cowen, George Roberts, 9 The Ropewalk, Nottingham. [286.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, Champdany Jute Works, Serampore, Bengal.

1883. Crampton, George, 4 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1884. Crighton, John, Union Engineering Co., 2 Clarence Buildings, Booth Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

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1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Flixton, near Manchester.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. ; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1886. Dale, Thomas, Townsend Foundry, Kirkcaldy.

1881. D'Alton, Patrick Walter, 49 Bugle Street, Southampton.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Crescent Villa, Lower Eglinton Road, Plumstead.

1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Carriage and Wagon Superintendent, Bengal-Nagpur Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, Westinghouse Brake Company, Canal Road, York Road, London, N.; and 9 Camden Street, Oakley Square, London, N.W.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

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1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, care of William M. Davison, "The Churchman," Adelaide, South Australia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Silverdale, Dore, near Sheffield.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, 3 Bramley Hill, Croydon.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, F.R.S.E., 115 St. Vincent Street, Glasgow; and 12 Rothesay Place, Edinburgh.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, 26 Croxted Road, West Dulwich, London, S.E.

1883. Dean, Francis Winthrop, East Taunton, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon. [*Loco, Swindon.*]

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 559.]

1882. Denny, William, F.R.S.E., Messrs. William Denny and Brothers, Leven Ship Yard, Dumbarton.

1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Newton Steel Works, near Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

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1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabrick, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1884. Donnelly, John, Assistant Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.; and 70 Studley Road, Clapham Road, London, S.W.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Trinity House, London, E.C. [2242.]

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1887. Douglass, William Tregarthen, Executive Engineer, Bishop Rock and Round Island Lighthouses, Scilly Islands; and Trinity House, London, E.C.

1879. Doulton, Bernard, Sentinel Works, Polmadie Road, Glasgow.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

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1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1886. Doxford, Charles David, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 2 Victoria Mansions, Victoria Street, Westminster, S.W. [*Doucine, London.*]; and 10 Airlie Gardens, Campden Hill, Kensington, London, W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony; and 42 Hough Green, Chester.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

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1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1887. Edlin, Herbert William, 44 Leathwaite Road, Battersea Rise, Clapham, London, S.W.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1866. Elce, John, 9 Hopwood Avenue, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth. [*Ellacott, Plymouth.* 47.]

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 26 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1885. Errington, William, 28 and 29 Insurance Buildings, Auckland, New Zealand. [*Refunditur, Auckland.*]

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Patent Shaft Works, Wednesbury.

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1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Smithfield Works, Sherlock Street, Birmingham.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Eastern Bengal Railway, Kanchrapara, Bengal, India.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, 2032 Locust Street, Philadelphia, Pennsylvania, United States.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, 27 Brompton Avenue, Sefton Park, Liverpool.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1887. Firth, William, Water Lane, Leeds.

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

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1885. Fitton, Joseph, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1864. Fleet, Thomas, Mayfield, Beeches Road, Westbromwich.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1885. Fletcher, Edward, Messrs. William Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users, Manchester.*]

1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C. [*Floramour, London.* 551.]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, Austin Villa, Chepstow Road, Newport, Monmouthshire.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Messrs. Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

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1866. Fox, Sir Douglas, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Mort and Co., 155 Fenchurch Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5420.]

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1886. Fulton, Arthur Robert William, Resident Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1882. Furrell, Edward Wyburd, 2962 Manchester Road, St. Louis, Missouri, United States.

1887. Gaertner, Ernst, Messrs. Klein Brothers Schmoll and Gaertner, III Jaquingasse 13, Vienna, Austria.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

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1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London.*]

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Ingleside, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India; Fernhill, Henbury, near Bristol: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

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1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1878. Grafton, Alexander, Bedford.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 1 Claremont Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, Whitmore Place, 418 Coventry Road, Small Heath, Birmingham.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Griffiths, James E., Messrs. Griffiths and Wills, Merchants' Exchange, Cardiff. [*Griffwill, Cardiff.*]

1873. Griffiths, John Alfred, care of Charles O'Reilley, Merchant, Brisbane, Queensland.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

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1884. Gulland, James Ker, Diamond Drill Co., 6A Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, Laurel Bank, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield. [*Hadfield, Sheffield.*]

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Ivy House, Bilston.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1886. Hall, William Jeremiah, Harbour Engineer, Limerick, Ireland.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby [*Canal, Derby.*]; and 39 Hartington Street, Derby. [*Silver Hall, Derby.*]

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Halpin, London.*]

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1874. Harding, William Bishop, Zerge-utcza 13, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, 66 St. George's Road, Bolton.

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1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1873. Harman, Harry Jones, 36 Gaisford Street, Kentish Town, London, N.W.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 139 Queen Victoria Street, London, E.C.; and 22 Granville Villas, Earlsfield Road, Wandsworth, London, S.W.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 2 Victoria Mansions, Victoria Street, Westminster, S.W.)

1882. Hart, Norman, London Chatham and Dover Railway, Locomotive (Marine) Department, Dover.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1886. Harvey, John Boyd, The Liverpool Nitrate Co., Oficina Ramirez, Iquique, Chile: (or care of Robert Harvey, Prospect Place, Truro.)

1883. Harvey, Robert, 12 Kensington Gore, London, S.W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C. [*Haskins, London.* 1539.]

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

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1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Belmont, 70 West Hill, Sydenham, London, S.E.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 28 Connaught Road, Harlesden, London, N.W.

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar. [*Haynes, Gibraltar.*]

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough, [*Head, Foxhead, Middlesbrough.* 22.]; and 26 Lombard Street, London, E.C.

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]

1879. Henchman, Humphrey, English Scottish and Australian Chartered Bank, Sydney, New South Wales: (or care of John Henchman, Uplands, Wallington, Surrey.)

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, El Callao Mine, Cuidad, Bolivar, Venezuela, South America: (or care of Mrs. Henderson, 7 Rutland Street, Pimlico, London, S.W.)

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

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1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1884. Hernu, Arthur Henry, 113 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester. [*Hethrinton, Manchester.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead-on-Tyne.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, The Colonial College, Hollesley Bay, near Woodbridge.

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough: and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham [*Hind, Nottingham.*]; and 62 Blackfriars Road, London, S.E.

1885. Hindmarsh, Thomas, 303 King Street West, Hammersmith, London, W.

1887. Hindson, William, Messrs. J. Abbot and Co., Park Works, Gateshead.

1870. Hodges, Petronius, 238 Barnsley Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.

1852. Holcroft, James, Red Hill House, Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.

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1885. Hollis, Henry William, General Manager, Butterley Iron Works, near Alfreton.

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Grove House, Oxford Road, Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 3 Westminster Chambers, Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire. [*Howard, Bedford.*]

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

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1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, North-Western State Railway, Sukkur, Sindh Section, India; and Balfunning, Sutherland Crescent, Helensburgh.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Kingston, Wareham.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1865. Hyde, Major-General Henry, R.E. (*Life Member*), India Office, Westminster, S.W.

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1885. Hyland, John Frank, Engineer to Navigation of Paulista Railway, Campinas, Sao Paulo, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, 50 Avenue de la Grande Armée, Paris.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and 72 Stafford Street, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay: (or Beltwood, Ranmoor, Sheffield.)

1886. Jackson, Thomas, Yorkshire College, Leeds.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, 3 Woodside Terrace, Grange Road, Darlington.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff. [*Engineer, Cardiff.* 29.]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1876. Jebb, George Robert, Engineer to the Shropshire Union Railways and Canal, Birmingham; and Fairyfield, Great Barr, Birmingham.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

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1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1884. Jenkins, Alfred, Sirhowy House, Romilly Road, Canton, near Cardiff.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Inspector of Machinery, Superintending Engineer, H.M. Dockyard, Bermuda; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1886. Johnson, William, 3 Kirbey Street, Poplar, London, E.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 13 Blenheim Square, Leeds.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Assistant Locomotive Superintendent, North Western Railway, Saharunpur, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

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1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1887. Jones, Thomas, Central Board School, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1880. Joy, David, 8 Victoria Chambers, Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham. [*Globe, Birmingham.*]

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1885. Kendall, George, Lloyd's Register of Shipping, Dock Street, Newport, Monmouthshire.

1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin. [*Kennans, Dublin.*]

1879. Kennedy, Alexander Blackie William, F.R.S., Professor of Engineering, University College, Gower Street, London, W.C.; and 3 Prince's Street, Westminster, S.W.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

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1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.
1887. Key, Alexander, Superintendent Engineer, Bedouin Steam Navigation Co., Mersey Chambers, Liverpool.
1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee.
1885. Keymer, Henry John Cubitt, Fisheries Iron Works, Gorleston, Great Yarmouth.
1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.
1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]
1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]
1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China; and Melita Cottage, Denny.
1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]
1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]
1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.
1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.
1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.
1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]
1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.
1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

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1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, 17A Great George Street, Westminster, S.W. [*Lapage, London.*]

1879. Larsen, Jorgen Daniel, 10 Tudor Road, Upper Norwood, London, S.E.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1886. Lee, Charles Eyre, 48 Manor Park Road, Harlesden, London, N.W.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., 106 Cannon Street, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 220 Boulevard Voltaire, Paris.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford Manchester.

1884. Lewis, Henry Watkin, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

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1887. Lewis, Rowland Watkin, Messrs. Edwin Lewis and Sons, Britannia Boiler Tube Works, Wolverhampton.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1887. Lindsay, Joseph, Messrs. Urquhart Lindsay and Co., Blackness Foundry, Dundee.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1885. Lister, Frank, Messrs. Wilkinson and Lister, Bradford Road Works, Keighley.

1887. Litster, David Michael, Executive Engineer, Public Works Department, India; care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Normal School of Science, South Kensington, London, S.W.

1867. Lloyd, Charles, care of E. J. Lloyd, 289 Norwood Road, Herne Hill, London, S.E.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1881. Lockyer, Norman Joseph, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

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1885. Longden, John Needham, Mining Engineer, Messrs. W. Pritchard-Morgan and Co., 1 Queen Victoria Street, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilric, Knutsford.

1880. Longworth, Daniel, Carnac Iron Works, Bombay.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Laboratory Department, Royal Arsenal, Woolwich.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, Manager, Tyneside Engine Works, Cardiff. [*Tyneside, Cardiff.*]

1873. Lowe, John Edgar, Messrs. Boiling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.

1887. Loynd, John Shaw, Messrs. Clayton Goodfellow and Co., Atlas Works, Park Road, Blackburn.

1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, Headingley, Leeds.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, 92 Beeston Hill, Leeds.

1877. MacColl, Hector, Messrs. MacIlwaine Lewis and Co., Ulster Iron Works, Belfast.

1879. Macdonald, Augustus Van Zundt, District Manager, New Zealand Railways, Napier, New Zealand.

1885. Mackenzie, John William, Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1884. Mackintosh, Archibald Robert, Post Office, Melbourne, Victoria.

1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.

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1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London.*]

1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Screwcock, London.*]

1884. Mais, Henry Coathupe, Engineer-in-Chief to the Government of South Australia, Jeffcott Street, North Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. Mallory, George Benjamin, 55 Broadway, New York.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds. [*Maclea, Leeds.*]

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff.

1887. Marriott, William, Engineer and Locomotive Superintendent, Eastern and Midlands Railway, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), 13 Ferron Road, Clapton, London, E.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

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1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge [*Marten, Stourbridge.*]; Pedmore, Stourbridge; and 4 Storey's Gate, Westminster, S.W.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Hanwell, Middlesex, W.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1884. Massey, George, Foy's Chambers, Bond Street, Sydney, New South Wales. [*Masseybond, Sydney.*]

1876. Mather, John, 4 Great George Street, Westminster, S.W. [3002]; and 23 Devonshire Road, South Lambeth, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

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1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, 57D Hatton Garden, London, E.C. [*Maxim, London.* 6507.]

1865. Maylor, John, Churton Lodge, Churton, near Chester.

1859. Maylor, William, Brooklyn, Hayne Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 2 Victoria Mansions, Victoria Street, Westminster, S.W.; and Wellesley, Warlingham, S.O., Surrey.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1868. McKay, Benjamin, Ellerslie, Mackay, Queensland: (or care of Henry C. Halliday, 4 Chestnut Grove, Springfield, Sale, Manchester.)

1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1882. McLaren, Raynes Lauder, 6 Grote's Place, Blackheath, London, S.E.

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Govan.*]

1884. McOnie, William, Jun., Messrs. W. and A. McOnie, Scotland Street Engine Works, Glasgow. [*Maconie, Glasgow.* 565.]

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1863. Meek, Sturges, Consulting Engineer, Lancashire and Yorkshire Railway, Manchester; and Dunstall Lodge, 18 Holland Villas Road, London, W.

1881. Meik, Charles Scott, 21 York Place, Edinburgh.

1858. Meik, Thomas, 21 York Place, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

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1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 49 Parliament Street, Westminster, S.W.

1886. Midelton, Thomas, Locomotive Overseer, New South Wales Railway, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1885. Miller, Harry William, Engineer, Pioneer Powder Factory, Bariaanspoort, Pretoria, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1887. Milne, William, Locomotive Superintendent, Natal Government Railways, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Spotland Vicarage, Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

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1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California; 6 Durham Road, East End, Finchley, London, N.: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1872. Moorsom, Warren Maude, Belvidere, Park Road, West Dulwich, London, S.E.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1885. Morse, Harold, care of Sydney Morse, 5 Lime Street Square, London, E.C.: (or Park, Nottingham.)

1858. Mountain, Charles George, Rose Hill House, Coalbrookdale, Shropshire.

1886. Mountain, William Charles, Gülcher Electric-Light and Power Co., Battersea Foundry, London, S.W.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Cross Street, Manchester. [1027.]

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Gilwern, near Abergavenny.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, Messrs. Taylor and Neate, Medway Works, Rochester.

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1863. Neilson, Walter Montgomerie, Clyde Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1884. Nelson, John, 39 Bootham, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1879. Neville, Robert, Butleigh Court, Glastonbury.

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis (*Life Member*), Engineer's Office, Dover Harbour, Dover.

1885. Newlove, Robert Robson, Crown Iron Works, Crocus Street, Nottingham. [*Newlove, Nottingham.*]

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, East Street, Bridport.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1884. Nicholson, Thomas Head, 32 Rye Hill, Newcastle-on-Tyne.

1884. Nicholson, Walter Elliott, Oakfield, Ryton-on-Tyne, R. S. O., County Durham.

1877. Nicolson, Donald, 42 Highbury Hill, London, N.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

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1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1887. O'Brien, Benjamin Thompson, 47 Kingsley Road, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1868. O'Connor, Charles, Mersey Forge, Liverpool.

1887. O'Flyn, John Lucius, Messrs. L. and H. Gu ret and Co., Exchange, Cardiff.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.* 1601.]

1887. Oliver, Hedley, Messrs. Amos and Smith, Albert Dock Works, Neptune Street, Hull.

1882. Orange, James, Surveyor General's Department, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1886. Owen, Thomas Henry, Dumfries Dry Dock Co., Pier Head, Cardiff.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Persehouse, care of Messrs. Henry Persehouse Parkes and Co., 7 Goree Piazzas, Liverpool. [*Persehouse, Liverpool.*]

1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.

1886. Parry, Alfred, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.

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1880. Parsons, The Hon. Charles Algernon, Elvaston Hall, Ryton-on-Tyne, R.S.O., County Durham.

1878. Parsons, The Hon. Richard Clere, Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, Elmhurst, Hamstead Road, Handsworth, R.O., Birmingham.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1884. Paul, Andrew Louis, Engineer, Oriental Telephone Co., India; (care of Messrs. Benn Ashley and Co., Bombay, India); and 38 Ashburn Place, London, S.W.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, M.P., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, care of T. D. Hay, 5 Central Exchange, George Street, Sydney, New South Wales: (or care of J. H. Peck, 52 Hoghton Street, Southport.)

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

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1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, care of Messrs. Brown and Daird, Australian Chambers, Queen Street, Brisbane, Queensland: (or care of Messrs. Hughes Pye and Rigby, Moray Street, Melbourne, Victoria.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [381.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1882. Pirrie, John Sinclair, 59 Elgin Road, Addiscombe, Croydon.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert Bath.*]

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1887. Place, John, Westinghouse Brake Company, Canal Road, King's Cross, London, N.; and 34 Highgate Road, London, N.W.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co, Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1884. Poillon, Louis Marie Joseph, 74 Boulevard Mont-Parnasse, Paris.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 5 Camden Row, Camberwell, London, S.E.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1884. Prest, Stanley Faber, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield. [*Preston, Kirkburton.*]

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W.

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1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.

1885. Pudan, Oliver, Fuel-Gas and Electric Engineering Works, Twenty-fifth and Liberty Streets, Pittsburgh, Pennsylvania, U.S.: (or 15 Princes Street, Yeovil).

1884. Puplett, Samuel, 59 Colmore Row, Birmingham. [*Ice, Birmingham.*]

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Cabul care of Messrs. Walsh Lovett and Co., Calcutta, India.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]

1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W. [*Basera, London.* 3117.]

1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

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1878. Rawlinson, Sir Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C. [*Wagon, London.*]

1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland. [*Chreed, Sunderland.* 17.]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Reunert, Theodore, Kimberley, South Africa: (or care of Messrs. Findlay Durham and Brodie, 61 St. Mary Axe, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1882. Rhodes, Vincent, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, near Sydney, New South Wales: (or care of Mrs. E. A. Rhodes, 5 Ainger Terrace, St. Catherine's Road, Grantham.)

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester. [*Richards, Altrincham.*]

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1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1887. Richardson, Thomas, Jun., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1887. Rickie, John, District Locomotive Superintendent, North Western Railway, Hirokh, Beluchistan, India.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Assistant Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 1 Gordon Villas, Park Road, Loughborough.

1887. Roberts, Thomas, Assistant Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1848. Robertson, Henry, Great Western Railway, Shrewsbury; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, Crosby Hall Chambers, Bishopsgate Street Within, London, E.C.

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

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1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., Billiter Square Buildings, London, E.C.)

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Manager, Wallsend Slipway and Engineering Works, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, The Cedars, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

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1859. Sacré, Charles, Consulting Engineer, Manchester Sheffield and Lincolnshire Railway, Manchester; 18 Fountain Street, Manchester; and Sunnyside, Victoria Park, Manchester.

1883. Sadoine, Baron Eugène, 57 Rue des Augustins, Liége, Belgium.

1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1887. Salter, Frank, Messrs. B. Donkin and Co., 55A Southwark Park Road, Bermondsey, London, S.E.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, Hillside House, Berkhamsted.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 56 Gresham Road, Brixton, London, S.W.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1886. Scholes, William Henry, Water Works Engineer, Oficina de las Obras de Salubridad de la Capital, 553 Calle Sinpacha, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W.

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

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1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and 3 Trafalgar Road, Twickenham.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, 9 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, Umlaas Wool-Scouring Works, Durban, Natal: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1885. Scott, Robert, Engineer, Messrs. Takata and Co., Tsukiji, Tokio, Japan; and 17 and 18 Basinghall Street, London, E.C.

1861. Scott, Walter Henry, Locomotive Superintendent, Great Southern Railway, Buenos Aires, Argentine Republic: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 86 Newman Street, Oxford Street, London, W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1884. Sellers, Coleman, Messrs. William Sellers and Co., 1600 Hamilton Street, Philadelphia; and 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.

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1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.

1882. Sharrock, Samuel Lord, 6 St. Mary's Terrace, Grassendale, Liverpool.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Liverpool.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, The Cast Steel Foundry, Middlesbrough.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Resident Engineer, Lake Aboukir Reclamation Works, near Alexandria, Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Shwebo, Upper Burmah.

1882. Simpson, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

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1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth. [*Sisson, Falmouth.*]

1885. Sivewright, George William, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Royal York Crescent, Clifton, Bristol.

1885. Slight, William Hooper, Woodborough Vicarage, Nottingham.

1886. Small, James Miln, 47 Woburn Place, Russell Square, London, W.C.

1879. Smith, Allison Dalrymple, Assistant Locomotive Superintendent, Locomotive Workshops, Victorian Railways, Newport, Victoria.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, 34 Avenue Road, Regent's Park, London, N.W.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells. [*Grovehurst, Pembury, Kent.*]

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, 24 Brazenose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

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1883. Snelus, George James, F.R.S., West Cumberland Iron and Steel Works, Workington.

1885. Snowball, Edward, Manager, New Plymouth Sash and Door Factory and Timber Co., Gill Street, New Plymouth, Taranaki, New Zealand.

1886. Snowdon, Frederick Seaton, 29 Tasman Road, Clapham, London, S.W.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay.

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1880. Stafford, George, 17 Russell Street, Nottingham.

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1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1866. Stephens, John Chasson, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]

1885. Stewart-Hamilton, Patrick, care of Rev. Alexander Hamilton, D.D., The Manse, Brighton.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1877. Stokes, Alfred Allen, The White House, Pauntley, Newent, Gloucestershire.

1887. Stone, Frank Holmes, Locomotive Carriage and Wagon Superintendent, Perak State Railway, Thaiping, Larut, Straits Settlements: (or care of L. H. Moorsom, 20 Cooper Street, Manchester.)

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

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1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow. [*Strype, Wicklow.*]

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Sturgeon, John, 4 Burlington Chambers, New Street, Birmingham. [*Air, Birmingham.*]

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazenose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, Messrs. Van Gelder Apsimon and Co., Victoria Works, Sowerby Bridge.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, 4A St. Andrew Square, Edinburgh.

1882. Swaine, John, Messrs. Wright Butler and Co., Panteg Steel Works, near Newport, Monmouthshire.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham. [*Taunton, Birmingham.*]

1882. Tayler, Alexander James Wallis, 63 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead. [*Britannia, Birkenhead.* 4045.]

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1887. Taylor, James, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.
1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.
1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.
1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]
1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.
1882. Taylor, Robert Henry, Regent House, Wilson Grove, Southsea, B.O., Portsmouth.
1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.
1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.
1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.
1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.
1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.
1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.
1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.
1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.
1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.
1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.
1887. Thompson, William Phillips, 6 Lord Street, Liverpool.
1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]
1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]
1880. Thornbery, William Henry, Jun., Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]
1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.
1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.
1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

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1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1885. Tijou, William, Pinners Hall, 15 Great Winchester Street, London, E.C.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium.

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 Croom's Hill, Greenwich, London, S.E.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., 64 Priory Road, West Hampstead, London, N.W.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1883. Trentham, William Henry, 6 Park Crescent, Manor Park Road, Willesden, London, N.W.

1876. Trevithick, Richard Francis, Locomotive Superintendent, Ceylon Government Railways, Colombo, Ceylon: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, 6 Brunswick Place, Swansea.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1885. Trueman, Thomas Brynalyn, Sola Works, Ferro Carril del Sud, care of T. W. Woodgate, 420 Rivadavia, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 7 Cambridge Villas, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Brook Street, Glasgow.

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

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1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Superintendent and Chief Engineer, Government Steam Flour Mills, Poona, India.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1880. Valon, William Andrew McIntosh, Engineer, Corporation Gas and Water Works, Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.

1887. Waddell, John, 4A St. Andrew Square, Edinburgh; and 4 Victoria Street, Westminster, S.W.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

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1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, 9 The Avenue, Lower Broughton Road, Manchester.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Black Boy Yard, Nottingham. [*Dynamo, Nottingham.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Yokohama Water Works, Yokohama, Japan: (or care of W. Walkinshaw, Hartley Grange, Winchfield.)

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 31 High Street, Tipton.

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1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1881. Warham, Richard Landor, 78 Warner Street, Derby.

1885. Warren, Henry John, Jun., Engineer-in-Chief, Venezuela Panama Gold Mine, Guayana, Venezuela, South America: (or Hayle, Cornwall.)

1885. Warren, William, Quebrada Railway Land and Copper Co., Tucacas, Venezuela; care of Messrs. Boulton and Co., Puerto Cabello, Venezuela, South America: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 94 Maida Vale, London, W.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford. [*Boiler, Bradford.* 72.]

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1878. Weatherhead, Patrick Lambert, Hotel Quatro Naciones, Seville, Spain: (or care of W. Weatherhead, Castlegate, Berwick-on-Tweed.)

1884. Webb, Richard George, care of Messrs. John Fleming and Co., Bombay: (or care of Francis Webb, 31 Southampton Buildings, Chancery Lane, London, W.C.)

1887. Webster, William, care of Messrs. Harris and Co., Samarang, Java.

1883. Weck, Friedrich, Town Hall Chambers, 86 New Street, Birmingham.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool.

1874. West, Nicholas James, 36 Upper Park Road, Hampstead, London, N.W.

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1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, St. Peter's Gate, Nottingham.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest Whieldon, 1 Albion Place, High Street, Peckham, London, S.E.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, Assistant Engineer, Rio Tinto Railway, Huelva, Spain.

1885. Whitehead, James George, Mechanical Engineer, care of Enrique Swayne, 156 Calle Carabaya, Lima, Peru.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1884. Whithard, Brooke Middlemore, 18 Cockspur Street, London, S.W.: (or care of Rev. G. H. West, Ascham House, Bournemouth.)

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., Ashton Road, Openshaw, Manchester; and Staucliffe, Matlock Bath.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: care of Messrs. J. Lennox and Co., 84 Lombard Street, London, E.C.: (or care of Dr. Wicks, 1 Park Parade, Westmorland Road, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

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1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C. [*Wigzell, London.* 1844.]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1885. Williams, Nicholas Thomas, Barcellos Gold Mines, Taquarembosinho, Dom Pedrito, Rio Grande do Sul, Brazil: (or care of the Barcellos Gold Mining Co., 3 Tokenhouse Buildings, King's Arms Yard, London, E.C.)

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 3 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1872. Wilson, Alfred, Gas Furnace Engineer, Stafford. [*Wilson, Stafford.*]

1883. Wilson, George Prangley, Assistant Manager, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.

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1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 24 Lincoln's Inn Fields, London, W.C. [*Palacol, London.*]

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 24 Poultry, London, E.C.

1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1884. Wilson, Thomas, Superintendent, General Steam Navigation Company's Works, Deptford, London, S.E.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1887. Winmill, George, Assistant Locomotive Superintendent, North Western Railway, India; and Hare Street, Romford.

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China; and 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China; and 11 Grafton Street, Moss Side, Manchester.

1886. Wolff, Henri Michel, Hafna Lead Mining and Smelting Works, Llanrwst, North Wales.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. J. and E. Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

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1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Woodward, William, Engineer and Manager, Corporation Gas Works, Bury, Lancashire. [*Woodward, Bury.*]

1885. Wootton, Albert, Falcon Engine and Car Works, Loughborough.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.

1874. Worsdell, Thomas William, Locomotive Superintendent, North Eastern Railway, Gateshead. [*Locomotive, Gateshead.*]

1884. Worssam, Charles Smith, 35 Queen Victoria Street, London, E.C.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Henry Wren, Manchester.*]

1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Bhilsa, viâ Bhopal, Central India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of the Hong Kong and Shanghai Bank, 31 Lombard Street, London, E.C.)

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E. [*Wright, Tipton.*]

1878. Wright, William Barton, 148 Cromwell Road, South Kensington, London, S.W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

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1886. Wylie, James, 8 Park Terrace, Govan, Glasgow.
1865. Wyllie, Andrew, 1 Leicester Street, Southport.
1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]
1877. Wyvill, Frederic Christopher, Denton Park, Otley.

1878. Yates, Henry, Brantford, Ontario, Canada.
1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)
1881. Yates, Louis Edmund Hasselts, District Locomotive Superintendent, Eastern Bengal State Railway, Sealdah, Calcutta: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)
1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester; and 33 Hartwood Road, Southport.
1880. York, Francis Colin, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York Sons and Co., Snow Hill, Wolverhampton.)
1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.
1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.
1879. Young, James, Low Moor Iron Works, near Bradford.
1887. Young, William Andrew, Messrs. Hawthorns and Co., Leith Engine Works, Leith.
1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

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ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Savile Street, Sheffield.

1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Chubb, Edward George, Ironbridge Gas Works, Ironbridge, R.S.O., Shropshire.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.

1886. Fisher, Harry, Messrs. Burys and Co., Regent Steel Works, Sheffield.

1865. Gössell, Otto, 41 Moorgate Street, London, E.C.

1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull.

1884. Livesey, Joseph Montague, Stourton Hall, Horncastle.

1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.*]

1883. Macilraith, James, 92 Regent Street, Glasgow. [*Macilraith, Glasgow.*]

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1885. Moser, Charles Henry, Messrs. Moser and Sons, 178 High Street, Southwark, London, S.E. [*Moserson, London.* 4563.]

1887. Neville, Edward Hermann, Messrs. Julius G. Neville and Co., Oriel Chambers, Liverpool.

1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.

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1884. Phillips, Richard Morgan, care of Messrs. Emile Des Marets and Co., 14 Stone Street, New York, United States.

1886. Raven, Henry Baldwin, Messrs. Hare and Co., 19 Surrey Street, Strand, London, W.C.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne.

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

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GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne.

1885. Addis, Frederick Henry, Ajmere, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Nunwick, Humshaugh, R.S.O., Northumberland.

1885. Amos, Ewart Charles, Rosslyn Grove, Hampstead, London, N.W.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, Leeds.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.

1878. Armstrong, Joseph, Great Western Railway, Stafford Road Works, Wolverhampton.

1887. Ashby, Joseph Harrison, Ascot Heath, Berkshire.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Railway Manager, Picton, Marlborough, New Zealand.

1881. Beesley, David Stanley, Messrs. D. S. Beesley and Co., Bracebridge Works, Bracebridge Street, Birmingham.

1884. Bell, Robert Arthur, Burrakur Coal Co., Barakar, East Indian Railway, Bengal: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., 64 Peru, Buenos Aires, Argentine Republic; and 62 Green Street, Grosvenor Square, London, W.

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Paseo de Julio, Buenos Aires, Argentine Republic: (or care of Joseph Harrison, Llanwye, Hampton Park, Hereford.)

1883. Booth, William Stanway, Messrs. Vivian and Sons, Hafod Foundry, Swansea.

1886. Bourne, Thomas Johnstone, Southborough, Tunbridge Wells.

1887. Bremner, Bruce Laing, Rose Cottage, Vale Street, Denbigh: (or Streatham House, Canaan Lane, Edinburgh.)

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1878. Brooke, Arthur, General Post Office, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1886. Brounlie, John, Kaiping Railway, Tientsin, North China; and 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1886. Brown, Andrew, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Peter Brown, 38 Pier Head, Erith, S.O., Kent.)

1880. Buckle, William Harry Ray, Union Dock, Limehouse, London, E. [*Buckle, Fletchdock, London.* 5109.]

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range, Manchester.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1887. Burnett, Arthur Sydney, 18 Ramsbottom Terrace, Horwich, near Bolton.

1885. Burrowes, Gerald Vaughan, Halmirah, Golahghaut, Assam, India: (or care of Miss Burrowes, 5 West Cromwell Road, London, S.W.)

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1886. Cairnes, Frederick Evelyn, 2 Maisemore Mansions, Canfield Gardens, London, N.W.

1883. Cairns, The Hon. Herbert John, care of Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1886. Carver, Charles, Lace Machine Works, Alfred Street, Nottingham.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1883. Clench, Frederick McDakin, Bamgaon Tea Estate, Ballipara Post Office, Tezpore, Assam, Bengal.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1883. Clinkskill, Alfred Alphonse Rouff, 1 Holland Place, St. Vincent Street, Glasgow.

1886. Conyers, Sidney Ward, 36 Wynyard Square, Sydney, New South Wales.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 106 Ebury Street, London, S.W.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1885. Crosta, Lorenzo William, Messrs. R. R. Newlove and Co., Crown Iron Works, Crocus Street, Nottingham; and 21 Mayfield Grove, Nottingham.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

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1884. Dixon, John, 115 York Place, Harpurhey, R. O., Manchester.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1885. Dutt, Jodoo Nauth, Chinsurah, Bengal, India.

1886. Duvall, Charles Anthony, care of John W. Newall, Arnold Road, Bow, London, E.

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1887. England, William Henry, 40 Matlock Terrace, Leeds.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1883. Gibbons, Charles Kenrick, 27 Choppington Street, Newcastle-on-Tyne.

1885. Grant, John Macpherson, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and 63 Westmorland Road, Newcastle-on-Tyne.

1886. Grant, Percy, South Eastern Railway, Ashford, Kent; and Surrey Villa, Ashford, Kent.

1878. Greig, Alfred, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1886. Halsey, William Stirling, Jun., Egerton Woollen Mills, Dhariwal, Amritsar, Punjaub, India.

1887. Hanby, Wrey Albert Edward, Assistant Engineer, Public Works Department, Bengal, India; care of Messrs. Dickeson and Stewart, 4 Queen Victoria Street, London, E.C.

1885. Head, Archibald Potter, 20 Elswick Row, Newcastle-on-Tyne.

1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 10 Rufford Road, Fairfield, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1887. Hogg, William, 108 Nantwich Road, Crewe.

1886. Holdsworth, Francis Matthew, Park Avenue, Handsworth, R.O., Birmingham.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1885. Holroyd, John Herbert, West's Patent Press Company, Aligarh, N.W. Provinces, India.

884. Holt, Follett, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

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1886. Hosgood, John Howell, Locomotive Department, Taff Vale Railway, Cardiff.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1887. Jones, Edward Ebden, 17 Denzil Terrace, Westcombe Park, Blackheath, London, S.E.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1885. Keyworth, Thomas Egerton, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and 38 Monks Road, Lincoln.

1884. King, Charles Philip, Royston House, Upper Richmond Road, Putney, London, S.W.

1885. Laidler, Thomas, Meldon House, Leopold Street, Burdett Road, London, E. [*Gravitation, London.*]

1883. Lander, Philip Vincent, Assistant Engineer, Argentine Great Western Railway, Mendoza, Argentine Republic: (or Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames.)

1881. Lawson, James Ibbs, Assistant Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff.

1886. Lucy, William Theodore, Thornleigh, Woodstock Road, Oxford.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., H.M.S. "Hibernia," Malta; and Burraton, Saltash, R.S.O., Cornwall.

1882. Martindale, Warine Ben Hay, Southern Mahratta Railway, Haveri, Bombay Presidency, India; and 21 Kensington Gardens Square, London, W.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1887. May, Harold Milton, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle.

1867. Mitchell, John, Swaithe Hall, Barnsley.

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1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1885. Mudie, Charles, Upper Assam Tea Co., Dibrugarh, Upper Assam, India: (or 52 Park Road, New Wandsworth, London, S.W.)

1878. Newall, John Walker, Arnold Road, Bow, London, E.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 6 East Seventeenth Street, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 110 Cannon Street, London, E.C.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Locomotive Department, New South Wales Government Railways, Redfern Works, Sydney, New South Wales.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1887. Price-Williams, John Morgan, Engineer's Office, Great Northern Railway, 7 York Road, King's Cross, London, N.

1886. Price-Williams, Seymour William, 38 Parliament Street, Westminster, S.W.

1887. Pullen, William Wade Fitzherbert, 18 Crookham Road, Fulham, London, S.W.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1882. Sanchez, Juan Emilio, Talleres de Marina Nacionales, Tigre, Buenos Aires, Argentine Republic: (or care of Messrs. J. E. and M. Clark and Co., 9 New Broad Street, London, E.C.)

1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1886. Silcock, Charles Whitbread, Messrs. Maudslay Sons and Field, 5 Belvedere Road, Lambeth, London, S.E.

1887. Simkins, Charles Wickens, The Lodge, Lowdham, near Nottingham.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1884. Sollory, George Henry, Messrs. H. Sollory and Son, 2 Mount Street, Nottingham.

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1884. Streatfeild, Mervyn Armytage, Chested, Chiddingstone, Eden-Bridge, Kent.
1883. Swale, Gerald, Ingfield Hall, Settle.
1887. Tabor, Edward Henry, Great Eastern Railway, Stratford Works, London, E.
1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, 1 Somerville Terrace, Ennersdale Road, Lewisham, London, S.E.
1884. Taylor, Maurice, Ateliers des Forges et Chantiers de la Méditerranée, Marseille, France.
1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.
1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.
1882. Wailes, George Herbert, St. Andrews, Watford, Herts.
1885. Wakefield, William Marsden, care of Mark W. Carr, Government Railway, Pietermaritzburg, Natal, South Africa.
1884. Walker, Matthew, 22 Burns Street, Nottingham.
1884. Walker, Ralph Teasdale, 3 Lucy Tower Street, Lincoln.
1886. Walker, Robert John, Church-Stile House, Shap, R.S.O., Westmoreland.
1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.
1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.
1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.
1880. Weymouth, Francis Marten, Messrs. Latimer Clark Muirhead and Co., 23 Regency Street, Westminster, S.W.; and 33 Alfred Road, Acton, London, W.
1879. Wood, Edward Walter Naylor, Resident Engineer, Great Indian Peninsula Railway, Nagpur, Central Provinces, India.
1882. Woollcombe, Reginald, District Locomotive Superintendent, Rajputana State Railway, Mhow, Central India; care of Messrs. King King and Co., Bombay.
1885. Wray, Charles Drinkwater, Bureau Anglais, La Pallice, La Rochelle, France.
1887. Wrench, John Henry Kirke, Broad Oaks Iron Works, Chesterfield.
1884. Yokoi, Saku, 110 Rue de Turenne, Paris.

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THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

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4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

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year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

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Articles of Association.

AUGUST 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

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MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the Bye-laws from time to time in force, as provided by the Articles.

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GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

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have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

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of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the Bye-laws, or any regulations of the Council made in accordance with the Bye-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

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no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the Bye-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BYE-LAWS.

24. The Bye-laws set forth in the schedule to these Articles, and such altered and additional Bye-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the Bye-laws, and all matters which consistently with the Articles shall be made the subject of Bye-laws. Alterations in, and additions to, the Bye-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

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Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

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26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the Bye-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the Bye-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the Bye-laws) be determined by the Council.

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POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the Bye-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

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(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

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38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

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Bye-laws.

(*Last Revision, January* 1885.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

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ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

11. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

12. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

13. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being

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inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

14. The Elections shall take place at the General Meetings only.

15. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

16. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

17. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

18. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the

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list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

19. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

20. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

21. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and Bye-laws and the directions of the President and Council; and shall refer to the

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President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

22. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

23. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

24. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

25. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

26. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

27. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

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3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

28. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

29. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

30. The President shall ex officio be Member of all Committees of Council.

31. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

32. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

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33. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

34. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months.

35. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

36. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

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APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

SIR,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

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FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

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Institution of Mechanical Engineers.

PROCEEDINGS.

February 1887.

The Fortieth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, the 3rd of February 1887, at Half-past Seven o'clock p.m.; Jeremiah Head, Esq., Retiring President, in the chair, succeeded by E. H. Carbutt, Esq., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-five candidates were found to be duly elected:—

MEMBERS.

Alberto de Arteaga, . . .	Buenos Aires.
William James Baker, . . .	Bradford.
George Beckwith, . . .	Swansea.
Edward John Bennetts, . .	Camborne.
Philip George Brunton, . .	Sydney.
Arthur George Evans, . . .	Manchester.
Nevill Henry Everitt, . . .	Wednesbury.
William Firth, ...	Leeds.
Richard Hargraves, . . .	Bolton.
John Henry Hargreaves, . .	Bolton.
George Hibbert, ...	Gateshead.
James Rossiter Hoyle, . . .	Sheffield.

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HENRY ALFRED IVATT,	Dublin.
LIONEL EDWARD IVATTS,	Neuilly sur Seine.
SAMUEL HENRY JOHNSON,	London.
ALEXANDER KEY,	Liverpool.
JOHN SHAW LOYND,	Blackburn.
WILLIAM MARRIOTT,	Melton Constable.
FREDERICK MELHUISH,	London.
JOHN OWDEN O'BRIEN,	Liverpool.
HEDLEY OLIVER,	Birmingham.
THOMAS SALTER PYNE,	Calcutta.
THOMAS ROBERTS,	Adelaide.
WILLIAM ROBERTS,	London.
WILLIAM MARK SMITH,	Cork.
WILLIAM PHILLIPS THOMPSON,	Liverpool.
FRANK TRIER,	London.
JOSHUA ALFRED ALEXANDER TURNER,	Poona.
DOUGLAS FITZGERALD WORGER,	London.

ASSOCIATE.

EDWARD GEORGE CHUBB,	Ironbridge.

GRADUATES.

ARTHUR SYDNEY BURNETT,	Manchester.
DELEVANTE WILLIAM CROSLAND,	London.
HORACE WYON ROGERS,	London.
CHARLES WICKENS SIMKINS,	Nottingham.
JOHN HENRY KIRKE WRENCH,	Chesterfield.

The following Annual Report of the Council was then read :—

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ANNUAL REPORT OF THE COUNCIL.

1887.

The Council have pleasure in presenting to the Members the fortieth Annual Report of the Institution of Mechanical Engineers.

The number of names in all classes on the roll of the Institution at the end of last year was 1674, as compared with 1640 at the end of the previous year. During the year 1886 there were added to the register 103 names; there were lost by deceases 17 names, and by resignation or removal 52, leaving a net gain of 34.

The following Associate, and five Graduates, have been transferred by the Council in the course of the year to the class of Members:—

WILLIAM RIPPER,	Associate	Sheffield.
EDWARD DISNEY ALEXANDER,	Graduate	Pickering.
RHYS JENKINS,	do.	London.
WALTER PECK,	do.	Nelson, N.Z.
HENRY JOHN SPOONER,	do.	London.
JOHN MACKWORTH WOOD,	do.	London.

The following twenty-three Deceases of Members of the Institution have occurred during the past year:—

SIR JOHN ANDERSON, LL.D., F.R.S.E.,	St. Leonard's-on-Sea.
WILLIAM FOTHERGILL BATHO,	London.
GEORGE BODDEN,	Oldham.
ROWLAND CHILDE,	Wakefield.
JAMES DAVIDSON,	Dunedin, N.Z.
PETER HAGGIE,	Gateshead.
SAMUEL COLLETT HOMERSHAM,	London.
ALEXANDER JACK,	Liverpool.
JAMES KENNEDY,	Liverpool.
THOMAS MOFFAT,	Whitehaven.
HARRY OLRICK,	London.
JOHN PATTINSON,	Russia.

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ROBERT CHARLES RANSOME,	Ipswich.
WILLIAM EDMUND RICH,	London.
DAVID SCOTT (deceased 1885),	Calcutta.
DAVID THOMSON,	London.
THOMAS TURTON,	Liverpool.
JOHN R. WARHAM,	Burton-on-Trent.
EDWARD WILLIAMS,	Middlesbrough.
ARTHUR WELLESLEY WESTMACOTT WILLMOTT,	Shanghai.
THOMAS WOOD,	Ebbw Vale.
ROBERT WYLLIE,	Hartlepool.
GEORGE JOPE YEO,	Shanghai.

Among these is the well-known name of Mr. James Kennedy, who died at the advanced age of eighty-nine. He had been a Member of the Institution from the commencement in 1847, and occupied the Presidential chair in the year 1860. Sir John Anderson had been a Member of the Institution for thirty years; he was for many years a Member of Council, and subsequently a Vice-President of the Institution.

The following eighteen gentlemen have ceased to be Members of the Institution during the past year:—

CHARLES EDWARD APPLEBY, Duke Street, Adelphi,	London.
ALEXANDER ARMSTRONG,	Auckland, N.Z.
EDWARD WINGFIELD BOWLES (Graduate),	London.
THOMAS SMITH BRIGHT,	Swansea.
ARTHUR SAMUEL HAMAND,	London.
MARCOS MAÑÉ,	Buenos Aires.
HENRY PARRY,	Newcastle-on-Tyne.
ARTHUR WALTER PIGOTT (Graduate),	Dublin.
JOHN THORPE POTTS,	Philadelphia, U.S.
CARL HEINRICH ROECKNER (Associate),	Newcastle-on-Tyne.
CHARLES JAMES SHARPE,	London.
ALFRED SIMPSON,	Hull.
WALTER PARKER SMITH,	London.
WILLIAM HENRY OSBORNE TAYLOR,	London.
DAVID WILLIAMS,	Pontypool.
FREDERICK CHARLES WINBY,	London.
JOHN FREDERICK WOLFF,	London.
FERDINAND HENRY ZIFFER,	Budapest.

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In addition to these there have been thirty-four Resignations of membership.

The Accounts for the year ending 31 December 1886 are now submitted to the Members (*see* Appendix I, pp. 12–15), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. It will be seen that the receipts during the year were £5,701 15*s.* 11*d.*, while the expenditure, actual and estimated, was £4,652 12*s.* 5*d.*, leaving a balance of receipts over expenditure of £1,049 3*s.* 6*d.* A Balance Sheet is appended, showing the financial position of the Institution at the end of the year. The total investments and other assets amount to £18,874 18*s.* 3*d.*; and allowing £300 for accounts owing but not yet rendered, the capital of the Institution amounts to £18,574 18*s.* 3*d.* The greater part thereof, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution.

For the further experiments in the Research upon Riveted Joints a set of specimens were designed early in 1885 and prepared shortly afterwards. They are made with thicker plates, larger rivets, and heavier pressures than any of the former ones. Owing however to unforeseen delay in the completion of the powerful testing machine at Lloyd's Proving House at Netherton, near Dudley, which will be employed for pulling asunder these stronger specimens, their actual testing has not yet been accomplished. Meanwhile the Research Committee are again indebted to the Landore Siemens-Steel Co. for their kindness in presenting the whole of the plates and rivet steel for the specimen joints, and to Messrs. Fielding and Platt for performing at cost price the shaping and riveting of the pieces, under the direction of Professor Kennedy and Mr. Ralph H. Tweddell.

For the further series of experiments arranged by the Research Committee on Friction, suitable apparatus has been designed by Mr. Beauchamp Tower under the direction of Mr. Tomlinson and

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Mr. John G. Mair. It is now being made by Mr. Mair at the works of Messrs. Simpson and Co., who have also kindly offered facilities for the experiments to be conducted at their works.

As a result of the discussion which took place at the Summer Meeting upon the value of the Steam-Jacket, a Committee has been appointed by the Council to investigate the subject; and the conduct of the research has been confided to Mr. Henry Davey, of Leeds, the arrangements being subject to the sanction of the President.

A Research Committee has also been appointed by the Council to draw up a standard system for conducting Marine Engine Trials, and to arrange for the carrying out of such trials in accordance with this system. The organisation of this research has been kindly undertaken by Professor Kennedy.

The additions to the Library of the Institution during the past year are enumerated in Appendix II, pp. 16–23. For these the Council desire to record their thanks to the several Donors. In order to increase the value of the Library they invite continued donations of books, of original pamphlets and reports, and particularly of records of practical experiments and researches. The Library has recently been undergoing the re-arrangement which had become absolutely necessary. A new catalogue is in course of preparation, and will be issued to the Members as soon as it is completed.

The General Meetings in 1886 were the Annual General Meeting, the Spring Meeting, and the Summer Meeting, which were held in London; and the Autumn Meeting, which was held in Leeds. The Papers read and discussed at the seven sittings devoted to the purpose, and published in the Proceedings, were as follows:—

Description of an Autographic Test-Recording Apparatus; by Mr. J. Hartley Wicksteed.

Description of Tensile Tests of Iron and Steel Bars; by the late Mr. Peter D. Bennett.

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Description of a Hydraulic Buffer-Stop for Railways; by Mr. Alfred A. Langley.

On the Distribution of the Wheel Load in Cycles; by Mr. J. Alfred Griffiths.

On the Raising of the Wrecked Steamship "Peer of the Realm;" by Mr. Thomas W. Wailes.

On Refrigerating and Ice-making Machinery and Appliances; by Mr. T. B. Lightfoot.

Experiments on the Steam-Jacketing and Compounding of Locomotives in Russia; by Mr. Alexander Borodin.

On the Working of Compound Locomotives in India; by Mr. Charles Sandiford.

On Triple-Expansion Marine Engines; by the late Mr. Robert Wyllie.

The attendances during 1886 were as follows:—at the Annual General Meeting 107 Members and 66 Visitors; at the Spring Meeting 62 Members and 60 Visitors; at the Summer Meeting 331 Members and 166 Visitors, of whom 93 were Belgian Engineers; and at the Autumn Meeting 120 Members and 78 Visitors.

The Summer Meeting of the Institution was held in London, an interval of twenty-four years having elapsed since it was held there before. The Association of Engineers from Liége University were invited to attend and take part in the proceedings, in recognition of the cordial reception given to the Institution on the occasion of the Meeting in Belgium in 1883. The invitation having been accepted, the Meeting commenced on the 17th of August, to suit the convenience of the Belgian visitors, of whom nearly a hundred attended. An elaborate programme was prepared with the assistance of the Local Members and their friends. The Meeting was opened by the President with a welcome to the Members and to the Belgian Engineers; followed by an Address in which the important subject of the prevailing depression of trade was dealt with in its bearings upon mechanical engineering and upon national industry. Two valuable papers upon compound locomotives followed, the one by Mr. Borodin and the other by Mr. Sandiford, who gave the results of their experience in Russia and India respectively. A discussion ensued which lasted throughout the remainder of the meeting. One result of this discussion has been the appointment of a committee for investigating the value of the steam-jacket. Besides visits to

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various engineering and industrial works in and near London, to the Mint, and to the Colonial and Indian Exhibition, special excursions were made to the government establishments at Enfield and Woolwich, the Beckton Gas Works, the Royal Victoria and Albert Docks, the Tilbury Docks, and the Crossness Main Drainage Works.

During the week following the Summer Meeting, various provincial excursions were arranged for the Belgian Engineers by Members and their friends, and extensive preparations were made for the reception and entertainment of the visitors. The following gentlemen are among those who specially exerted themselves, and who are entitled to the best thanks of the Institution:—Swansea, Mr. Hort. Huxham, Secretary of the South Wales Institute of Engineers; Cardiff, Mr. Archibald Hood, President, and Mr. T. Hurry Riches, Vice-President, of the South Wales Institute of Engineers; Crewe, Mr. Francis W. Webb, and Mr. Henry Chapman; Liverpool and the Vyrnwy Water Works, Mr. Anthony Bower, Mr. George F. Deacon, Mr. William Laird, and Mr. Henry Shield; Wigan, Mr. William H. Hewlett; Barrow-in-Furness, Sir James Ramsden and Mr. Josiah T. Smith; Blackpool, Mr. M. Holroyd Smith; Derby, Mr. Samuel W. Johnson; Burton, Messrs. Allsopp and Messrs. Bass; Birmingham, Professor Robert H. Smith, and Mr. Alexander Smith, Secretary of the South Staffordshire and East Worcestershire Institute of Engineers; Middlesbrough, The President, and Sir Lowthian Bell, Bart., Past-President, Mr. Percy C. Gilchrist, Mr. John Gjers, and Mr. Walter Johnson; Newcastle, Mr. Percy G. B. Westmacott, Past-President; Edinburgh and Glasgow, Mr. Charles A. Knight.

The fund raised by the London Members and their friends for the reception and entertainment of the provincial Members and the Belgian visitors was on this occasion augmented by contributions from other Members who were desirous of taking advantage of the opportunity thus afforded for reciprocating the hospitalities received in Belgium in 1883. In accordance with the unanimous desire of a large number of the contributors to the fund so raised, a portion amounting to £324, out of the sum representing their own share of

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the surplus remaining from the fund, has been presented to the Library of the Institution. The Council are confident that they are giving expression to the sentiments of the Members generally, in here recording their hearty thanks to the donors.

The following letter of thanks has been received from the Association of Engineers from Liége University:—

Le Rond Chêne, par Esneux, Province de Liége.
Le 2 décembre 1886.

Monsieur le Président,

Nous avons l'honneur de vous exprimer toute la reconnaissance de l'Association des Ingénieurs sortis de l'École de Liége, pour la réception si cordiale que l'Institution des Ingénieurs Mécaniciens a faite au mois d'août dernier aux membres de notre Association qui se sont rendus en Angleterre.

Nous vous en remercions bien sincèrement, ainsi que tous ceux qui ont contribué à rendre nos excursions en Angleterre et en Écosse aussi intéressantes qu'utiles et agréables.

Nous espérons, Monsieur le Président, que nos associations resteront en relations suivies, et que vous voudrez bien disposer de nous dans le cas où l'Institution des Ingénieurs Mécaniciens serait disposée à tenir de nouveau un de ses meetings en Belgique.

Veuillez agréer, Monsieur le Président, l'assurance de notre considération la plus distinguée.

Le Secrétaire, A. HABETS. *Le Président,* G. MONTEFIORE-LEVI.

À Monsieur le Président de l'Institution des Ingénieurs Mécaniciens, à Londres.

On the invitation of the authorities of the Yorkshire College, Leeds, the Autumn Meeting of the Institution was held there to celebrate the opening of the Engineering Department of the College, of which the successful establishment is largely due to the energetic exertions of the Leeds Members of the Institution of Mechanical Engineers. After the reading and discussion of a valuable paper by the late Mr. Robert Wyllie on triple-expansion marine engines, the discussion of which will be resumed at the present meeting, the Mechanical Department of the College was declared open by the President of the Institution. The Members then proceeded to inspect it, and subsequently were entertained at dinner by the

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Engineers of Leeds and the district, under the presidency of the Most Honourable the Marquis of Ripon, K.G., President of the College.

In view of the kind hospitalities offered to the Members on this and previous occasions, the Council think it but right that attention should be called to the frequent discrepancy between the number of acceptances received and of guests actually present. The dinner invitation from the Engineers of Leeds was definitely accepted by 180 Members, of whom only 104 were present. Except in the case of about a dozen of the absentees, neither previous intimations of inability to ratify the acceptance were received, nor subsequent expressions of regret. The Council hope that in future those gentlemen who accept invitations will favour their entertainers by their presence; or, if circumstances should render this impracticable, that they will notify the change as early as possible. During the Summer Meeting of the Institution, the proportion of absences was in some cases even greater. The Council take this opportunity of expressing their regret to the hosts concerned, at the disappointment they must have undergone.

To meet a wish expressed by various Members, that written contributions to the Discussions upon the Papers read at the Meetings should be received for publication in the Institution Proceedings, the Council have pleasure in announcing that they have passed the following minute:—

"Any Member who may be unable to attend a Meeting, or who may be prevented by the closing of a Discussion from having an opportunity of taking part therein, may send for publication in the Proceedings written remarks upon any Paper read at that Meeting. The publication shall be subject to the following conditions, namely:—

1st, that the written communication be in the Secretary's hands within a week after the closing of the Discussion.

2nd, that it be original, and pertinent to the subject of the Paper.

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3rd, that it be free from anything of a personal character, and from reference to questions of patent right or priority of invention.

4th, that it be subject to the approval of the Council.

5th, that the Author of the Paper, and finally the Chairman of the Meeting, be entitled to reply thereto."

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

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APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1886 . . .	682	17	10			
„ Reprinting former Proceedings	126	14	0			
	809	11	10			
Less Authors' Copies of Papers, repaid	17	12	0	791	19	10
„ Stationery, Binding, and General Printing				228	12	4
„ Rent				550	0	0
„ Salaries and Wages				1,377	19	0
„ Coals, Firewood, and Gas				28	2	6
„ Fittings and Repairs				51	19	10
„ Postages				248	13	10
„ Insurance				5	2	3
„ Petty Expenses				48	18	9
„ Meeting Expenses—						
Printing	318	1	3			
Translations &c.	72	19	0			
Reporting	46	18	2			
Diagrams, Screen, &c.	78	19	7			
Travelling and Incidental Expenses	101	12	5	618	10	5
„ Dinner				166	11	6
„ Research				221	18	7
„ Books purchased				14	3	7
				4,352	12	5
Accounts owing, not yet rendered, say				300	0	0
Balance, being excess of Receipts over Expenditure, carried down .				1,049	3	6
				£5,701	15	11

To amount invested in £1270 Great Eastern Ry. 4% Debenture Stock				1,499	17	3
Cash Balance at this date	1,679	16	9			
Less Reserve to pay accounts not yet rendered, as above	300	0	0	1,379	16	9
				£2,879	14	0

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APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1886. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
75 *New Members at £2*	150	0	0			
7 *New Associates at £2*	14	0	0			
20 *New Graduates at £1*	20	0	0			
5 *Graduates transferred to Members at £1*	5	0	0	189	0	0
„ Subscriptions for 1886—						
1345 *Members at £3*	4,035	0	0			
33 *Associates at £3*	99	0	0			
110 *Graduates at £2*	220	0	0			
5 *Graduates transferred to Members at £1*	5	0	0	4,359	0	0
„ Subscriptions in arrear—						
62 *Members at £3*	186	0	0			
6 *Graduates at £2*	12	0	0	198	0	0
„ Subscriptions in advance—						
20 *Members at £3*	60	0	0			
1 *Associate at £3*	3	0	0			
4 *Graduates at £2*	8	0	0	71	0	0
„ Donation to Library				324	0	0
„ Interest—						
From Investments	476	14	9			
From Bank	23	4	2	499	18	11
„ Reports of Proceedings—						
Extra Copies sold				60	17	0
				£5,701	15	11

By Balance brought down	1,049	3	6
Cash Balance 31st December 1885	1,830	10	6
	£2,879	14	0

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Dr. **BALANCE SHEET**

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	300	0	0
Capital of the Institution at this date	18,574	18	3
	£18,874	18	3

(*Signed*) E. H. CARBUTT
JOSEPH TOMLINSON
SIR JAMES N. DOUGLASS
ALEXANDER B. W. KENNEDY
} *Finance Committee.*

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AS AT 31ST DECEMBER 1886.

Cr.

	£ s. d.	£ s. d.
By Cash—*In Union Bank, on Deposit*	800 0 0	
„ „ „ *on Current account* . .	379 16 9	
In Imperial Bank	500 0 0	1,679 16 9
„ Investments—		
£		
3,178 *London & N. W. Ry.* 4% *Debenture Stock*		
2,200 *North Eastern* „ „ „ „		
2,466 *Midland* „ „ „ „		
1,800 *Great Western* „ „ „ „		
1,270 *Great Eastern* „ „ „ „		
891 *Metropolitan* „ „ „ „		
1,325 „ „ 3½% „ „		
13,130 . . . . . *cost*		13,467 1 6
Note—The Market Value of these investments at 31st Dec. 1886 *was about* £15,239.		
„ Subscriptions in Arrear		423 0 0
„ Office Furniture and Fittings		315 0 0
„ Library and Proceedings		2,670 0 0
„ Drawings, Engravings, Models, Specimens, and Sculpture .		320 0 0
		£18,874 18 3

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

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APPENDIX II.

LIST OF DONATIONS TO LIBRARY.

Report of the Kew Observatory, 1885; from the Committee.

Lightning Conductors, by Richard Anderson; from the author.

Catalogue of Pumping, Water-Works, Hydraulic, Mining Machinery, Steam Engines, &c.; from Messrs. Hathorn Davey and Co.

Notes de Voyage d'un Ingénieur aux États-Unis, by Paul Trasenster; from M. Louis Trasenster.

Berly's universal Electrical Directory, 1886; from Messrs. William Dawson and Sons.

List of Members &c. of the Société Belge d'Électriciens; from the Society.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 30 June 1886; from the Registrar.

Calendar of the City of London College, 1885–86 and 1886–87; from the College.

Adcock's Engineer's Pocket-Book for 1886; from the proprietor.

Manufacture of Large Forgings for Marine purposes, by Henry Cameron; from the author.

Precautions to be adopted on introducing the Electric Light, by Killingworth Hedges; from the author.

Reports of the U.S. Chief of Ordnance; from the Ordnance Committee Office, Washington, U.S.

Exposé sur les Freins continus pour Chemins de fer, by J. G. Hardy; from the author.

Memoir of John Wyatt; from Mr. John Chater.

Calendar of the Mason Science College, Birmingham, 1885–86; from the College.

Swiss Railways, Instructions and Working Plans; from Mr. Druitt Halpin.

Estudio Administrativo-Militar de la Exposicion Universal de Paris, 1878, by Augusto Muñoz y Madrid and Fernando Aramburu y Silva; from the authors.

Examen Microscópico del Trigo y de la Harina, by Fernando Aramburu y Silva; from the author.

Molineria y Panaderia en Alemania, by Fernando Aramburu y Silva; from the author.

Employment of Autographic Records in Testing Materials, by W. Cawthorne Unwin, F.R.S.; from the author.

Graphic Analysis of the Kinematics of Mechanisms, by Robert H. Smith; from the author.

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Calendar of the University College of South Wales and Monmouthshire, 1885–86; from the College.

Annual Report of the Comptroller of the Currency, United States, 1885; from the Comptroller.

Nouvel Éclairage par l'Electric-Gas, by M. Georges Delaporte; from Mr. Henry Chapman.

Report of the British Chamber of Commerce, Paris, on the fraudulent use in France of the word "Sheffield;" from Mr. Henry Chapman.

Cornell University Register, United States, 1885–86; from the University.

Report connected with the project for the construction of Docks at Calcutta Part I; Papers relating to the Orissa Coast Canal; Reports connected with the improvement of the River Hooghly; from the India Office.

Tables for the use of Engineers and Architects in taking out Quantities, by C. J. Bellamy; from the author.

Modern Steam Engines and Boilers, by Frederick Colyer; from the author.

Use of Refrigeration in the Services, by a Seafarer; from Mr. A. Scale Haslam.

Final Report of H.M. Commissioners on Accidents in Mines; from the Commission.

Marine Engine working at reduced speeds, by Paul du Buit and P. Sabathier; from Mr. Henry Chapman.

Frequent Repetitions of Load, by Alexander B. W. Kennedy; from the author.

Hydraulic Rams, by H. D. Pearsall; from the author.

Catalogue of Engines, Boilers, and Machinery; from the Reading Iron Works.

Address on the History of Art, by the Rector of the Royal Technical High-School, Berlin; from the Rector.

Crampton Engines, 1886; from Mr. Thomas R. Crampton.

Papers connected with the construction of the Madras Harbour; from the India Office.

Spectra of the Gases and Vapours evolved on heating Iron and other Metals, by John Parry; from the author.

Establishment of an Engineer Volunteer Corps for India, by Guilford L. Molesworth; from the author.

Our Guns, by E. H. Carbutt, M.P.; from the author.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1886; from the Inspector-General of Chinese Customs.

Return on Continuous Brakes, 31 Dec. 1885; from the Board of Trade.

Iron Trade of the United Kingdom, by Sir Lowthian Bell, Bart., F.R.S.; from the author.

British and Foreign Patents, Designs, and Trade-Marks, by Messrs. Abel and Imray; from the authors.

Description of a Weighing-Machine, and Suggestions as to mode of Testing Weighing-Machines; from the Board of Trade.

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Templeton's Workshop Companion, by Walter S. Hutton; from the author.
Civil Engineer's Pocket-Book, by John C. Trautwine, Jun.; from the author.
Field Practice of laying out Circular Curves for Railroads, by John C. Trautwine, Jun.; from the author.
Opening Bridges on the Furness Railway, by Charles J. Light; from the author.
Telpherage, by John Perry; from the author.
Lartigue Elevated Single-Rail Railway; from the Lartigue Railway Company.
Convention in Dublin of the National Association of British and Irish Millers, June 1886; from Mr. T. Stuart.
Blow-Holes in Open-Hearth Steel, by John Head; from the author.
Dissociation Temperatures with special reference to Pyrotechnical questions, by Frederick Siemens; from the author.
Catalogue of Soda-Water and Ice-Making Machinery; from Messrs. Barnett and Foster.
Boiler Explosions, by Perry F. Nursey; from the author.
Fuel, by Perry F. Nursey; from the author.
English and Continental Intercommunication, by Perry F. Nursey; from the author.
Explosive Compounds, by Perry F. Nursey; from the author.
Economic Uses of Blast-Furnace Slag, by Perry F. Nursey; from the author.
Mechanical Puddling, by Perry F. Nursey; from the author.
Channel Railway, by Perry F. Nursey; from the author.
Illumination by means of Compressed Gas, by Perry F. Nursey; from the author.
Bronze Alloys for Engineering Purposes, by Perry F. Nursey; from the author.
Presidential Address to the Society of Engineers, by Perry F. Nursey; from the author.
Roller Flour Milling, by Henry Simon; from the author.
Papers relating to the Rushikulya Project, Madras; from the India Office.
Catalogue of the Crosby Steam Gage and Valve Co.; from Mr. George A. Mower.
Catalogue of the American Elevator Company; from Mr. William A. Gibson.
Circular Chimney Shaft at Mechernich, near Cologne, by John M. Wood; from the author.
Calendar of University College, Bristol, 1886–87; from the College.
What I believe, by Leon Tolstoi; from the publisher.
Canadian Economics; from the Montreal Committee of the British Association for the Advancement of Science.
Association pour la Surveillance des Chaudières à Vapeur, Brussels (Report for 1885, with Note on Locomotive Explosions); from M. Robert Vinçotte.
Progress and Development of Marine Engineering, by William Parker; from the author.
Papers relating to the Buckingham Canal, Madras; from the India Office.
Depreciation of Silver, by Guilford L. Molesworth; from the author.

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Centenaire de M. Chevreul; from the French Academy of Sciences.

Papers connected with the Periar Irrigation Project, Madras; from the India Office.

Wave Motor, by Terrence Duffy; from the author.

Prospectus of the Firth College and Sheffield Technical School, 1886–87; from the College.

Distances of the Moon, the Planets, and the Sun, deduced theoretically, by G. Pinnington; from the author.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Board of Trade Reports on Boiler Explosions, Nos. 87 to 129; from the Manchester Steam Users' Association.

Calendar of Letters from the Mayor and Corporation of the City of London, 1350–1370; from the Corporation.

Analytical Index to the Series of Records known as the "Remembrancia," 1579–1664; from the Corporation of the City of London.

London's Roll of Fame, 1757–1884; from the Corporation of the City of London.

Calendar of the Yorkshire College, Leeds, 1886–87; from the College.

Steam and Steam-Engines, by Andrew Jamieson; from Messrs. C. Griffin and Co.

Report to the Board of Trade respecting the Cracking of a Mild-Steel Shell-Plate for a Boiler; from Mr. Thomas W. Traill.

Fifty-Ton Radial Block-Setting Crane, Roker Pier Works, Sunderland; from Mr. H. H. Wake.

Abridgments of Patents relating to Velocipedes, 1818–83, by R. E. Phillips; from the author.

Report on Weights and Measures, 1886; from the Board of Trade.

Abt system of Ascending Steep Inclines, by Guilford L. Molesworth; from the author.

Dredger at the Bristol Docks, by John W. Girdlestone; from the author.

Guildhall of the City of London, its History and Associations, by John Edward Price; from the Corporation.

Boiler Explosions at Hull and at Stainland; from the Yorkshire Boiler Insurance and Steam Users' Company.

Canal Communication, by Samuel Lloyd; from the author.

Quelques particularités du Service de la Traction dans les Chemins de fer des États-Unis, by David Banderali; from the author.

Glossary of Scotch Mining Terms, by James Barrowman; from the author.

Conversion of Heat into Work, by William Anderson; from the author.

Hydraulic Power and Hydraulic Machinery, by Henry Robinson; from the author.

Abuse of the Steam Jacket practically considered, by William Fletcher; from the author.

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The following Abridgments of Specifications from the Patent Office:—

Drains and Sewers, Part i, 1619–1866. Part ii, 1867–1876.

Marine Propulsion, Part ii, 1867–1876.

Manufacture of Iron and Steel, Part i, 1620–1866. Part ii, 1867–1876.

Watches, Clocks, &c., Part ii, 1867–1876.

Fire-arms, Ammunition, &c., Division i, Part ii, 1867–1876; Part iii, 1877–1883. Division ii, Part ii, 1867–1876; Part iii, 1877–1883.

Cutting, Folding, and Ornamenting Paper, &c., Part ii, 1867–1876.

Letterpress and similar Printing, &c., Part ii, 1867–1876.

Preparation of India-rubber and Gutta Percha, Part ii, 1867–1876.

Metals and Alloys, Part *ia*, 1860–1866. Part ii, 1867–1876

Photography, Part iii*a*, 1877–1883.

Weaving, Part ii, 1867–1876.

Music and Musical Instruments, Part ii, 1867–1876.

Railways, Part ii, 1867–1876.

Saddlery, Harness, Stable Fittings, &c., Part ii, 1867–1876.

Writing Instruments and Materials, Part ii, 1867–1876.

Umbrellas, &c., Part ii, 1867–1876.

Farriery, Part ii, 1867–1876.

Preparing and Cutting Cork, Bottling Liquids, &c., Part ii, 1867–1876. Part iii, 1877–1883.

Cooking, Bread-making, and the preparation of Confectionery, Part ii, 1867–1876.

Metallic Pipes and Tubes, Part ii, 1867–1876.

Milking, Churning, &c., Part ii, 1867–1876.

Artificial Leather, Floorcloth, Oilcloth, Oilskin, and other Waterproof Fabrics, Part ii, 1867–1876.

Agriculture, Division iii, Agricultural and Traction Engines, 1618–1866.

Ice-making Machines, Ice Safes, and Ice Houses, Part ii, 1867–1876.

Unfermented Beverages, Aerated Liquids, Mineral Waters, &c., Part ii, 1867–1876.

Tea, Coffee, Chicory, Chocolate, Cocoa, &c., Part ii, 1867–1876.

Dressing and Finishing Woven Fabrics, &c., Part ii, 1867–1876.

Electricity and Magnetism, Division i, Generation of Electricity and Magnetism, Part ii, 1867–1876. Division ii, Conducting and Insulating, Part ii, 1867–1876. Division iii, Transmitting and Receiving Signals, Controlling Mechanical Action, and Exhibiting Electric Effects, Part ii, 1867–1876. Division iv, Electric Lighting, Igniting, and Heating, Parts i and ii, 1839–1876. Division v, Electro-Deposition and Electrolysis, Parts i and ii, 1805–1876. Division vi, Electric Motive Power Engines and similar Apparatus, Parts i and ii, 1837–1876.

Carriages and other Vehicles for common roads, 1625–1866.

Brewing, Wine-making, and Distilling Alcoholic Liquids, 1634–1866.

Starch, Gum, Size, Glue, and other Stiffening and Adhesive Materials, Parts i and ii, 1717–1876.

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The following Publications from the respective Societies and Authorities :—

Reports of the Academy of Science, France.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Journal of the Marseilles Scientific and Industrial Society.
Annales de l'École Polytechnique de Delft.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Architects' and Engineers' Society of Hanover.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Industrial Society of St. Quentin.
Proceedings of the Industrial Society of Mulhouse.
Proceedings of the Industrial Society of the North of France.
Proceedings of the German Society of Engineers.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Society of Engineers.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the American Railway Master-Mechanics' Association.
Proceedings of the United States Naval Institute.
Transactions of the Technical Society of the Pacific Coast, San Francisco.
Proceedings of the Massachusetts Institute of Technology; from Mr. George A. Mower.
Report of the United States Geological Survey.
United States Patent Office Gazette.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal.
Report of the Sassoon Mechanics' Institute, Bombay.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.

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Transactions of the Society of Engineers.
Journal of the Society of Telegraph-Engineers and Electricians.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Proceedings of the Chesterfield and Midland Counties Institute of Mining, Civil, and Mechanical Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the West of Scotland Mining Institute.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the Royal Society of London.
Proceedings of the Royal Institution.
Transactions of the Institution of Surveyors.
Transactions of the Sanitary Institute of Great Britain.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers Institute.
Proceedings of the Royal Artillery Institution.
Journal of the Royal Agricultural Society of England.
Journal of the Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions of the Royal Institute of British Architects.
Transactions of the Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Report of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

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Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1885; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Company; from Mr. Michael Longridge.
Report of the London Association of Foremen Engineers and Draughtsmen.
Report of the Manchester Association of Engineers.
Catalogue of the Liverpool Free Public Library.
Report of the Newcastle-on-Tyne Public Library.

The following Periodicals from the respective Editors:—

Revue Générale des Chemins de fer.
Revue Universelle des Mines.
Revue Industrielle.
Portefeuille Économique des Machines.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
The Railroad Gazette.
The American Engineer.
The American Manufacturer.
The Sanitary Engineer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Indian Engineer.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
The Building and Engineering Times.
The Electrical Review.
The Electrical Engineer.
Iron.
The Iron and Coal Trades Review.
The Ironmonger.
Ryland's Iron Trade Circular.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Contract Journal.
The Gas and Water Review.
The Plumber and Decorator.
The Shipping World.
The Fireman.
Invention.
Phillips' Monthly Machinery Register.
Industries.
The Universal Engineer.
The Railway Record.
The British Trade Journal.

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The PRESIDENT, in moving the adoption of the Annual Report of the Council, said there were certain points therein deserving special comment. It would be observed that the number of Members was still on the increase; that the income of the Institution exceeded its expenditure by £1000 a year; that the accumulated capital amounted to no less than £18,500; and that at the present time there were no less than four research committees engaged on investigations of the deepest interest to mechanical engineers. The attendance at the meetings during the past year had been exceedingly good. The munificent gift of £324 from the Reception Committee of last year's summer meeting to the library would certainly be of very great benefit to that department of the Institution. The Members had also done something to promote technical education by their assistance in opening the engineering department of the Yorkshire College, Leeds. The only one thing which was perhaps not very pleasing in the Report was the appeal which the Council had deemed it their duty to make to the Members generally in regard to their entertainers wherever they went. In future he trusted that invitations would be ratified by the presence of those who had accepted them. The minute which the Council had passed respecting written contributions to discussions was one to the framing of which they had given great care and attention, in order that any Member prevented from taking part in a discussion might be enabled under certain reasonable conditions to send written remarks subsequently upon the subject of the discussion. This arrangement he trusted would enhance the value of future Proceedings.

The motion for the adoption of the Annual Report of the Council was unanimously agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

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PRESIDENT.

E. H. CARBUTT,	London.

VICE-PRESIDENTS.

CHARLES COCHRANE,	Stourbridge.
ARTHUR PAGET,	Loughborough.
RICHARD PEACOCK, M.P.,	Manchester.

MEMBERS OF COUNCIL.

WILLIAM ANDERSON,	London.
SAMUEL W. JOHNSON,	Derby.
WILLIAM LAIRD,	Birkenhead.
EDWARD P. MARTIN,	Dowlais.
SIR JAMES RAMSDEN,	Barrow-in-Furness.

The Council for the present year will therefore be as follows:—

PRESIDENT.

E. H. CARBUTT,	London.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S.,	Northallerton.
SIR FREDERICK J. BRAMWELL, D.C.L., F.R.S.,	London.
THOMAS HAWKSLEY, F.R.S.,	London.
JEREMIAH HEAD,	Middlesbrough.
JOHN RAMSBOTTOM,	Alderley Edge.
JOHN ROBINSON,	Manchester.
PERCY G. B. WESTMACOTT,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

DANIEL ADAMSON,	Manchester.
CHARLES COCHRANE,	Stourbridge.
DAVID GREIG,	Leeds.
ARTHUR PAGET,	Loughborough.
RICHARD PEACOCK, M.P.,	Manchester.
JOSEPH TOMLINSON, JUN.,	London.

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MEMBERS OF COUNCIL.

WILLIAM ANDERSON, ...	London.
WILLIAM DENNY, F.R.S.E., . .	Dumbarton.
BENJAMIN A. DOBSON, . . .	Bolton.
SIR JAMES N. DOUGLASS, . . .	London.
SAMUEL W. JOHNSON, . . .	Derby.
ALEXANDER B. W. KENNEDY, . .	London.
WILLIAM LAIRD, ...	Birkenhead.
EDWARD B. MARTEN, . . .	Stourbridge.
EDWARD P. MARTIN, . . .	Dowlais.
SIR JAMES RAMSDEN, . . .	Barrow-in-Furness.
E. WINDSOR RICHARDS, . . .	Middlesbrough.
T. HURRY RICHES, ...	Cardiff.
BENJAMIN WALKER, ...	Leeds.
J. HARTLEY WICKSTEED, . . .	Leeds.
THOMAS W. WORSDELL, . . .	Gateshead.

The PRESIDENT said that it now became his duty to surrender once again into the hands of the Members the trust which they had reposed in him two years ago, and to induct into the presidential chair his successor, Mr. Carbutt. He assured them that he had at first felt exceedingly timid about undertaking so grave a responsibility as that of presiding over their meetings and taking the lead in the conduct of their affairs. But the Report of the Council which had just been read convinced him that, notwithstanding the many imperfections of which he was conscious on his own part, the Institution had not practically suffered at his hands. In fact it seemed to be in a most satisfactory and flourishing condition. In his successor they would find a gentleman who he was sure would do them credit as their President. Mr. Carbutt was a native of Yorkshire, the inhabitants of which county they were accustomed to regard as pre-eminent for their business capacity, their industry, and their clear-headedness. It was true that, although a trained mechanical engineer, and one who had been exceedingly successful

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in that capacity, Mr. Carbutt had not been actively engaged in business for the last few years; but he had retired only in order to undertake duties of a still more important character for engineers and for his country generally. While a Member of Parliament he had done some excellent work. He had obtained a committee to enquire into the question of Indian Railways, and that committee had reported in favour of their very considerable extension. He had also taken a leading part in advocating the cause of Indian civil engineers engaged in the Public Works Department, and there was reason to believe that his efforts were being rewarded with considerable success. He was also well known as having moved for a committee to enquire into the design and supply of guns, and into the organisation of the government workshops at Woolwich, Enfield, Waltham, and Birmingham. Therefore in Mr. Carbutt they had a President whose past doings were sufficient warrant of the interest he took in mechanical engineers, and of his capacity for working ably and energetically in their behalf.

He now desired to thank them all from the bottom of his heart for the kindness and courtesy they had displayed towards himself during the last two years, and for the loyalty with which they had always supported his ruling in the chair. He asked from them the same kindness, the same courtesy, and the same consideration on behalf of their new President. He had not the slightest doubt that he would merit it, and that they would give it. It only remained for him, on his own behalf, and he was sure he might say on theirs also, to wish Mr. Carbutt perfect health and complete success in the occupation of that chair, and in the fulfilment of the many important duties connected with the presidency.

Mr. E. H. CARBUTT, President elect, on then taking the chair, said he accepted the office of President with very great pleasure, but with considerable fear and trepidation. For any man to follow in the wake of the distinguished engineers who had been Presidents of this Institution was no slight task; and to follow Mr. Head, who for the last two years had worked so assiduously as their President, was no light matter. Mr. Head had fulfilled his duties as an

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(The President.)
Englishman should do, and as an engineer should do. On every occasion he had shown that urbanity and that kindly spirit which had always conducted their meetings to a proper and successful issue. He himself was proud of being an engineer, and had joined the Institution at an early age,—as early as many of the young men now present. While still a pupil he had attended the meetings of the Mechanical Engineers, and as soon as he was of age he joined the Institution; so that he had now been connected with it for more than a quarter of a century. This being the jubilee year of Her Majesty's reign, he considered it an extra honour the Members had done him in now electing him as their President, because they would have important duties to do; and while so many people were claiming credit for all the advantages which had accrued to this country during the last fifty years, he could say of a truth he believed the engineers had done more for the welfare of Her Majesty's subjects than any class or body of men in the world. The engineers he believed had added immensely to the happiness, welfare, and prosperity of the country; there was no doubt that a larger number of people were well off now than was the case fifty years ago; a larger number of people had made fortunes than fifty years ago; and although there might periodically be distress in their midst, its actual pinch he believed was far less severe than it had been fifty years ago. By cheapening production and facilitating the movement of the population from one town to another in the United Kingdom, engineers he believed had helped to make up the amount of happiness and comfort which existed at the present time. In looking back through their long list of Past-Presidents, he thought the Members would agree with him that it was a formidable thing for him to follow engineers who had achieved a world-wide fame, like their first two Presidents, George and Robert Stephenson, who had done so much for the railway interests of the country; or like Sir William Fairbairn, who had done so much in bridge-building and other engineering works; or like their lately deceased friend, Sir Joseph Whitworth, who by his refined accuracy of work, by his skill in manipulation, and by his various mechanical improvements, had done so much to raise the art of

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engineering to its present height of excellence. Next in succession after Sir Joseph Whitworth came John Penn, than whom no man had ever done more for marine engineering; only the other day it had been mentioned how, during the Crimean War, he had built ninety marine engines in three months, which helped to get the nation out of a great difficulty. Next came James Kennedy, whose recent death at the advanced age of eighty-nine had already been alluded to in the Report of the Council, and who had taken a prominent part in the development of the locomotive engine from the very commencement of the railway system. Then followed Sir William Armstrong, who had achieved so great renown in gun-making, and not less in hydraulic machinery. Then followed Robert Napier, who had done so much for shipbuilding, and whom he had once heard declare that he would rather build a fleet of ships than make a single speech; and no wonder, considering the profit which in the first case could not have failed to reward the excellence that was characteristic of all the work he did. Then after him came their well-known friend, Mr. John Ramsbottom, with regard to whom every locomotive engineer was thankful to acknowledge how much he had done for locomotive building and engineering in this country. Next came the late Sir William Siemens, of whom he thought it might fairly be said that he and Sir Henry Bessemer were the two who had done more for the steel trade than any other men in the country. To him succeeded Sir Frederick Bramwell, whom they were all delighted to see occupying so conspicuous a position as one of the leading engineers in the country. Then followed the friend whom they were glad to see with them on the present occasion, Mr. Hawksley, who had done more for the water and gas supply throughout the country than any other man, and who, notwithstanding the number of years through which his labours had extended, was still as actively engaged and as well able to work as ever. After him came Mr. John Robinson, who had done so much in tool making and locomotive building. Then followed Mr. Cowper, whose name was associated with the attainment of high temperatures of hot blast, and with the introduction of intermediate receivers for compound engines; then Mr. Westmacott, worthy partner of Sir William Armstrong;

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(The President.)
and lastly, immediately preceding their President who had just retired, came Sir Lowthian Bell, who had done so much for the iron manufacture by his elaborate investigations into the working of the blast-furnace. When therefore the Members called upon himself now to follow all these eminent engineers, he thought it could hardly be for his own mechanical ability; but he believed they considered that, this being the jubilee year of Her Majesty's reign, the Institution should be represented by a London member, through whom it might take a prominent position, and the talents and abilities of its Members might be made known if possible, so as to increase the reputation of Englishmen as the leading engineers of the world. With that view he should be most happy to do everything that lay in his power to increase the utility of the Institution. If he failed, it would not be for want of will, but only because he was not able to do the work. Seeing however the numerous gentlemen who surrounded him as a Council, he felt convinced that they would help to keep him in the right path; and he hoped at the end of his term of office the Members would be able to say, as they had said of their retiring President, Mr. Head, that the Institution had prospered during his presidency. He thanked them cordially for having elected him to this position; and trusted that if he could render any assistance or advice, either to the Institution collectively or to any individual Member, they would command his services.

Mr. CHARLES COCHRANE, Vice-President, invited all the Members to join him in returning their thanks to the retiring President, Mr. Head, who had accepted office two years ago under grave doubts and difficulties, of which the Council had been fully conscious at the time. Nothing however could bear out the wisdom of their choice more than the present position of the Institution, which was certainly the outcome in large measure of the urbanity and devotion to their interests that their late President had displayed. The list would indeed be a long one of all his acts during the past two years, both in the Council and among the Members, whether in London or at the various provincial meetings; and he had ever borne in mind

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solely the interests of the Institution. He therefore asked all the Members to join with him in returning their cordial thanks to Mr. Head for his able exertions during his presidency, and in assuring him of their warmest feelings on this occasion.

Mr. JOSEPH TOMLINSON, Vice-President, in seconding the vote of thanks to the retiring President, agreed most cordially with everything that had been said by Mr. Cochrane. They had found Mr. Head during his two years of office one of the most indefatigable men to work with that they had ever known. Not a single hitch had occurred in any of their consultations, and they had all been guided by Mr. Head along the straight path of duty.

The vote of thanks was carried by acclamation.

Mr. HEAD said he was exceedingly obliged to the proposer, to the seconder, and to the Members, for the way in which this vote of thanks had been moved and received. He could certainly concur in what had been said as to the substantial prosperity of the Institution at the present moment; but he could not altogether concur in the share of this success which had been attributed to his own exertions. It was quite true that he had done his very best, and had taken a pride and a pleasure in his work; but he should have been utterly powerless, had he not been ably and loyally supported by every member of the Council. He desired also to express his approval of the services performed by the permanent staff of the Institution. He thanked the Members very much indeed for their kindness, courtesy, and good feeling towards himself. He wished Mr. Carbutt every success as President; and if he could be of any use in assisting him, especially at the outset, his services would be at his disposal.

The PRESIDENT said it was now the duty of the Members to appoint an Auditor for the present year.

On the motion of Mr. FREDERICK COLYER, seconded by Mr. HENRY DAVEY, it was unanimously resolved that Mr. Robert A.

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McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

The PRESIDENT announced that the Summer Meeting of the Institution in the present year would be held in Edinburgh early in August, the Members having been invited by the Senatus of the University to meet in their Buildings. An invitation had also been received from Sir John Fowler and Mr. Benjamin Baker to visit the work in progress at the Forth Bridge; and another from Messrs. Barlow and Son to inspect the new Tay Bridge. It was also thought that many of the Members might be glad to spend a day in Newcastle in returning, so as to see the Mining, Engineering, and Industrial Exhibition which would then be open there.

The Adjourned Discussion upon the following Paper read at the Autumn Meeting in Leeds (Proceedings 1886, page 473) was then resumed, and completed :—

On Triple-Expansion Marine Engines; by the late Mr. ROBERT WYLLIE, of Hartlepool.

Shortly after Ten o'clock the Meeting was adjourned till the following evening. The attendance was 116 Members and 96 Visitors.

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The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, the 4th of February 1887, at Half-past Seven o'clock p.m.; E. H. CARBUTT, Esq., President, in the chair.

The PRESIDENT, alluding to the loss which the Institution had so recently sustained through the death, on the 22nd of January, of their distinguished Past-President, Sir Joseph Whitworth, Bart., at the advanced age of eighty-three, said that the Council had addressed a letter of condolence to Lady Whitworth, to express their deep regret. He was quite sure the Members would all concur in the feeling of the Council that no man had deserved better of his country than Sir Joseph Whitworth, who had done so much to render engineering what it now was. In every sense of the word he had embodied truth in every machine that he had made, giving it the highest amount of excellence possible; and by the adoption of his standard gauges and standard set of screws, which were now used all over the world, no doubt an immense amount of money had been saved to the country in those matters alone. He only wished that other engineers would follow in his wake, and that they might be able to settle upon standards for doors and windows and every other structural element that was used throughout the world. If anything of that kind could be done, it would cheapen production considerably. In addition to having done so much for engineers, Sir Joseph Whitworth had also done a great deal for the defence of the country in the magnificent guns which he had made; and had greatly promoted the advancement of mechanical engineering by the scholarships which he had so liberally endowed. His death would therefore be a great loss to the country at the present time.

The following was the letter of condolence which the Council, at their meeting held yesterday, had ordered to be sent to Lady Whitworth:—

Institution of Mechanical Engineers.
3rd February, 1887.

Madam,

I have the honour to inform your Ladyship that at a meeting of the Council of this Institution held here today, being the first opportunity since the

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decease of our late colleague, Sir Joseph Whitworth, Bart., the following Resolution was moved from the Chair and carried unanimously:—

"That the Council desire to record their sense of the loss sustained by the "Institution of Mechanical Engineers in the death of their eminent colleague, "Sir Joseph Whitworth, Bart., who occupied the position of President of the "Institution in the years 1856, 1857, and 1866, and who did so much to raise the "standard of excellence in mechanical work, by the refined accuracy which he "furnished the means of attaining. The Council also recall with admiration the "munificent gift which he presented to the nation during his lifetime, for the "establishment of scholarships in mechanical engineering; and they beg to "express to Lady Whitworth their sincere sorrow and heartfelt sympathy on the "occasion of her sad bereavement."

This expression of sympathy on the part of the Council represents also I am sure the feelings of the Members of the Institution generally.

I have the honour to be, Madam,
Yours truly,

Lady Whitworth,
Stancliffe, Matlock Bath.

JEREMIAH HEAD,
President.

The following Papers were then read and discussed:—

Description of a Portable Hydraulic Drilling-Machine; by M. MARC BERRIER-FONTAINE, of Toulon.

On Copper Mining in the Lake Superior District; by Mr. EDGAR P. RATHBONE, of London.

Notes on the Pumping Engines at the Lincoln Water Works; by Mr. HENRY TEAGUE, of Lincoln.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated shortly after Ten o'clock. The attendance was 77 Members and 43 Visitors.

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ON TRIPLE-EXPANSION MARINE ENGINES.*

BY THE LATE MR. ROBERT WYLLIE, OF HARTLEPOOL.

Adjourned Discussion, February 1887,
continued from Proceedings October 1886, *page* 531.

Mr. D. B. MORISON, referring to the remarks made by various speakers in the discussion at the previous meeting in Leeds, said it was now generally admitted by shipowners that the three-crank engine was very economical in respect of wear and tear; and although tandems were still advocated by some engineers, there was no doubt that the three-crank engine was preferable. Looking at the question generally, it seemed natural that there should be a decided inclination towards three cranks, instead of two, because it might reasonably be supposed that with three the motion was more uniform, and the wear and tear less. The experience of the last three years proved that this assumption was correct, inasmuch as it was seen that owners who had two-crank tandems as well as three-crank triples had been discarding the former design while they were continuing the latter. It was certain however that in converting existing two-cylinder compounds into triples the tandem arrangement must in many cases be adopted; and a solution of the problem was to put an additional cylinder on each of the two existing, and so use quadruple expansion with say 170 lbs. boiler pressure. This arrangement would involve but little alteration in the existing engines; and the necessarily high ratio of expansion which was required if the present low-pressure cylinder was retained must naturally be conducive to economy of fuel. Experience had proved that compound tandems were not so economical as receiver compounds

* See Proceedings 1886, pages 473–531 and Plates 89–108, for the numerous references made thereto throughout the adjourned discussion here recorded.

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(Mr. D. B. Morison.)
with cranks at right angles, owing to the range of temperature being greater in the former than in the latter; why then should a tandem triple be as efficient as a receiver triple? With a tandem engine there was longer communication between the successive cylinders during expansion than in a receiver engine; and as this meant that the temperature of the steam in the smaller cylinder must fall to that in the larger, and as the whole intention in compounding was to reduce the range of temperature and the consequent condensation and re-evaporation in each cylinder, it appeared to follow that the receiver engine would, other things being equal, prove the more economical.

As to the best ratios for the cylinders in a triple engine, there certainly did seem to be great difference of opinion. Considerable latitude however was due to the requirements of the case, inasmuch as it would not be expected that the same ratio would be suitable for an economical land engine, where the space occupied and the weight were of minor importance, as in a war-ship where the conditions were reversed. In the land engine for example a theoretical terminal pressure of about 7 lbs. above absolute vacuum would probably be aimed at, which would give a ratio of capacity of high-pressure to low-pressure of 1 to 8½ or 1 to 9; whilst in a war-ship a terminal pressure would be required of 12 to 13 lbs., which would need a ratio of capacity of 1 to 5; yet in both these instances the cylinders were correctly proportioned and suitable to the requirements of the case. It was obviously unwise therefore to introduce any hard and fast rule.

In order to show the effect produced on the diagrams of twisting moments by taking into account the weight of the moving parts and the pressure consequently required for their acceleration, the diagrams shown in Figs. 50 and 51, Plate 2, had been constructed for the twisting moments on the "Shakespear's" crank-shaft. Fig. 50 was simply a reproduction of Fig. 24, Plate 99, in which the weight of the moving parts had been neglected; while in Fig. 51 the weight of the moving parts was allowed for. The indicator diagrams had been corrected accordingly, for the weight and the accelerating pressure; and the diagrams so corrected had then been used for

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calculating the twisting moments in the manner explained in the memorandum at the end of the paper (page 491). As the speed of the engine was in this case comparatively low, not exceeding 66 revolutions per minute, the pressure required to accelerate the moving parts was not great; and it would consequently be seen that the difference thereby produced upon the diagram of twisting moments might be neglected for purposes of comparison. The crank-shaft stresses in Fig. 51, including the weights of the moving parts, were—maximum 121, mean 100, minimum 78·5; while those in Fig. 50, neglecting the weights, were—maximum 117, mean 100, minimum 78·7.

The value of the data which would be obtained, if the weight of steam used could be ascertained, had been thoroughly appreciated by the author, as seen from page 484 of the paper; but all marine engineers would agree that it was sufficiently difficult to get the usual indicator diagrams and coal consumption on board a steamer; and although these results as given in the paper were only approximately correct, they nevertheless served to indicate the efficiency of the machinery generally. At the same time every one would also agree how valuable would be correct data; and he was sure the firm with which he was connected would gladly afford every assistance for obtaining them. Some of the indicator diagrams and accompanying data having been criticised by Professor Kennedy as implying impossible results in regard to the evaporative duty of the coal, he should be happy to arrange for a trip from Hartlepool to Plymouth with one of the steamers included in Professor Kennedy's table on page 506, and to give him every possible assistance for taking indicator diagrams and measuring the coal throughout the trip, although he could not undertake to introduce any feed-water measurer, or anything which would interfere with the working of the ship.

The roughly approximate results from the "Para," given in Table 1 (pages 492–6), for which he was himself directly responsible, had been obtained entirely for the information of the author, and with no idea of publication. Three special indicators had been used, and with the assistance of the chief engineer he had taken

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(Mr. D. B. Morison.)
diagrams at what was practically the same instant at regular intervals throughout the seventy-two hours. The boiler-pressure had been kept steady, and the coal and ash had been weighed, as described in page 496; in fact he had done his very best to get a good idea of what a triple engine was really burning. He had again brought for inspection the whole of the original diagrams actually taken on the trial and correctly worked out; the "Para" was burning the same amount of coal and travelling at the same speed now as then, and had done so ever since. The consumption of coal per indicated horse-power per hour he considered by no means satisfactory as the sole basis for estimating the general efficiency of the engine, inasmuch as the latitude available in dealing with diagrams admitted of so many inaccuracies. It was desirable in addition that different steamers of the same class and of approximately similar dimensions should also be compared, as regarded the dead weight carried, and the speed attained on a given consumption of coal; the commercial value of the results would then be known, which after all was the main question to be considered. The "Lusitania," on her return Australian voyage after conversion to triple expansion had effected a saving of about £1000 over any previous voyage; and in the still later instance of the Union Company's "Spartan," the saving on a return Cape voyage had been 500 tons of coal, representing a monetary value of £750, or at the rate of £3000 a year. As a proof that these results had been appreciated, Messrs. Richardson had just finished converting the engines of the "Athenian," and were now busy with those of the "Trojan" and "Mexican," as well as with Sir Donald Currie's steamers, the "Grantully," "Garth," and "Drummond Castle," the whole representing a total of nearly 27,000 indicated horse-power.

With reference to the "Anglian," it had been remarked by Professor Kennedy (page 508) that the advantage given by triple expansion "had been properly got, and in a perfectly legitimate way, by using a higher boiler-pressure, and taking additional work out of the steam by expanding it." Of course this was so. Then further—"it did not prove that three cylinders were better than two: what it did prove was that it was far better to use 150 lbs. pressure than only

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50 lbs." It appeared to himself that what it did prove was that a three-cylinder triple-expansion engine was an economical engine for using steam at a pressure of 150 lbs. Of course the work was in the steam itself, and not in the three cylinders; and theoretically therefore one cylinder was as good as three. Still a steam engine could not be considered in its purely theoretical aspect, since the chief source of loss in all engines, namely initial condensation, was the very thing overlooked in such theoretical considerations. It was the reduction of this loss, by reducing to a minimum the cooling due to the cylinder surfaces, which rendered a three-cylinder expansion engine superior even to a simple condensing engine.

Attention had been called by Mr. Mudd (page 511) to the fact that, the nearer the work represented by the indicator diagrams approached the theoretical amount, the greater was the efficiency of the steam. This was indeed axiomatic. It had been the endeavour of the late author to put as much valuable information into the paper as possible, while naturally leaving room for various evident conclusions to be drawn from the information so furnished. In a paper of this sort, if every point had to be amplified throughout the whole of the details and the consequences that were involved, a volume would be the result. Passing over therefore all minor details, and coming to the one important question of the sequence of cranks, the sequence recommended in the paper was high, low, intermediate; while that advocated by Mr. Mudd (page 513) was high, intermediate, low. The former sequence—high, low, intermediate—gave an approximately horizontal exhaust line, and thus minimised the range of temperature and the initial load; the latter sequence—high, intermediate, low—increased the range and also the load. In order to show the manner in which the sequence of cranks affected the passage of steam between the cylinders, he had prepared the two pairs of diagrams shown in Figs. 48 and 49, Plate 1, considering for the sake of clearness the high and intermediate cylinders only. In Fig. 48 the sequence high, low, intermediate, was illustrated, in which the angle between the high and intermediate cranks was consequently 240°. Supposing steam to be admitted into the top of the high-pressure cylinder, it would be seen from Fig. 48 that the high-pressure crank moved through 127°,

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(Mr. D. B. Morison.)
when the top of that cylinder began to exhaust into the bottom of the intermediate which had been previously open, and continued exhausting into the intermediate till the high-pressure crank had passed through 162°; from 180° to 233° the steam was compressed into the receiver, and during this compression the high-pressure piston passed through 17 per cent. of its stroke. At 233° of the high-pressure crank the top of the intermediate cylinder began to take steam from the top of the high-pressure cylinder, and at 315° from the bottom also of the cylinder; and the top of the intermediate cylinder continued to take steam until the high-pressure crank had passed through 334°. The high-pressure piston again compressed into the receiver from 360° to 51° in the next revolution; and during this period the piston passed through a distance equal to 22 per cent. of its stroke. Taking the other sequence of cranks—high, intermediate, low—it was seen from Fig. 49 that, when the high-pressure crank had passed through 127° as before, the top of its cylinder began to exhaust into the top of the intermediate cylinder which had been previously open. This continued till the high-pressure crank got to 215°, when the steam exhausting from the high-pressure cylinder was compressed into the receiver from 215° to 292°, during which period the piston passed through 56 per cent. of its stroke. At 292° the top of the high-pressure cylinder began to exhaust into the bottom of the intermediate; and shortly afterwards the bottom of the high-pressure cylinder began also to exhaust into the bottom of the intermediate. The bottom of the intermediate cylinder continued to take steam till the high-pressure crank had got to 42° in the next revolution. Steam was then compressed into the receiver from 42° to 112°, during which period the high-pressure piston had passed through a distance equal to 58 per cent. of its stroke. Thus with the cranks arranged in the sequence high, low, intermediate, the mean compression into the receiver was 19½ per cent. of the stroke; with the sequence high, intermediate, low, it was 57 per cent. In the former case the compression was just what was required to keep the receiver pressure practically uniform; in the latter case the compression caused a variation in the receiver pressure to the extent sometimes of 22½ lbs.

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In the classification given by Mr. Mudd (page 511) of the principal sources of loss in efficiency of steam, the first of those enumerated was the excess of condensation over re-evaporation; and this loss it was attempted to minimise by reducing the range of temperature in any one cylinder. Yet it was subsequently stated on page 515 that considerations respecting the detrimental effect of condensation during admission had led to the conclusion that diagrams in which the dividing lines were oblique were preferable to those having horizontal lines of division, although it was acknowledged that the oblique diagrams showed greater ranges of temperature. It appeared evident to himself that the reduction of the range of temperature was essential to maximum economy. Considering again the initial load, it was clear that, the greater the load, the larger should be the crank-pin and the bearing surfaces; consequently for a given pressure per square inch larger bearings would be required with the oblique diagrams than with those having horizontal dividing lines. Many of the engineers who had commenced with the sequence high, intermediate, low, were now adopting that advocated in the paper; and it was acknowledged by engineers at sea who had had experience of both plans that the sequence high, low, intermediate, resulted in what was commonly called the sweetest running engine.

The statement made in the paper (page 476)—that for obtaining even approximate equality in powers, temperatures, and stresses, the greatest care was required in designing the steam passages throughout the engine—seemed to him to be really confirmed by Mr. Mudd's remark (page 518) as to the object to be aimed at in designing the steam passages; for the desired equality could certainly not be obtained unless the steam passages were so designed that the steam could be got freely on to the piston and freely off again at the proper times, as mentioned by Mr. Mudd.

With regard to the ratio 3–5–8 for the diameters of the three cylinders (page 518), this was equivalent to 9–25–64 or 1—2·78—7·11 for the capacities; and he believed the ratio approximately accepted for the capacities in the ordinary class of cargo steamers was 1—2·66—7·11.

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(Mr. D. B. Morison.)

As properly pointed out in Mr. Adamson's remarks (page 520), the practical results given in the present paper were valuable for comparison, rather than as presenting an absolute conformity with conclusions arrived at by theory. It was indeed perfectly true, as mentioned by Professor Smith (page 526), that, if the range of temperature were settled in each cylinder, this would settle the range of pressure; and if the cylinder ratios were so settled in conformity with those ranges of pressure as to give equality in stresses, it would then be impossible to get exact equality of power in the three cylinders concurrently with those two other conditions. But what was meant in regard to the three conditions of efficiency enumerated in the paper (page 474) was that an approximate equality should exist between the three cylinders in those three respects; and the nearer to absolute equality the better.

Respecting the application of artificial draught to marine boilers, he might mention that Messrs. Richardson were fitting steamers with artificial draught, on plans more or less resembling that shown in Plates 105 and 106; and he should very much like to know the general opinions which prevailed among engineers respecting it. It was a question whether the artificial draught would be detrimental to the boiler or not; and he believed there was a prevailing impression that forced combustion would be so. But in the case of the "Stella" (page 489), which had now made three Indian voyages, everything had gone on satisfactorily; and in the "Chelydra," which had now been running six months with artificial draught, the daily consumption of coal had been reduced to 18 tons from the previous consumption of 22 tons at the same speed; and in the sister ship, the "Federation," belonging to the same owners, the daily consumption without artificial draught was still 22 tons. This was certainly a great difference, and he could not quite understand it; but he was satisfied that the economy resulting from the artificial draught would at any rate amount to from 12 to 15 per cent.

Mr. CHARLES COCHRANE, Vice-President, drew attention to the reference which he had made in the previous discussion (page 504)

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to the velocity of the steam between the cylinders in these engines. Without going into the details of the sections of the steam passages, perhaps Mr. Morison could give the lineal velocity of the steam, on which he based his calculations for the outlets and inlets from cylinder to cylinder according to the different temperatures and pressures.

Mr. MORISON replied that, taking the area of the cylinder multiplied by the piston-speed in feet per second, and dividing by the area of the port, the velocity of the initial steam through the high-pressure cylinder port would be about 100 feet per second; the exhaust would be about 90. In the intermediate cylinder the initial steam had a velocity of about 180, and the exhaust of 120. In the low-pressure cylinder the initial steam entered through the port with a velocity of 250, and in the exhaust port the velocity was about 140 feet per second.

The PRESIDENT mentioned that two letters had been received on the subject of this paper, one from Mr. Kirk and the other from Mr. Wright, which he thought it would be desirable to read at the present stage of the discussion.

Mr. A. C. KIRK wrote that the compound engines of Mr. Elder's time, which constituted a great step in marine engineering, were Woolf engines with four cylinders, the steam first expanding in the high-pressure cylinders, and then simultaneously in the high and low-pressure cylinders. This had indeed the great defect that the high-pressure cylinder worked through the full range of temperature from that of the admission of the boiler steam down to that of the exhaust opening to the condenser; but it was thus less than in the single cylinder, in which the range of temperature was from that of the boiler down to that of the condenser; and hence its advantage. The next step was in the introduction of the receiver, and the cranks at right angles, the high-pressure cylinder over one crank and the low-pressure over the other; to the best of his knowledge this was due to Mr. E. A. Cowper. The high-pressure cylinder then worked

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(Mr. A. C. Kirk.)

through a range of temperature from that of the boiler down only to the initial temperature of the low-pressure cylinder; thus the range of temperature was much more equally divided between the two cylinders. As the construction of boilers was improved, and the confidence of owners increased, the steam pressure was gradually raised, until at length, if by expansion full advantage was taken of the higher pressure attainable, too great a range of temperature began to take place in each cylinder, and the full economy due to the expansion could not be got. This had led him to divide the expansion into three steps, instead of as before into two, with the beneficial results now so well known. When the "Aberdeen" was built, the economy practicable was a question of boilers; for although 125 lbs. per square inch would not now be regarded as at all a high pressure for a marine boiler of the ordinary type, it was then a great and bold step; and in taking it he had been much indebted to the confidence placed in him by her owners, and to the support he had received from the Chief Surveyor of Lloyd's Register.

On the subject of triple expansion he considered there really was not much to discuss. Few would now dispute the importance of reducing as much as possible the range of temperature in the cylinder of any steam engine. This meant expanding in successive steps; and the number of these for a given initial pressure became a commercial rather than a mechanical question. This was a rough statement of the case, but not very wide of the truth.

Mr. JOSEPH WRIGHT (Tipton) wrote that he regarded what were now called triple-expansion or three-cylinder engines as only another step toward the final adoption of quadruple-acting engines, the consideration of which he thought would more properly occupy the attention of the Institution at the present time than the smaller questions of two or three-cylinder engines. Sooner or later, quadruple engines must be adopted, if the economy of using very high-pressure steam was to be secured. It was not so much for the cylinders, as for the slide-valves and crank-pins working in connection with them, that quadruple action became so imperatively

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necessary. The objections to over-loaded crank-pins, and also the importance of imparting power to crank-shafts in more places than one, were well known; and if the good old rule were better observed of making crank-pins one-fourth the diameter of the cylinder, or even larger in case of very high pressures, the principal difficulties in regard to cranks and crank-shafts would mainly disappear.

The proportions of cylinders he looked upon as of secondary importance. If the terminal steam in the first cylinder was sufficient to secure a satisfactory terminal pressure in the last, it mattered little what the intermediate sizes were, provided that the available area of passage through the slide-valve and ports bore the same ratio to the cylinder area in all cases, and that the steam speed did not exceed 40 feet lineal per second. It was not so much a question of four cylinders or three, as whether four ordinary slide-valves could deal with 200 lbs. pressure of steam better than three. With the statement contained in the paper (page 477) that the steam passages should be as small in capacity as possible, he was not at all able to agree; because if the exhaust steam left in the passages and clearances was cushioned up at the end of each back stroke to only the same pressure as the terminal, and not higher, no loss would then arise from ample passages and clearances.

Judging from the great diversity of opinion upon the vexed question of steam-jacketing the cylinders, but little additional knowledge appeared to have been gained upon this subject since the introduction of Mr. Cowper's well-known hot-pot or intermediate heater. In the course of a number of years he had himself taken about 170 sets of indicator diagrams from various cylinders, some with ordinary steam-jackets on and off, and others with his own interheater on and off, hoping thereby to arrive at some rule. His experience showed however that about fourteen out of every fifteen of the cylinders were overheated by their steam-jackets, and some so much so that they showed a positive loss upon the engine's working. Whenever the temperature of the steam in the cylinders was only slightly increased by the jackets, there appeared to be considerable economy; but when the temperature was increased largely, the economy partly or entirely disappeared, in consequence

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(Mr. Joseph Wright.)
of the greatly increased heat and friction produced in the engine by superheated steam; although the indicator diagram showed a large increase of power in the cylinder, the engine lost speed in working against the same load. By an automatic arrangement, as in his own interheater, for controlling the temperature of the steam in the jacket to within certain limits varying with the mean pressure in the cylinder, he had been able to secure good results; but without some such control he had found steam-jackets on cylinders to be rather a disadvantage than otherwise.

Fully to consider the numerous indicator diagrams exhibited in illustration of the present paper would far overstep the limits of fair discussion; and he would therefore only remark that from his own manner of reading them they seemed by no means satisfactory, as there appeared to be a considerable difference in the weight or relative volume of steam in each cylinder; and it seemed strange to exhibit, in illustration of what was called triple expansion, diagrams which showed more than 70 per cent. of wire-drawing and loss of pressure. He did not mean to say that all this loss might be recovered; but that it was very excessive, and principally due to defective valve arrangements.

Mr. W. W. BEAUMONT, in continuation of his remarks at the close of the previous meeting (page 531), said he had by no means wished to under-estimate the value of the information to be obtained from indicator diagrams; but at the same time he thought that the information obtained from very numerous voyages, or from observations taken over a large number of hours, was of great value, and enabled an opinion to be formed of the relative economy of different kinds of engines. In the remarks made by Professor Kennedy (page 508) it had been said, with reference to two-cylinder and three-cylinder compound engines, that there was no reason theoretically why the higher pressure in the three-cylinder engine should not be equally well utilised in the two-cylinder compound. The issue turned very much upon what was taken to constitute theory; and Professor Kennedy's theory did not appear to include the consideration of practical conditions, as well as of those which in an indicator

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diagram would relate to the behaviour of the steam as a gas. After the remarks already made on the present occasion by Mr. Morison, it was unnecessary to say there was no doubt whatever that the triple-expansion engine had proved more economical than the two-cylinder compound. By taking special cases it might of course be shown that two-cylinder compounds had given results as good as any yet obtained from triple-expansion engines; and similar instances were well known in which single-cylinder engines, worked very carefully under special conditions, had yielded results as economical as any compound engine. But engines must be taken generally; and no one he believed would care to say that theory now indicated as good results with one cylinder as with two. When the practical conditions under which steam had to be used were taken into consideration, and it was not looked upon as merely expanding in a cylinder without doing any work, what theory really indicated was that the range of temperature in any one cylinder must be reduced as much as was consistent with employing a moderate number of cylinders. After all therefore, the information obtained by ship-owners as to what it cost to carry a ton of cargo from port to port was the information that was most important, and must be used by engineers in selecting their type of engines.

Mr. THOMAS MUDD, referring to the combined indicator diagrams from the screw steamer "Abeona," shown in Fig. 45, Plate 107, said his principal object in exhibiting them had been to endeavour to prove that the high-pressure crank leading—or the sequence high, intermediate, low—gave better results than the low-pressure crank leading—or the sequence high, low, intermediate—by showing that there was less space lost between the diagrams with the former sequence. He might now take the opportunity of adding that the diagrams seemed to him to prove also another point, namely that piston-valves did not necessarily cause contracted steam passages, as it might seem to be implied in the paper (page 476) that they did. All the three valves in the engine of the "Abeona" were piston-valves; and apparently from these indicator diagrams, Fig. 45, there was not much loss due to contracted passages.

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(Mr. Thomas Mudd.)

From the combination of these diagrams in Plate 107, it might seem that they could not be accurate, because they overlapped one another: causing it to appear, for instance, that the steam pressure during the admission into the second cylinder was higher than the back pressure at the same time in the first cylinder, which seemed to be impossible. But this appearance arose merely from the diagrams not being combined in their relative sequence in working; and in order to show that such a conclusion did not really follow, he had now prepared the continuous diagram shown in Fig. 55, Plate 3, in which it would be seen that the lines did not at any point overlap each other when combined in strict order of sequence in working. The wedge-shaped areas CC were compression areas, and PP were the forward-pressure areas: so that it was clearly seen where the changes occurred from forward pressure to compression. This diagram also explained why there was the hump H or rise in the steam line shortly after the beginning of the stroke in the intermediate cylinder. Immediately above this hump the line of the high-pressure diagram represented practically the receiver pressure; and where the receiver pressure rose, as it did just on passing from the forward pressure to the compression in the high-pressure cylinder, that rise was communicated into the next cylinder, only a little later on.

Although, for the purpose of comparison with the numerous combined diagrams illustrating the paper, the combined diagram shown in Fig. 45 had been put together in the same way, which had also been commended by Professor Kennedy (page 509) as the proper mode for comparing the successive indicator diagrams with the theoretical expansion curve, that method did not appear to himself to be correct. For in the first place, wherever there was compression he did not think it was right to debit the engine with the whole of the clearance, that is, to expect the engine to show as large an area of diagram as a theoretical diagram which included the whole of the clearance. And in the next place, with regard to the relative positions of the three successive diagrams, the same vertical line had been taken for all three alike, as the starting point for measuring off the whole amount of the clearance in each

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cylinder. If however the compression in the first cylinder was carried up to the full initial pressure of the steam, he considered that the whole of that clearance ought to be left out from the theoretical diagram, and that the theoretical expansion curve ought to be drawn out for only the quantity of steam received fresh from the boiler, taking no account of the steam that was retained in the cylinder for compression. Taking the case of a single-cylinder engine, and supposing that it had neither clearance nor compression, it would then be expected to fill up the whole of the theoretical diagram A B C D E in Fig. 56, Plate 3. Adding now a large amount of clearance F A E G, while the engine still had no compression, there would then be the larger quantity of steam F B to expand, which would give the much higher expansion curve B H; and as there was no compression, the engine would receive the quantity of steam F B from the boiler, and the diagram F B H D G would contain the correct area of reference for efficiency of steam in this case. Supposing now that with the same clearance A F there were such a compression J A as would raise the cylinder steam up to the boiler pressure, it was evident that the engine could not be expected to perform work for nothing; and that, as the clearance space A F was here filled full of steam at boiler pressure, it would take in no more when the valve was opened, and the only fresh steam admitted would be that represented by the shorter line A B, just as it would be if there were no clearance at all. As therefore the engine did not receive from the boiler the steam represented by A F, it could not be expected to give any work from that steam; and accordingly the clearance area A G ought to be removed from the theoretical diagram, which thus became shortened to the same length as before any clearance was added. The higher expansion curve B H was however in this case still the correct one for the whole steam F B; but the additional expansion area B H C had not been got for nothing, but only in exchange for the compression area A J E, which represented the work done upon the clearance steam A F for enabling the higher expansion curve B H to be obtained. The theoretical diagram for the engine working with this compression should therefore include only one of the two areas, B H C or A J E, and not both; and

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(Mr. Thomas Mudd.)
it seemed clear that the proper theoretical diagram to be taken for the efficiency of the steam in such an engine was the area A B C D E, which was the same as if there had been no compression at all, and represented the expansion only of the quantity of fresh steam A B received from the boiler after compression had taken place. At the same time it was advisable to show also on the theoretical diagram the higher expansion line B H for the whole quantity of steam F B, because the expansion line actually obtained ought to come up as closely as possible to that curve.

Next with regard to the positions of the second and third diagrams from a triple engine, relatively to the first and to each other, the same diagrams from the "Abeona" were re-combined in Fig. 57, Plate 3, on the method he advocated. According to the foregoing principles, the point A, Fig. 57, would be found by prolonging the compression curve from J upwards to the initial pressure. The lower expansion curve B C should be that due to the fresh boiler-steam A B supplied for each stroke. A F represented the volume filled by compression at boiler pressure. The line F G had no value whatever, and the point F was only of interest inasmuch as the line F B represented the whole of the steam in the first cylinder at cut-off. The higher expansion curve B H was that due to the steam F B, and was the line that should be followed by the first diagram. Beyond H the curve B H was valueless, because at J the valve divided the steam G H into two parts, the part J G being retained in the first cylinder for compression, and the part J H only being passed on to the next cylinder. For placing the second diagram, the important point to be accurately noted was the point J, which had the same importance for the second diagram that A had for the first; and J should now be taken as the starting point for the second cylinder, just as A had been for the first, by measuring off forwards from J just so much of the second cylinder's clearance as was not filled up by compression. This would give the position for the second diagram; and so on for the third, by similarly starting from the corresponding point K, Fig. 57. It would be seen that this plan linked up the compression curves into a continuous chain; but they

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did not in the actual diagrams form a true continuous compression curve, because it was the upper end of the compression curve of one diagram that was theoretically continued up to the lower end of the next, so that the chain was made up of links of actual compression alternating with links of theoretical compression. In Fig. 57 the lower theoretical expansion curve B C was drawn from the quantity of fresh steam A B received from the boiler for each stroke; consequently A B C D E was the theoretical area which served for determining the relative efficiency of the steam in the whole engine, down to the back-pressure actually existing in the low-pressure cylinder, namely 11½ lbs. below atmosphere; and the diagrams shown within that area represented an efficiency of 76·4 per cent. by this standard. If the theoretical diagram were made to include the area E D M N, so as to refer the efficiency to an absolute zero of pressure taken at 15 lbs. below atmosphere, the efficiency of these diagrams would be 70 per cent.; but the former was the more useful standard of reference, especially if the line E D were a fixed line at a reasonably good vacuum, say 11½ lbs. below atmosphere as in this case. This method he considered a much more accurate one for comparing actual diagrams with theoretical; and it put all engines on a fair basis, making due allowance both for clearance and for compression. If the diagrams illustrating the paper had been combined by the author according to this plan, they would have shown a much greater efficiency he was sure than was at present apparent; and much of the discrepancy between one set and another he believed would have disappeared.

Professor RYAN, referring to the three general conditions of efficiency set forth in the paper (page 474), questioned whether equality in the range of temperature in each cylinder was really worth striving after. As far as could be gathered from the paper, the object in aiming at it seemed to be to divide the total range of temperature between the three cylinders, so that no one of the three should be exposed to an inordinate range of temperature. But he thought it was not by any means proved that inequality in the range of temperature caused any large amount of evil through condensation.

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(Professor Ryan.)

If indeed the condensation by the cylinder surfaces was directly proportional to the first power of the range of temperature, there could be no reason why the total range should not be unevenly divided amongst the cylinders. But if, as there seemed reason to believe, the condensation depended upon some other power or function of the range of temperature, then perhaps there might be some slight advantage in this equality. The question arose whether the equality in range of temperature affected anything else besides the cylinder condensation; and in theory at all events there was a definite connection between equality of horse-power and equality of range on the absolute scale of temperature. Of the three equalities mentioned, he considered the third the most desirable, since the equality of power ensured ease and regularity in turning. With regard to the compatibility of the three equalities, he would point out that theoretically, in an ideally perfect triple-expansion engine, the equality in range of temperature would depend solely and wholly on equality in horse-power; and practically also, to whatever extent the processes taking place in these engines were strictly reversible, and so far as the same defects existed in all the three cylinders alike, he considered equality in range of temperature would follow equality of horse-power. Thus in the combined diagrams exhibited from the "Hispania," Fig. 18, Plate 97, where the ranges of temperature in the high-pressure and intermediate cylinders were nearly equal, being 76° and 78° respectively, it was seen that the horse-powers were also approximately equal, being 214 and 205 respectively. The initial stresses on the other hand, which were as 31 to 35, could have no disturbing effect upon these relations, otherwise the horse-power in the intermediate cylinder would have been greater than in the high-pressure, instead of which it was less. The same remarks applied also to the cases of the first and second cylinders in Fig. 30, Plate 102, and in Fig. 45, Plate 107. Others also of the diagrams showed that the connection was between temperature-range and horse-power, utterly irrespective of stress.

With regard to the consumption of steam calculated by Professor Kennedy (page 506) from the indicator diagrams illustrating the paper, it appeared to him that the results arrived at might be

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interpreted to show, not that the evaporative power of the fuel was much too great, but that there was comparatively little condensation in the high-pressure cylinder. It was the opinion of some engineers, in which he concurred, that the condensation and re-evaporation in the high-pressure cylinder were of much less account than in the other cylinders. From several of the examples adduced in the paper it would be seen that the temperature range was greater in the low-pressure cylinder than in the high-pressure, while at the same time the horse-power of the low-pressure was less than that of the high-pressure. From page 475 he inferred that in the author's practice the low-pressure cylinder was steam-jacketed, and the high-pressure was not; so that it appeared the high-pressure cylinder with a smaller range of temperature and without steam-jacketing gave a larger horse-power than the low-pressure. Various considerations led him to conclude that the condensation must be greater in the low-pressure cylinder than in the high-pressure. Initial condensation and re-evaporation in any cylinder depended on three things: firstly, on the range of temperature; secondly, on the area of surface exposed to the steam; thirdly, on the mass of metal that might be involved in the thermal changes. This third element again depended on three others, namely: on the time t occupied in the periodic changes of temperature; on the conductivity c of the metal; and on the specific heat s of the metal, or its capacity for heat. Hence the mass of metal practically affected in each stroke would vary directly as the square root of t and of c, and inversely as the square root of s. Assuming equality in the ranges of temperature, and efficient lagging, the reasons why he considered that steam-jackets would be more usefully applied to the intermediate and low-pressure cylinders, in accordance with the author's experience, than to the high-pressure, might be briefly summarised as the nine following. First, the fall of temperature occupied less time in the high-pressure cylinder than in either of the others: although the range of temperature might be the same in each cylinder, yet, owing to the fact that the admission lasted for a certain time, and that in the high-pressure cylinder it was boiler steam of constant temperature which was entering during the whole period of

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(Professor Ryan.)
admission, the change of temperature took place during a shorter portion of the stroke or in a shorter time in that cylinder than in the others. Second, the face of the piston and of the cylinder cover constituted a larger percentage of the total surface exposed to the steam during the stroke in the larger cylinders; and these two faces were wholly exposed throughout the entire stroke. Third, the ratio of exposed metallic surface to weight of steam increased in each successive cylinder, since it was the same weight of steam which passed through each. Fourth, the weight of metal involved in the thermal changes was greater in the cylinders which exposed the larger surfaces. Fifth, condensation in the high-pressure cylinder lubricated the cylinder, thereby dispensing with oil and its consequent evils at high temperatures. Sixth, the steam became wetter and wetter as it passed through the successive cylinders. Seventh, condensation in the low-pressure cylinder produced greater ultimate loss than in the high-pressure; because re-evaporation in the low-pressure cylinder contributed steam to the condenser, but in the high-pressure to the next cylinder. Eighth, a steam-jacket on the high-pressure cylinder would be partly idle during admission; and, considering the high mean temperature in this cylinder, would be very little better than efficient lagging. Ninth, a steam-jacket would be very effective on the intermediate and low-pressure cylinders, on account of the steep gradient of temperature between the hot boiler-steam in the jacket and the cooler steam inside these cylinders. His view appeared to be borne out by the concurrent testimony of all the author's own diagrams, that the unjacketed high-pressure cylinder was much more efficient than the jacketed low-pressure cylinder, considering their respective ranges of temperature.

Mr. JOHN G. MAIR considered they were all exceedingly indebted to the author of the paper for having given them so freely the practical results of his own experience. They had also to thank Mr. Cochrane for having so clearly pointed out at the last meeting (page 503) that the statement of the weight of coal consumed by an engine was utterly valueless. So it was; an engine did not consume coal at all,

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it simply used steam or heat; and what ought to be known was how much heat it did use; then it would be seen exactly how the efficiency of different engines stood. There was no doubt at all about the fact that the three-cylinder compounds were more efficient than the two-cylinder compounds; but for conducing to this result a diminution in the range of temperature he thought was not so important as previous speakers seemed to imply. For, looking at the example given of the "Anglian" (page 487), it was seen that the ranges of temperature in the ordinary two-cylinder compound had been 70° and 75°, while in the triple they were 71° and 71° and 79°: showing a very small difference indeed between the two plans. Again, in the "Lusitania" (page 489) the ranges of temperatures for the two-cylinder compound had been 72° and 78°, while in the triple they were 71° and 68° and 76°: so that there was not so much diminution in the range of temperature in the triple engine as to account for its greater economy. The simple reason why the three-cylinder engine was more economical than the two-cylinder lay in the fact that, as it was not convenient in a marine engine to cut off at earlier than 60 per cent. of the stroke in the high-pressure cylinder for various practical reasons, sufficient expansion could not be got with two cylinders, if the power was kept equal in each cylinder. In the two-cylinder engine of the "Anglian" (page 487) the ratio of the cylinder areas was 3·07, which, with the cut-off at 60 per cent. in the high-pressure cylinder, gave only 5·11 expansions; but when she was changed to triple, the cylinder ratio became 7·04, and the cut-off at 60 per cent. then gave 11·74 expansions: so that the difference in the rates of expansion was 5·11 with the two-cylinder against 11·74 with the triple. That was where the economy came in. It was exactly the same with the "Lusitania" (page 489), which had only 5·26 expansions with her two cylinders, and made 11·85 expansions after conversion to triple.

With regard to the number of expansions that could advantageously be made in an ordinary two-cylinder compound engine, the following were the results of experiments that he had made with a pumping engine, raising the boiler pressure from 60 up to 120 lbs. per square inch above atmosphere while working throughout at practically the same speed:—

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(Mr. John G. Mair.)

Boiler pressure, lbs. per sq. inch above atm.	60	80	100	120
Number of expansions	9·2	13·2	14·1	13·7
Thermal units used per I.H.P. per minute	334	327	325	330

These figures showed that after obtaining somewhere about ten or twelve expansions—say eleven—there was no economy in going to any higher expansion with two cylinders, as the saving in heat expended was not sufficient to make up for the increased frictional loss due to the larger cylinders required. The triple engine he thought would then come in; and the requisite number of expansions he considered had not yet been reached for obtaining all the economy that could be got by the triple-expansion engine.

As to the use of steam-jackets, he did not think there was much advantage in putting on jackets where the range of temperature was so small as in the triple engines described in the paper, and with a high piston-speed. Undoubtedly economy would result from the use of jackets; that was a question beyond dispute. But the point was whether that economy was commercially worth the trouble and the expense of putting the jackets on, because the stoke-hole was not a good place in which to get them properly looked after; even engines on shore often had their jackets choked up with water and neglected by the drivers, and much more was this likely to be the case at sea.

With regard to the heat given up by steam-jackets to cylinders, there was a statement * in a recent discussion (Proceedings 1886, page 377) "that the heat received by each pound of jacket steam was

* A letter has subsequently been received by Mr. Mair from Mr. G. A. Hirn, of Colmar, Alsace, dated 7th March 1887, in which he says, after reading the reference made to the Alsatian trials (Proceedings 1886, page 377):—"I have naturally read with the closest attention the comment referred to upon the engine trials made by the Alsatian engineers, and trust the above statement can easily be shown to be erroneous. In a properly constructed steam-jacket, supplied with steam through a sufficiently large pipe, and having sufficient clear space between the inside of the jacket and the outside of the cylinder, the steam, which is constantly renewed in the jacket, has almost exactly the same pressure and specific volume as in the boiler. The partial condensation which it undergoes in the jacket is due to two causes: first, external cooling, which by [illegible] may be rendered insignificant; second, transmission of heat to the

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not the same as the heat received by each pound of steam which went into the cylinder. The jacket steam was virtually formed under condition of constant volume, being condensed without doing work; the cylinder steam was formed under condition of constant pressure. Thus only the cylinder steam received in formation the quantity of heat required for external work." Now the way in which Regnault had made his experiments on the heat of steam was this: he had a boiler in which water was evaporated under a constant pressure, and a condenser in which the steam was condensed exactly as fast as it was made, so that the pressure was kept constant throughout the apparatus. Some of the steam on its way to the condenser was led into calorimeters, also under the same constant pressure, and was there condensed with cold water. The rise of temperature in the calorimeters was then measured; and this, in connection with the quantity of water contained in them, was found to give the total heat of the steam: not only the internal heat of vaporisation, but also the heat due to external work. If however the steam was isolated and condensed in a vessel of constant volume, the condensation then took place at gradually diminishing pressures and temperatures, and in that case no external work was done, and the internal heat of vaporisation only was given up. But if the vessel was replenished with steam during condensation, so that the pressure and temperature were maintained, then, although the volume of the apparatus remained constant, condensation took place at constant pressure, and the external work done in evaporation was

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steam working in the cylinder. The condensation in the jacket due to this second cause, and consequently the heat transmitted into the cylinder, is under precisely the same conditions as in Regnault's experiments. Its value, as worked out in the Alsatian trials, is therefore closely correct. As regards the use made of the heat so transmitted, we determined this by means of the well-known laws of thermodynamics; taking account of what is going on in the cylinder during admission, during expansion, and during exhaust into the condenser. Practically it is during these three stages of the stroke that the cylinder receives all the heat which is given up by the steam condensed in the jacket. We thus took into account, I consider, all the conditions of the problem we were investigating, without overlooking any one of them."

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(Mr. John G. Mair.)
reproduced in the condenser as heat. Regnault's experiments exactly corresponded with what went on in the steam-jackets on an engine or in any other form of condenser: provided steam was being made in the boiler as fast as it was being taken away, the steam in the jacket was then being condensed under constant pressure, because the steam was continuing to flow from the boiler into the jacket. Hence it did not matter whether the steam was going through the cylinder of the engine, or into a condenser, or was being condensed in a steam-jacket: in any case it gave up its total heat in exactly the same way.

Mr. DRUITT HALPIN said the present valuable paper on compounding as applied to marine engines had followed two very interesting papers at the preceding meeting on compound locomotives, and he trusted that it would itself be followed by a similar paper on the same subject in connection with stationary engines, which would then complete the cycle.

With regard to steam-jackets, he certainly did believe in them, and particularly for marine engines; because, wherever it was advisable and advantageous to use liners, no extra complication whatever was involved in turning the liners into jackets; and further, the ordinary marine engines, like the mercantile engines referred to in the paper, had the enormous advantage that in all cases they had a fall of six or eight feet from the bottom of the cylinders back to the boiler, so that the jacket in that condition would take care of itself. Hence he did not agree with the statement (pages 501 and 56) that jackets wanted very careful looking after at sea. If they were simply provided with a separate pipe for supplying them with steam from the boiler, and a separate pipe for draining the water back from them into the boiler, they would look after themselves. He regarded the jacket in the same light as the bed-plate; the latter had to be looked after in the sense of seeing that it would not break, and it was in just the same sense that the jacket had to be looked after.

By way of trying to trace what might be the efficiency of the jacket on the successive cylinders of a triple engine, he had drawn out the following table, in which the cylinder diameters and stroke

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Screw Steamer "Para"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	19	35	53
Length of Stroke, inches	33	33	33
Mean Total Pressure, lbs. per square inch . .	131·6	39·2	11·2
Boiler Steam, 146 lbs. above atm., Temperature Fahr.	364°	364°	364°
Temperature in Cylinders, Fahr.	348°	266°	199°
Difference of Temperature, Fahr.	16°	98°	165°
Cylinder Volume, cubic inches	9356	31750	72804
Area of Jacketed surface, square inches . .	1970	3629	5497
Ratio, $\frac{\text{Cylinder Volume}}{\text{Jacketed surface}}$	4·75	8·75	13·25
Ratio, $\frac{\text{Difference of Temperature}}{\text{Cyl. vol.} \div \text{Jacketed surface}}$ . .	3·4	11·2	12·5

were those of the "Para," and the mean total pressures per square inch above perfect vacuum were got from the mean effective steam-pressures and mean back-pressures as given in her three days' log (pages 493–4). From these mean total pressures were then known the corresponding mean temperatures inside the three cylinders; and in the jacket outside there was the constant temperature of the boiler steam. In the next line the differences of temperature indicated the heat available for doing the work for which the jacket was intended. Taking also the volume of each cylinder and the area of its cylindrical jacketed surface, the quotient of the former divided by the latter showed how many cubic inches of cylinder volume there were to be heated up by one square inch of heating surface in the jacket: namely 4·75 in the high-pressure, 8·75 in the intermediate cylinder, and in the low-pressure 13·25 cubic inches to be heated per square inch of jacketed surface. Further dividing by these figures the corresponding differences of temperature, the final coefficients so arrived at were 3·4 and 11·2 and 12·5, which might possibly serve as a rough approximation to the heating value of the jackets on the three cylinders. It was certainly not by any means a complete representation of the case, because the weight of steam passing through the engine in any cycle was constant, while its volume was continually varying and the area for heating the varying volume was also varying; but it might be a means of helping to educe in future some law showing the various values of the jackets on the successive cylinders.

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(Mr. Druitt Halpin.)

Great thanks he thought were due to Professor Kennedy for having taken up the matter of the water evaporated per pound of coal. From the last column of his table (page 506) it would be seen that the average result amounted to an evaporation of 12·9 lbs. of water per pound of coal, even with the very low coefficient of only 15 per cent. which he had liberally allowed for the usual deficiency in the evaporation as deduced from indicator diagrams. In the steam-jacket experiments about to be made by a Research Committee of the Institution he hoped therefore that meters would be used to measure the feed-water; for although no form of meter might be absolutely accurate, they came within 3 or 4 per cent. of the truth, which was far better than having to make an allowance of 15 per cent. in calculating from indicator diagrams. If a meter were used, it might be connected as a by-pass, so that if anything broke down in it the engine need not stop; and in such a steamer as the "Para" the quantity of water to be dealt with was but little more than a thousand gallons an hour, which was only a small matter for a meter. If it were wanted to make experiments still more complete, this he thought could easily be done at a very slight additional expense by putting in an inferential meter to measure also the discharged water: from which might be got valuable, if not accurate, commercial results, showing whether or not it was cheaper to expend more power in driving a larger volume of water through a smaller surface of brass tubes in the condenser.

From the last column of the "Para's" log (page 496) it appeared that only about three half-tons of the coal used per day were actually weighed, while the rest was only measured in skips; consequently the daily consumption of 10¼ tons given in page 495 was only estimated, not more than one-seventh of the whole having been weighed. Such a plan seemed likely to give rise to far greater errors than would occur in estimating evaporation by means of indicator diagrams; and if possible it would be much better always to weigh the whole of the coal.

Some marine-engine experiments he believed had been made by Mr. Mudd about a year and a half ago, by putting the whole engine on a bed-plate and working it on shore; but so little load had

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been put upon it that it had not worked nearly up to its full power, and the indicator diagrams taken showed scarcely anything beyond the engine friction. With a suitable brake wheel however, applied at a very slight additional expense, the whole load that the engine could take might have been thrown on. As he had previously mentioned (Proceedings 1886, page 370), with a brake wheel of 5 feet diameter by 2 feet width, put up by Professor Thurston, 500 horse-power had been taken up at 100 revolutions per minute, without nearly reaching the limit of the brake-power. By testing a marine engine on shore with a wheel of that sort, which would be cheap to rig up, far more accurate results he thought could be got than could be obtained at sea. The feed-water could be perfectly measured; and this being done, the steam could be supplied from any land boilers at hand, if it were found inconvenient to use the vessel's own boilers.

The indicator diagrams from the high-pressure cylinders shown in Figs. 7 to 9, Plate 93, appeared to him exceedingly valuable, as showing the effect produced upon the steam admission by the area of the steam-pipes and by the size of the steam ports. With the ports indeed it was a question of compromise: if they were too large, there was too much clearance. This was seen very clearly in Figs. 7 to 9, which showed not only the drop in pressure between the boiler-pressure and the initial cylinder-pressure, due to the insufficient steam-pipe area, but also the further loss of pressure during admission, due to the too restricted area of the port opening.

With regard to the figures so carefully given by the author for the vacuum throughout the whole of the watches in the "Para's" log (page 492), namely 27 or 27¼ inches of mercury, this statement was not of the full value that it might have been, because the barometer reading at the same time was not given. As there was always a barometer on board ship, its reading should certainly have been given, and then it would have been known what was the real value of the vacuum. He would suggest however that if, instead of giving both the vacuum and the barometer reading, the former were divided by the latter and the quotient given as a percentage, this would be all that was wanted. Thus if the vacuum was 27 inches

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(Mr. Druitt Halpin.)
and the barometer 30, it would be called a vacuum of 90 per cent., which would be understood at once all over the world, independent of inches or millimetres or other units of measurement.

With regard to the three cranks of the triple engines, of course as far as the turning moment went they were very good and made an easy motion for the engine; but when it was seen from the side elevation of the engine that the three cranks had to be accompanied by their six bearings, the plan was not altogether so simple. For however true those bearings might be got in the first instance, and while the engine was in the erecting shop, they could never be kept true at sea, and even in port could never be got true a second time without boring them out with a bar, which was a very difficult matter in the confined space of the engine-room in a steamer.

Mr. E. A. LINNINGTON (Admiralty) thought that from Figs. 7 to 9, Plate 93, there was some experience to be derived which would be of great value to marine engineers. It would be seen that with 135 lbs. boiler-pressure there was an initial pressure in Fig. 7 of only 120 lbs., owing to objectionable bends in the steam-pipe, as explained in the paper (page 476); in Fig. 8 there was an improvement to 130 lbs. initial pressure when the bends were taken away; while in Fig. 9, with the same sized cylinder but a lower speed, the initial pressure and the steam line to the cut-off were satisfactory. It would be very useful therefore if Mr. Morison could give the sizes of the steam-pipes and ports in each example, and also any particulars of the fittings. According to his own experience with marine engines, the difficulty was to know what to avoid, especially with high-speed engines; and from these diagrams, supplemented by the additional particulars asked for, some experience he thought might be obtained as to what should not be done. There were also Figs. 15 and 16, Plate 96, where an increase of ten revolutions per minute increased the back-pressure by $1\frac{3}{4}$ lbs.; and here again, if the particulars could be given of the steam ports and the exhaust ports, he thought they would be of great value. Having had to do with engines supplied from a great number of different makers, he had found that there was a

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very great difference in practice with the velocities allowed for steam; and if the particulars could be ascertained in any instances such as those referred to, they would be of great service.

On the subject of jackets, he considered that for high-pressure cylinders a loose liner was desirable, because the wear was sometimes great, and, as pointed out by the author, it gave facilities for renewal. The objection to jacketed cylinders was the greater first cost; and this was probably the reason why some engineers supplied cylinders unjacketed. Although jackets did not appear of much use on the high-pressure cylinder, he thought them favourable to economy on the intermediate and low-pressure cylinders.

As to piston-speed, the three-crank engines that had now become so popular certainly gave a well balanced engine, while the increasing use of steel gave a material which admitted of higher piston-speeds without much increase in the wear and tear. With a well-balanced engine and with the better material now coming into use, higher piston-speeds he considered might be adopted with great advantage, and without much probability of any perceptible increase in the wear and tear. First-class workmanship was of course wanted with high speeds; but higher piston-speeds permitted the use of smaller engines for a given power. There was therefore some diminution in the first cost, which was always a matter for consideration; there were less weight and less space, and probably also more economical working with the high steam-pressures that were now used.

With regard to artificial or forced draught, further practical information would be very valuable; for he was sure that marine engineers generally were considering the question of forced draught as more important than any manipulation of indicator diagrams. In war-ships, by using a few fans and light air-screens, 50 per cent. more power was got out of the boilers with only about 10 per cent. more consumption of fuel per horse-power, as compared with natural draught; and as the maximum power was required only for short periods of time and on special occasions, that small increase in consumption was not a drawback. But in the mercantile marine, what was required for enabling forced draught to become the

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(Mr. E. A. Linnington.)
general practice was that it should be accompanied by a diminution in the consumption of fuel without any deterioration of the boilers. Further practical information upon these points, especially on the durability of boilers working under a continuous forced draught, would be acceptable to marine engineers.

Mr. WILLIAM SCHÖNHEYDER said he had just heard for the first time from Mr. Mudd an approximation to the proper mode for combining the indicator diagrams from compound engines; but he differed from him in regard to the expansion curve, which he considered was quite independent of the compression in the cylinder. In the paper it was seen that the diagrams had been combined by ranging in the same vertical line the boundary of the clearance volume for each of the three cylinders. But that was entirely wrong, he believed; and his own view of the matter was illustrated in Fig. 52, Plate 2. Referring to the top diagram, from the first cylinder, where in addition to the expansion curve there was also shown the compression curve up to a certain height, if a horizontal line *a b c* were drawn right across at any pressure, then the volume *a b* would represent the amount of steam compressed back into the clearance space, and the volume *a c* the total volume which was expanding in the cylinder and clearance space; and the difference between the two, namely the volume *b c*, was that which would exhaust from the first cylinder and pass forwards into the second, after having been further expanded down to the pressure represented by the bottom of the first diagram. Similarly in the second cylinder, *h m* represented the volume of the cylinder with clearance, *h l* the volume of the clearance, and *h i* the amount of steam which was pressed back into the second cylinder. The amount of steam which was received from the first cylinder by the second, and which afterwards passed out of the second into the third, was represented by the line *i k*, or by any other horizontal line intercepted between the expansion curve and the compression curve. In the same way *n r* was the volume of the third cylinder with clearance, *n p* the volume of the clearance, *n o* the amount of steam pressed back into the third cylinder, and *o q* the amount of steam which was exhausted from the

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second cylinder and passed into the third. In the case of the second cylinder, by setting out the entire clearance *h l* backwards from the point *l*, the point *h* might come either in the vertical line *a e* or on either side of it, depending entirely upon the extent of compression and the volume of the clearance space. Similarly in regard to the point *n* for the third cylinder. The expansion curve for the first cylinder should be set off from the clearance line *a e*, because it was the expansion of the total volume of steam, contained both in the cylinder and in the clearance space, which gave the expansion curve. In the same way the compression curve *i b f* should also be set off from the same line *a e*. In the second cylinder the expansion curve below *k* should be set off from the vertical line drawn through *h*, because it was the total volume *h k* which was expanding in the second cylinder; and in the same way it was the volume *h i* which was compressed in the second cylinder. The whole expansion curve was not necessarily a continuous curve throughout for all three cylinders; it might have breaks or angles in it at the points of changing from one cylinder to another. A similar explanation of this subject he had already given at a previous meeting (Proceedings 1879, page 359), as well as at an earlier date.*

Mr. THOMAS HAWKSLEY, Past-President, considered the whole matter lay in the smallest possible compass:—temperature at the commencement, so much; and at the end, so much less. Then this difference had been utilised by the engine; and it was the same whether there were three or more cylinders or only one.

Mr. WILLIAM PARKER said that since the discussion at the previous meeting he had obtained some information with regard to the question whether, by utilising a high pressure of say 110 lbs. in a two-cylinder compound engine, anything like the same result could be realised as in a triple-expansion engine. The figures he had got were obtained from actual practice. Of two steamers, both working at 110 lbs. pressure, one had a compound engine with 47-inch high-pressure cylinder and 86-inch low-pressure, and 4 ft.

* See "Engineering," 27 October 1871, page 269.

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(Mr. William Parker.)

9 ins. stroke. That engine exerted 2600 horse-power, and consumed 55 tons of coal per day, these being mean figures taken from voyages to Australia and back. A consumption of 55 tons per day represented 1·97 lb. of coal per indicated horse-power per hour. The other steamer was fitted with a triple-expansion engine having cylinders 34 and 45 and 70 inches diameter with 4 ft. 6 ins. stroke, which exerted an average of 1900 horse-power throughout her voyage, on a mean consumption of 35 tons of coal per day, or 1·72 lb. per indicated horse-power per hour, as compared with 1·97 lb. in the other steamer.

Mr. ARTHUR PAGET, Vice-President, enquired whether the boilers were identical in the two steamers, as the value of the comparison would depend upon their being so.

Mr. PARKER replied that the boilers were exactly alike, except that in the case of the two-cylinder engine they were of course much larger; but in other respects they were identical.

Mr. HAWKSLEY enquired what were the terminal pressures in the two engines, or what amount of expansion did each produce; because that might account entirely for the difference in the consumption. If one engine was working with a great amount of expansion beyond the other, the economy would be greater.

Mr. PARKER replied that he could not give the terminal pressures in these two engines, but the expansion in the triple engine was much greater than in the two-cylinder compound engine, which of course accounted for its greater economy. Such a high degree of expansion however could not have been obtained in a two-cylinder compound engine without a loss from the sudden drop in temperature.

With reference to forced draught, he knew of a steamer which had now been running with this system between America and London for two years and a half. The present boiler had exactly half the heating surface of the previous boiler; it had three furnaces, as compared with six. The consumption per square foot of grate per hour in the

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present boiler was over 50 lbs. of coal, as compared with 20 lbs. under the old conditions. After 2½ years' running the boiler had been carefully examined both internally and externally; and it did not seem to have deteriorated in any way whatever, notwithstanding the rapid rate of combustion which took place with the forced draught, and the constant admission of cold air when firing and cleaning fires.

He was very pleased to hear that the Council of the Institution had determined to enquire into the subject of marine-engine trials; and he should be very glad indeed to render them all the assistance in his power. At the same time he would take this opportunity of remarking that in his opinion it was rather a difficult task to measure the efficiency of a marine engine at sea. It was a very different matter from measuring the efficiency of an engine in a mill or factory, or of an engine in a laboratory, or even of a locomotive. The temperatures of the steam, both at the inlet and at the outlet, and also the temperature of the feed, could be measured easily enough; but to measure the volume of the feed water and the volume of the circulating water was in his opinion somewhat difficult in a large engine, and would require to be done over a number of days in order to give accurate results. In some steamers trading from the port of London the feed pumps were of a different description from those ordinarily used; they were driven by separate engines and were slow-running, and he understood they were so contrived that the air should be excluded from them, so that they should be filled full with water alone at every stroke. If that were actually the case, and if the capacity of the pumps could be measured carefully, then the number of strokes made by the pumps would be a very good measure of the feed water; and perhaps some suitable means could be devised for measuring the circulating water also. The steam-ship owners of the port of London he felt sure would be very pleased to give to the Research Committee all the information they could, and to render them facilities for going down channel with steamers, and to help them as much as possible to measure the exact efficiency of their engines, and to get this matter placed on a satisfactory basis.

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Mr. HENRY DAVEY observed it was recommended by Mr. Wright (page 45) that the velocity of the steam through the ports should not exceed 40 feet per second, while Mr. Morison had given 100 to 250 feet per second (page 43). A general rule in land practice was that, for a piston-speed of 500 feet per minute, which seemed about the speed of several of the engines referred to in the paper, the steam ports should be made about one-fourteenth or one-fifteenth the area of the cylinder. As the steam velocities given by Mr. Morison ranged from 100 to 250 feet per second, or from twelve to thirty times the piston-speed of 500 feet per minute, the ratio of port area to cylinder area would range from one-twelfth to one-thirtieth; while Mr. Wright's velocity would require the ports to be nearly as large as one-fifth of the cylinder area. There seemed therefore to be a great discrepancy, which wanted putting right.

The PRESIDENT said it was a very important subject which had been brought before the Institution in the present paper and discussion; and when the Research Committee who were going to take up the matter of marine-engine trials had made such progress as could be reported, he hoped their report would lead to a further paper, so that the subject could be discussed again. In the meanwhile he was sure the Members all felt themselves greatly indebted to the late Mr. Wyllie, and would join in passing a cordial vote of thanks to his representatives, and also to his successor Mr. Morison, for all the trouble that had been taken in bringing this valuable paper before the Institution.

Mr. W. SILVER HALL wrote to point out that on this, as on several previous occasions when a paper had been illustrated by indicator diagrams, the discussion had been partly occupied with the true interpretation of those diagrams, and with suggestions as to their probable inaccuracy owing to contracted passages, sharply bent pipes &c. There also seemed to be a considerable difference of opinion,

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both as to the proper method of combining and collating sets of diagrams from compound engines, and as to the theoretical curve with which they should be compared. If the subject could be once thoroughly settled, much valuable time would be saved in future discussions.

Professor ALEXANDER B. W. KENNEDY, Member of Council, wrote that Mr. Morison's obliging offer of a trial trip (page 37) had unfortunately been qualified by a reservation which neutralised its value to himself, inasmuch as the measurement of the feed-water was the very one which in his own opinion was most essential; and he trusted the work of the Research Committee on marine-engine trials would presently demonstrate that there was no difficulty in making trials which should be both convenient from a practical point of view and satisfactory from a scientific.

In reference to the method he had followed for calculating the steam quantities from the indicator diagrams (page 507), it was necessary to take that point, in each of the three combined diagrams, which showed the greatest weight of steam per stroke; and in this case that point ought obviously to be as high up the curve as possible, remembering especially that the adiabatic curve, which was the one drawn as the standard for comparison, represented the expansion of a continually decreasing weight of steam, in consequence of the liquefaction of steam which was physically inevitable during the performance of work in adiabatic expansion. It appeared to him that the expanding or combining of the successive diagrams from any compound engine, so as to compare them with those from a single-cylinder engine, was merely a conventional operation, in which the essential point was to get the best possible graphic comparison between the work done in the compound engine and the work which the same weight of steam would do in a perfect single-cylinder engine. For this purpose the latter quantity of work was represented best by the theoretical expansion diagram from such an engine, which would of course be an engine without clearance. The admission line A B in such a diagram, Fig. 53, Plate 2, represented the volume of steam corresponding with

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(Professor Kennedy.)
the feed-water used per single stroke; the expansion curve B C D was adiabatic; the back-pressure line E F G corresponded with the vacuum in the cylinder; the compression curve G A was again adiabatic, and corresponded with the liquefaction of the remaining steam G L, and the raising of its temperature until it was all again water at A. The part C D E F of the diagram was lost in any case, because of deficient expansion. In whatever way the successive diagrams from a compound engine were plotted, so long as they were all reduced to the same scales of volumes and pressures, the ratio of their combined areas to the area A B C D E F G would represent the efficiency of the engine as compared with a perfect engine using the same weight of steam.* As shown by Mr. Schönheyder, the theoretical expansion curves in the different cylinders could not coincide with portions of the curve B C, nor could the compression curves coincide with G A; but then there was no reason why they should do so. The comparison was essentially of areas, or quantities of work; and not of lines. Theoretically it would perhaps be best to complete the compression line for each diagram up to the initial pressure, so as to get the point H, Fig. 54, Plate 2, and the curve H K, which was the expansion curve for the steam in the clearance space at admission; and then to set off to the right of A the whole breadth of the diagram measured to the right from H, instead of from N. In this way the actual horizontal distance from O A of any point in the expansion curves would represent the volume occupied at that pressure by the steam which had come from the boiler, quite independently of the cushion steam in the clearance space. The horizontal distances or abscissæ to the right of O A might therefore be directly compared with the abscissæ of the curve B C at the same pressures. But he thought the uncertainty and trouble attendant on this method were not compensated for by any great practical advantage which it possessed over the very simple and ready method employed by the

* A detailed illustration of this comparison is given in the writer's Presidential Address to the Junior Engineering Society on Steam-Engine Economy, 24 Sep. 1886; a copy of which is in the Library of the Institution.

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author of the paper. In practice, the compression curve G A was not usually drawn, and the comparison was made between the areas of the actual diagrams and the area A B C F L, which represented the work done by an engine using the same weight of steam and having the same nominal expansion, but receiving its water at the temperature corresponding with the back pressure at F L.

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DESCRIPTION OF A PORTABLE HYDRAULIC DRILLING MACHINE.

BY M. MARC BERRIER-FONTAINE, OF TOULON.

The small Portable Hydraulic Drilling Machines, shown in Figs. 1 to 5, Plates 4 and 5, are capable of drilling in their place and after erection nearly all the holes required for rivets, bolts, &c., in all kinds of iron or steel structures—such as ships, bridges, girders, and boilers — wherever hydraulic pressure is available for working them. With these portable machines the parts can be drilled in their places as rapidly as they would be drilled by stationary drilling machines in the shops, the shifting of the portable machine from one hole to another being as easily accomplished as the shifting of a piece of work of equal weight under a stationary machine. In this way holes are drilled in place even more readily than the same holes could be severally drilled by a stationary machine in the shops; because by drilling in place a single operation serves to drill through all the superposed thicknesses without stopping the drill; whereas when the pieces are separate, as in the shop, as many separate drilling operations are required as there are pieces, and the work consequently involves much more labour and time. Besides effecting considerable saving, this mode of drilling in place presents also the great advantage of ensuring that the holes are quite true through all the superposed thicknesses, without having been previously set out on each separate piece; and thus all such preparatory work is dispensed with, as well as the labour and time necessary for carrying the separate pieces, first to the drilling shop from the places where they have been marked, and then back again to their places after they have been drilled.

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The size and weight of the portable hydraulic drills, by which these advantages are secured, are so small that these machines can be used for drilling nearly all the holes required in the most complicated structures, even in the most confined spaces; and they can be used for driving the drills either directly or through flexible shafts or other intermediate apparatus. In Plates 4 and 5 is shown one of the two sizes of portable hydraulic drilling machines which have hitherto been made by the author for use in Toulon Dockyard. Other sizes for different powers could be easily designed, as they might be required.

The drill shown in Plates 4 and 5 is of 1 HP., and drills holes up to 2 inches diameter, either directly, as in Figs. 1 and 2, or through a flexible shaft, as in Figs. 3 to 5, the driving shaft making 90 revolutions per minute; the sockets of the drill-holder, and of the flexible shaft No. 8, which can be fixed to it, are identical with those of a No. 4 Morse twist drill, and consequently fit the conical shanks of the twist drills from $1\frac{5}{16}$ to 2 inches diameter. The smaller machine is of $\frac{1}{2}$ HP., and drills holes up to $1\frac{1}{4}$ inch diameter, either directly or through a flexible shaft, the driving shaft making 150 revolutions per minute; the sockets of the drill-holder, and of the flexible shaft No. 6 which can be used with it, are identical with those of a No. 3 Morse twist drill, and therefore fit the conical shanks of the twist drills from $\frac{15}{16}$ to $1\frac{1}{4}$ inch diameter.

Each drilling machine is composed of two parts:—

Firstly, a small hydraulic motor M, Plates 4 and 5, driven by water pressure supplied from a main through flexible or jointed pipes, like those commonly used for portable hydraulic riveters. The discharge water is led away through india-rubber tubing. The motors shown in the drawings are Brotherhood's three-cylinder engines; but other hydraulic motors could be applied, provided they were sufficiently light and compact.

Secondly, a drill-holder, consisting of a small frame F of C shape, in which are arranged the bearings of the driving shaft A from the motor, and of the hollow drill spindle D at right angles to it, Fig. 1. On the motor shaft A is keyed a bevil wheel B, gearing

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with a bevil pinion P on the drill spindle D. At one end of the drill spindle is a socket S for holding the drill; and the other end is threaded internally for receiving the setting-up screw T, which is turned by the hand-wheel W, Fig. 1, either to give the feed whilst drilling or to withdraw the drill when the hole is finished. A longitudinal slot L for the key of the bevil pinion P allows the drill spindle to slide through the pinion while the latter is kept in place by an annular recess R. Beyond the hand-wheel W, the screw T terminates in a point J, which can be pressed against a cross-piece or frame, such as is used for drilling with a ratchet-brace. The central part of the frame F is bolted to the flange of the motor M, and thus forms a long bearing for the shaft A; and small closed lubricators ensure the bearing being properly oiled, in whatever position the drill may be held. In the base G of the motor are slotted holes, for fixing it by bolts put into holes in the structure, thus ensuring perfect steadiness in drilling. A ring with two handles H, Fig. 2, is placed at the centre of gravity, so that a workman can easily carry the drill from place to place.

When the drill is driven direct, the drill spindle D is geared to run at the same speed as the driving shaft A of the motor, by making the two bevil wheels B and P of equal diameter, as shown in Fig. 1, Plate 4. But when a flexible shaft is used for conveying the power from the motor to the drill, the flexible shaft itself must be made to run five times as fast as the motor shaft and the drill; it is therefore geared both to the driving shaft A at one end and again to the drill spindle at the other end by bevil wheels in the proportion of five to one, as shown in Figs. 3 and 4, Plate 5. The flexible shaft is fixed at one end to the pinion P by a clutch K, Fig. 5, similar to that used for attaching it to a driving pulley; and the other end similarly drives the drill. In this case the drill spindle D has no longitudinal movement, the feed of the drill being given at the other end of the flexible shaft, by means of the screw belonging to it.

Owing to the great importance of reducing to a minimum the weight of these portable machines, so that they may be shifted as easily as possible from hole to hole, they are made entirely of steel

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and phosphor-bronze. By this means the weight of the whole machine complete, including the two stop-valves for inlet and outlet, does not exceed 105 lbs. for the 1 HP. drill, and 62 lbs. for the ½ HP. Trials made for a lengthened period have proved that, in the case of a large armour-clad man-of-war, built on the cellular system and consequently of very complicated design, the number of holes drilled in place by these small hydraulic machines is at least 25 per cent. greater than the number of similar holes that can be drilled in the same time by stationary machines in the shops; and is at least six or seven times greater than the number of similar holes that can be drilled in place by ratchet-braces.

The first two of these drills, which have now been in regular use for nearly three years in the Mourillon yard at Toulon, have been found so advantageous in working, alike in quality and rapidity and economy of work, that thirteen more were added last year for daily use in the same yard, of which four are of 1 HP. and nine of ½ HP. Two of each size have also been started for use on the shipbuilding slips at Brest Dockyard, where they are reported to give the same satisfactory results as at Toulon. Others have been put to work on trial in Great Britain, two of them in the very cradle of water-pressure machinery, Sir William Armstrong's works at Elswick.

Discussion.

A number of photographs were exhibited, showing the actual application of the portable hydraulic drill in a variety of positions, as employed upon different kinds of work in course of execution at Toulon Dockyard, and at Sir William Armstrong's works, Elswick. A specimen was also shown of the Brotherhood three-cylinder engine with drill attachment, represented in the drawings.

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Mr. JEREMIAH HEAD, Past-President, considered the present paper a very valuable one, inasmuch as it was obvious that there were many circumstances and conditions in which a machine of the sort described would be exceedingly useful, and would effect a great saving in time and labour. It would be interesting to know what loss of power, if any, there was in the use of flexible shafts; for it was clear that they might be applied in many other ways than that mentioned, provided the loss of power was not too great. Where the direction was turned half round, so as to be completely opposite, as shown in one of the photographs, and still more where it was turned further till it came quite round again as at first, there must surely be an appreciable loss of power. Universal joints in shafting certainly involved a loss of power; and the flexible shaft might be regarded as a continuous series of universal joints. If any experiments had been made by the author to ascertain the loss of power that there would seem to be from transmission through flexible shafts, it would be very interesting to have the results; and also to know what became of the power so lost, whether it re-appeared in heating the flexible shafts or in some other way.

Mr. WILLIAM SCHÖNHEYDER enquired whether the speed of 90 revolutions per minute, mentioned in the paper, was the maximum; and whether there was any means of regulating the speed. A hydraulic engine could be contrived to run at almost any speed within certain limits; thus if a heavy pressure were put on the drill the machine would run slowly, and if only a light pressure it would go quicker.

Mr. JOSEPH TOMLINSON, Vice-President, said the plan appeared to him to be a modification of one that had been adopted in America for a long time, for drilling in various positions by means of flexible shafts; but the drills had there been driven directly off the shop shafting, without the intervention of a separate motor. As remarked by Mr. Schönheyder, it was clear that if too much pressure was put on the drill the speed must slacken;

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or if enough was not put on, the speed must increase. By the speed given in the paper, of 90 revolutions per minute, he inferred was meant the natural cutting speed for the fair pressure required to cut a hole of $1\frac{1}{4}$ to 2 inches diameter. The flexible shaft shown in the drawings seemed to be very much stronger than those he had seen of the American type, which were generally from $\frac{7}{8}$ to $1\frac{1}{4}$ inch diameter. How the shaft might work when made of that extra thickness, he did not know; but of course for transmitting the power necessary to drive a 2-inch drill through a 2-inch hole the flexible shaft must be made strong enough, otherwise it would necessarily twist itself up, instead of turning round and driving the drill.

Mr. E. B. ELLINGTON was not aware why the particular speed of 90 revolutions per minute had been fixed upon for the 1 HP. drill. As regarded the engine, there was certainly no necessity for running at so slow a speed, because in some of the experiments made with three-cylinder hydraulic engines like the specimen exhibited they had run at 400 revolutions a minute. The use of the portable hydraulic drill was not entirely confined to Toulon; there had been one at least in operation recently at the Forth Bridge, where experiments were being made with it; and one had been at work at Sir William Armstrong's works at Elswick for some little time past. As to the flexible shaft, he doubted whether there was any material loss in its use; just at starting there was certainly a loss of power in the winding up of the shaft before it attained the full motion; but after that, it seemed to him there could be no loss, but that the power would be transmitted to the full extent, the whole power applied at one end being given out again at the other; he did not see where the loss could arise. As to the general efficiency of the machine, including both the motor and the gearing, he imagined that the power developed at the drill itself must be only a small proportion of the whole power supplied to the motor. But the machine seemed to be a very neat and useful application of hydraulic pressure to rotary driving.

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The PRESIDENT said those who had served their time in the shop knew very well what great objections there were to having to use a ratchet-brace for drilling a hole. It would be a very good thing if steam or hydraulic power could be applied instead of manual labour in all such operations. In fact it was the duty of every engineer to do away with manual work as far as possible, and to make some kind of machinery that would take its place, as had been done in the present instance by M. Berrier-Fontaine, to whom he proposed a hearty vote of thanks for his paper.

Mr. RALPH H. TWEDDELL wrote that some months ago he had suggested the use of these tools to Sir W. G. Armstrong Mitchell and Co., Elswick, for whom two machines were accordingly made under his direction by the Hydraulic Engineering Co., Chester. The results of their application to the armour-clad "Renown," now constructing at the Elswick yard, had been most satisfactory; and he had been furnished with the following notes respecting their performance. "The plating through which the holes are cut is of mild steel $2\frac{1}{4}$ inches thick, built in two thicknesses of $1\frac{1}{2}$ inch and $\frac{3}{4}$ inch. Firstly a 1-inch hole is put through; then a cutter-block is attached, and the hole is knifed out to $3\frac{1}{2}$ inches diameter. The shortest time occupied in doing both these operations is $12\frac{1}{2}$ minutes, that is after the machine is placed in position; the time occupied in doing the same work by hand is three hours. A similar machine was adapted to enlarge the above holes to $5\frac{1}{4}$ inches diameter, through the same thickness of plating. The space in which this machine worked was exceedingly cramped, and almost dark; and even under these conditions these holes were each cut out in one hour, as against nine hours by hand." The above machines were worked at a pressure of 750 lbs. per square inch, and at a very great distance from the accumulator; but he had supplied others to work at 1500 lbs. per square inch in other English works where his own hydraulic machinery was working at this pressure. The Brotherhood type of

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hydraulic engine was adopted for these also; for although it was remarked in the paper that other hydraulic motors could be applied, he had yet to see how this arrangement could be improved upon for portable drilling apparatus. So far back as the Liverpool meeting of this Institution in 1872 he had suggested (Proceedings 1872, page 202) that for quick revolving machines, such as small lathes and drilling machines, some hydraulic centre of rotary motion such as a turbine or water engine should be provided, to drive a small quantity of shafting. And again at the Cardiff meeting in 1874 he had stated (Proceedings 1874, page 173) that in Brotherhood's three-cylinder hydraulic engine all the objections hitherto met with in other designs had been successfully obviated. To M. Berrier-Fontaine however was due the entire credit of making a practical success of portable hydraulic drilling machines, as a branch of the writer's hydraulic system of shop tools at Toulon.

The present paper had been confined to portable hydraulic drilling apparatus; but there was of course no such limit to the application of hydraulic power for drilling, although other applications, where the tool was not portable, possessed less interest, because they involved fewer difficulties. In connection with and attached to his own stationary hydraulic riveting machines, hydraulic motors had been applied to work rimering tools, thus preparing the holes to receive the rivets about to be closed by the riveter. Another application was in connection with hydraulic keel-riveting machines; this dispensed with a vast amount of labour, since both of the garboard strakes could be drilled along with the keel bar immediately on their being put in position, the riveting machine holding the different thicknesses of plates tightly together, while the drilling was being done. Other applications it was obvious were very numerous.

It would be of more immediate interest however to give some further data as to the results obtained at Toulon Dockyard by the author of the paper. There were now eighteen of these portable hydraulic drilling machines in daily work: six on one vessel, four on another, three on another, and one on a torpedo boat, at Toulon; and four at Brest Arsenal. Each machine drilled an average of

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(Mr. Ralph H. Tweddell.)
175 holes per day, varying from 80 to 300 according to local circumstances: the work being done with the greatest regularity and exactitude, and much more economically than if the same holes were drilled in the shops before erecting. So readily had the men taken to these machines that it was considered a mere question of time until the only holes drilled in the shops would be those required for fixing or attaching the work; all other holes would then be drilled on the spot after erecting, thereby not only ensuring accurate work, but also dispensing with all previous setting and marking of the holes.

On the ground of economy also the results of the three-cylinder hydraulic motor had been so satisfactory that M. Berrier-Fontaine was beginning to think its use might with profit be extended to the working of machine-tools, even those having a continuous motion, such as lathes and planing and plate-edge cutting machines. Although the writer was not prepared to go quite so far as M. Berrier-Fontaine, yet in regard to lathes, especially when the work to be done was fairly uniform, he saw no reason to alter the views expressed in his paper at Cardiff twelve years ago, when he had shown a drawing (Proceedings 1874, Plate 60) of a Brotherhood engine applied as now proposed.

In M. Berrier-Fontaine's valuable paper read at the Paris meeting in 1878, it was stated (Proceedings 1878, page 361) that from the data then given it would be clearly seen what an enormous disproportion might exist, for a collection of hydraulic machines such as those described, between the power of the prime mover and the sum of the powers which could be exerted by the several machines at any given moment. This explained concisely why rotary hydraulic machine-tools when suitably applied could be not only efficient but also convenient.

Although the applications of these machines at Toulon had hitherto been confined to ship work, there was no such limit to their application. The writer had himself applied them to the drilling of marine boilers, and their use for that purpose was daily increasing; while in bridge building there was a still larger field open for their application. In fact wherever holes had to be drilled, if it was

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possible to convey a $\frac{3}{8}$ inch copper pipe to the place, they could be drilled through any thickness, and quite irrespective of the distance of the work from the prime mover.

M. BERRIER-FONTAINE wrote that he greatly regretted his duties prevented him from being present at the meeting and replying verbally to the remarks made on his paper, in regard to which he had much pleasure in furnishing the following information.

No experiments had hitherto been made, so far as he was aware, for determining precisely the loss of power due to the use of flexible shafts, when bent more or less out of the straight line. Should he find an opportunity for carrying out trials of this kind at Toulon, he should be very happy to communicate the results to the Institution. In default of any experimental evidence on this subject, it would seem that the use of flexible shafts must necessarily be attended with a loss of power, inasmuch as, even assuming that the shaft revolved at a perfectly uniform speed, which was never exactly the case, each of its component wires was constantly subjected in working to a continuous and periodical series of changes in shape by bending and torsion; and such changes could not take place without giving rise to friction between the wires, and to a general heating of the whole shaft in consequence. But on the other hand, if this were really so, it was proved by experience that the loss of power was of very little importance, inasmuch as the consequent heating by which the loss might be measured was scarcely perceptible, even after long continued working with shafts of the largest size and bent to the sharpest curves they would admit of. Clearly therefore the loss of power must be of the same kind that resulted from the friction of ordinary driving shafts in their bearings.

The plan of driving the drill direct by a flexible shaft, as referred to by Mr. Tomlinson, was carried out, but only for drills of very small diameter, or for larger drills when used for drilling softer material such as wood. The flexible shafts were also employed at Toulon for driving direct without any bevil gearing the rimering tools, which could advantageously be driven much faster than the drills.

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(M. Berrier-Fontaine.)

For drilling holes of ordinary size through metal, bevil gearing had to be interposed between the end of the flexible shaft and the drill, both in order to allow of providing a mechanical feed for the tool, which required a heavier pressure than could be exerted by hand, and also in order to maintain the proper relation between the speed of the drill, which must be kept running at from 80 to 160 revolutions per minute according to the diameter of the hole, and the speed of the shaft, which should be five or six times as great as that of the drill, for transmitting the necessary power without increasing its diameter and weight too much, as would have to be done if it ran at the same speed only as the drill. The flexible shafts in use at Toulon were those of the Stow Flexible Shaft Co., Philadelphia; and no change had been made in regard to the arrangement of their gearing. At the present time fourteen different sizes of flexible shafts were made.

The use of these flexible shafts, including even the largest sizes, had never been attended with any real difficulty. In the Mourillon shops thirty or forty of them were constantly running in regular work, including not only those driven by portable hydraulic motors, but also several driven by wood pulleys temporarily fixed as occasion might require on the shop shafting, and others again that were driven on the slips by rope gearing carried sometimes to a considerable distance.

Although as above explained it was almost indispensable to interpose gearing between the flexible shaft and the drill in the case of the larger shafts transmitting a considerable amount of power, similar intermediate gearing he considered was not necessary between the hydraulic motor and the flexible shaft; and it might even be advantageous, in view of the consequent reduction in weight and cost, to make the motor drive the flexible shaft direct without any intermediate connection, if, as mentioned by Mr. Ellington, it was possible to run small hydraulic motors as fast as 400 revolutions per minute, without too great loss of power through eddies and friction in the water at such high speeds. It would certainly be of much interest to have some trials made on this point by constructing a Brotherhood motor of suitable proportions for running at the same speed as the

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shaft: say for instance a motor of 1 HP. running at 450 revolutions per minute, for driving a No. 8 flexible shaft to drill holes up to 2 inches diameter; or a motor of ½ HP. running at 600 revolutions, for driving a No. 6 flexible shaft to drill holes up to 1¼ inch diameter.

The speeds mentioned in the paper (page 73), of 90 revolutions per minute for the 1 HP. drill and 150 for the ½ HP., were the natural cutting speeds for these drills, as explained by Mr. Tomlinson. The speed would of course become greater whenever the resistance was diminished, in consequence either of using a smaller drill or of giving it less feed; and the speed would fall off whenever the size of the drill or the rate of feed was increased. Too much feed soon stopped the drill; and care was therefore required for getting the maximum work out of these small machines; but a clever workman soon found out the best rate of feed for getting through the most work. The stop-cock admitting the water pressure to the motor could also be used for regulating the speed by throttling the water supply; but this was not a good plan, because the power and useful effect of the motor would thereby be reduced at the same time. It was therefore much better to endeavour in every case to utilise fully the maximum power of the motor, by opening the stop-cock to its full extent, and so regulating the feed of the drill by means of the hand-wheel as to drill the holes in the shortest time possible. A clever careful workman soon succeeded in attaining this result.

As regarded the duty realised with the small hydraulic motors described in the paper, he did not think that theoretically it was high. Every machine of this kind was subject to great loss of power in working, either in the gearing, or in the hydraulic motor itself, irrespective of any loss attending the flexible shaft when used for driving the drill. But too much importance he considered should not be attached to the circumstance of the duty being low, even though it might be found that the loss of power for each individual machine while at work was relatively very great. The ultimate efficiency ought practically to be estimated on the whole of the machinery collectively, including both motors and gearing, and over a long period, such as a whole day's working. For it was clear there

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(M. Berrier-Fontaine.)
would be no advantage, for instance, in selecting tools of higher efficiency, if, while themselves economical, they necessitated the adoption of a less economical mode of driving. In any works employing machinery, economy was not dependent on the appliances individually, but on the whole taken collectively. Regarding the question in this aspect, the conclusion was clear enough to himself after the twelve years' experience he had now had in the use of hydraulic machinery in the Mourillon yard: not only did the adoption of hydraulic appliances allow of driving with an average of only 10 to 12 HP. the whole of the machinery in a shop where the ordinary mode of driving would require at least 60 HP.; but also, without appreciably increasing the necessary driving power, he had already been able to make several successive additions to the original machinery. These additions comprised, firstly, all the hydraulic machines employed on the shipbuilding slips, namely two capstans, six powerful riveting machines, and fifteen portable drills; secondly, inside the shops, two capstans, two large cranes, and several other hydraulic appliances; and thirdly, in the new forge, a large angle-iron shears, and three powerful presses, one for straightening, another for flanging, and the third for stamping and forging. The practical result of working the whole of this machinery by hydraulic power had been a saving of as much as 85 per cent. With such a result it would be readily seen how little it mattered if one or other of the individual machines which went to make up the whole was in itself not particularly economical during its periods of effective work.

It was a notable feature of hydraulic power that, while it fared ill in the theoretical investigations which should always precede its practical adoption, yet when actually carried out on a large scale it was found to give far more satisfaction in working and far greater economy than had been reckoned upon beforehand. He was accordingly convinced that the applications of hydraulic power which could be made with practical advantage were very far from having been yet exhausted. These applications could not fail to become more and more extended, as objections and apprehensions became more and more dissipated by the results of experience. For his own part, when he first began to turn his attention to the use of water power

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at Mourillon, he had laboured under the conviction that the use of water under pressure could not be economical for working such tools as lathes, planing, surfacing, and drilling machines, and others having a continuous motion; but that conviction had now been greatly shaken, and he had been led to believe that it might even be economical to work all the machines of a large fitting shop by hydraulic power alone. It would certainly be very interesting for some trials to be made in this direction: to begin with, the driving belt of a large lathe or planing machine might be replaced by a small hydraulic motor of suitable power, applied direct to the end of the main shaft of the machine.

He was much obliged to Mr. Tweddell for the interesting particulars he had given respecting the use of the portable hydraulic drills at Toulon and at Elswick. The remark made in the paper (page 73), that other hydraulic motors could be applied for driving the drills, was not meant to imply that he knew of any better or more satisfactory hydraulic motor than the Brotherhood three-cylinder engine, which appeared to him the best in consequence of its being so small and so light in proportion to its power; and he had accordingly selected it for driving these drills, on account of its great advantage in these most important respects.

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ON COPPER MINING IN THE LAKE SUPERIOR DISTRICT.

BY MR. EDGAR P. RATHBONE, OF LONDON.

In the present paper the author purposes dealing with the subject under the three following divisions:—

I.—General description of the district.
II.—Methods pursued in mining.
III.—System of ore-dressing, and machinery employed.

I.—GENERAL DESCRIPTION OF THE DISTRICT.

The district of Lake Superior, Fig. 1, Plate 6, has for a long series of years been the principal centre of copper mining in the United States, and continues to be so at the present time. The total production of fine copper in the United States in 1885 is estimated at about 83,000 tons (American tons of 2000 lbs., equivalent to about 74,100 English tons). Of this quantity 36,000 tons were produced from the Lake Superior district alone, the balance being credited chiefly to the States of Montana and Arizona, of which the former produced about 33,000 tons, and the latter about 11,000 tons. Of the 36,000 tons produced by the Lake Superior mines, the enormous production of about 23,600 tons is from a single enterprise, namely the Calumet and Hecla mines; the balance at the present time is principally from some half dozen other mines, the low price of copper having caused the suspension of work at all the smaller mines.

The ore from which this large production of fine copper is obtained is that known mineralogically as "native copper," being metallic copper in a state more or less approaching absolute purity. The copper-bearing strata from which it is so largely mined extend throughout the whole length of the Keweenaw peninsula, the extreme north-westerly portion of the State of Michigan, Figs. 1 and 2, Plate 6; it

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commences at the Montreal River, Fig. 1, the mouth of which is near the south-western extremity of Lake Superior, about fifty-six miles south-west from the town of Ontonagon at G, Fig. 2; and the peninsula thence trends out into the lake towards the north-east, traversing the counties of Ontonagon, Houghton, and Keweenaw. From its commencement at the Montreal River to its termination nearly in the centre of Lake Superior, a distance of about 150 miles, the peninsula is composed of two distinct formations, running alongside each other throughout its whole length: the eastern consists of beds of silurian sandstones dipping gently to the south-east; and the western of a series of igneous and metamorphic rocks, made up principally of alternating beds of trap and conglomerate, which dip to the north-west at inclinations varying from 55 to 60 degrees in the Portage Lake district and from 23 to 33 degrees elsewhere. The trap rocks appear to be composed principally of melaphyr (augitic porphyry devoid of quartz) and diorite (hornblendic porphyry); the former is frequently of a distinctly amygdaloidal character. The conglomerates consist of an agglomeration of small pebbles and boulders, doubtless of glacial origin, cemented together by a hard felspathic mass. Throughout these rocks the copper does not occur in true fissure veins, but rather in beds, or as they are not inaptly termed in the district "belts," dipping at the same inclination as the "country" or rock enclosing them. For simplicity however the term "veins" will be used for these particular copper-bearing beds or belts.

From exhaustive scientific investigations into the origin and derivation of the copper in these deposits, it appears probable that it was infiltrated into them in the form of an aqueous solution of copper, which also appears to have had a strong chemical affinity for special constituents of the rocks, thereby giving rise to a series of chemical reactions, whence resulted the precipitation of native copper in a more or less concentrated state, according to the proportion and the even distribution or otherwise of the precipitating or displacing agent present in the original rocks. In the amygdaloidal trap rocks the displacing agent appears generally to have been less evenly distributed than in the conglomerates, or at

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any rate less evenly than in the beds of conglomerates worked in the Calumet and Hecla mines, where the copper is found in a fine state of division and very evenly disseminated throughout the whole of the veinstone proper; it is this cause alone which renders these mines probably the richest in the world. In certain places the concentration of the displacing agent has been so excessive as to give rise to the formation of large masses of copper, which will be subsequently referred to. Whether or not the precipitating action was connected with some natural process of leaching or lixiviation, influenced by terrestrial electrical currents, it is impossible to decide. In the amygdaloidal trap rocks the veinstone is frequently composed largely of epidote, a mineral whose presence is regarded as favourable or "kindly" to copper. Other minerals found in association with the hornblendic and augitic porphyries that constitute the veinstone proper are quartz, calcspar, and many varieties of the zeolite group.

The percentage of copper distributed throughout the veinstone, so far as concerns practical mining, may be said to range from 0·75 per cent. as at the Atlantic mine, to about 4 per cent. as at the Calumet and Hecla mines. Native silver of remarkable purity is occasionally found in association with the copper; but seldom in quantity sufficient to render its extraction commercially profitable.

The commercial copper smelted from these ores, being entirely free from all deleterious matter, such as arsenic, bismuth, antimony, &c., is especially valuable for electrical purposes. In a paper by Mr. Preece on electrical conductors * it was stated that, while in 1861 electricians were content to specify that copper should not fall below 85 per cent. of purity, they now specify 96 per cent., and indeed find no difficulty in getting an electrical conductivity equal to 99 per cent. of purity. It was also stated that a mere trace of arsenic in copper reduced its conductivity 40 per cent., while contact with air when in a molten state reduced it 24 per cent.; and further that the carrying capacity of a cable for messages is increased in the same proportion as the conductivity of the copper is improved, so that a cable of the

* Proceedings of the Institution of Civil Engineers, 1883, vol. lxxv, pages 64, 65, 68.

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copper of today will carry twice the number of messages that a similar cable of copper would in 1858. Owing to its greatly superior conductivity as compared with that of iron, it would appear probable that copper or some alloy of copper will before long supplant iron for aerial telegraph wires. At its present low price of 11 cents per lb., or about £50 per English ton, it should not cost more per mile than iron, when its greater efficiency is taken into consideration.

It is in the manufacture of brass however that the largest quantity of copper is employed. In this connection it is antimony which is most deleterious; one-tenth of 1 per cent. converts first-rate "best selected" into the worst possible; one-fortieth of 1 per cent. renders it unfit for anything but inferior brass; and one-eightieth of 1 per cent. changes it from "best selected" to "tough ingot" quality. One-tenth of 1 per cent. of either bismuth, arsenic, phosphorus, nickel, or cobalt is sufficient to convert best selected into tough ingot.

II.—Methods pursued in Mining.

The uneven distribution of copper in some veins and its even distribution in others have given rise to two different methods of mining, namely:—

"Mass Mining," where the copper is found concentrated into masses varying in weight from a few hundred pounds up to many tons.

"Stamp-Rock Mining," where the copper occurs in a more or less finely divided state, and usually pretty evenly disseminated throughout the whole veinstone, so that its separation from the matrix or gangue can be economically effected only by stamping and by the subsequent processes ordinarily employed in mechanical ore-dressing. The more evenly the copper is distributed throughout the veinstone, the more valuable is the latter; and it is largely due to the evenness of the distribution that the Atlantic mine, whose veinstone produces only 0·75 per cent. (three-quarters of 1 per cent.) of copper, is able to work profitably at the present low price of copper.

Mass Mining.—In the earlier history of copper mining on Lake Superior, operations were entirely confined to the extraction of large

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masses of copper. As shown in the longitudinal section of the Central mine, Fig. 3, Plate 7, the method of mining consisted in sinking a number of shafts following the inclination of the vein and at short distances apart, and connecting them in the usual manner by a series of levels. The ground thus laid open was then stoped or worked away, by breaking the veinstone away close to the under side or foot-wall of the vein, masses of copper (shown black in Fig. 3) being more frequently discovered on the foot-wall than on the hanging-wall or upper side of the vein. On the discovery of a large mass during this operation of stoping, the next process was that of desuing, or working away the surrounding ground so as to lay the mass bare all round; formerly very large quantities of powder were employed for this purpose, many kegs of powder being used in one blast. As soon as the extent of the mass has been definitely ascertained, and it is fairly liberated from the enclosing veinstone, it is cut up by hand with chisels into pieces of convenient size for handling in the mine and then hoisting to the surface, their weight ranging from 1000 to 3000 lbs. "Barrel copper" is the name given to pieces of such size as can be conveniently packed into ordinary petroleum barrels.

The most productive mines belonging to this class occurred in Ontonagon county; the most important were the Minnesota and National mines, both of them working on the same vein. One mass discovered in the Minnesota mine is said to have weighed over 500 tons, and another in the National nearly 1000 tons. Some large masses have also been discovered in mines situated in Keweenaw county, notably in the Cliff mine, which is said to have produced several masses weighing over 300 tons each; the Phœnix mine is credited with a mass of 600 tons, and the Central with several of about 150 tons each. These large masses however are quite exceptional; for the most part the masses do not weigh more than from 1 to 15 tons.

The value of an exceptionally large mass of native copper imbedded in a hard rock is not so great as would at first sight appear. Thus thirty separate masses of from 1 to 15 tons, and equal in the aggregate to 300 tons, would yield a larger profit, supposing them to

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be discovered in fair proximity, than a single large mass of equal weight. Moreover the occurrence of the large masses is so irregular, and the amount of exploratory or "dead" work between them is frequently so great, as seen in Fig. 3, Plate 7, and other difficulties of working are so considerable, that it is found that a mine with a more or less regular percentage of copper disseminated in particles throughout the veinstone is of far greater commercial value. Of late years diamond drills have been introduced for the purpose of discovering by bore-holes the position of these masses and of rich veinstone, so as to avoid as far as possible the extraction of barren ground. In earlier times, when copper was worth double and even treble as much as now, enormous profits were realised from some of the mass mines. Thus the Minnesota mine is stated to have repaid the whole of the capital outlay more than four times over during a period of about twenty years. Since the discovery of rich "stamp-rock" veins, mass mining has been almost entirely abandoned; and the once populous and flourishing district of Ontonagon county, in which many of the richest mass mines were situated, is now almost completely neglected. This however is not because stamp-rock veins do not occur there; but rather because there is seldom a sufficiency of water to supply a large Ball stamp-mill, without which veins of this description cannot be profitably worked.

Stamp-Rock Mining.—The plan of working stamp-rock mines consists firstly in sinking shafts, which are usually inclined, following the dip of the vein, and are at a distance of from 500 to 1000 feet apart. They are rectangular in section, a common size being 12 ft. by 8 ft. At some of the larger mines man-engines are placed in the shafts for lowering and raising the miners to and from their work. Shaft sinking is usually done by contract; the price paid in 1884 varied from 15 to 30 dollars per lineal foot, equal to about £18 to £36 per fathom, according to the size of the shaft and character of the ground.

Levels or horizontal drifts are driven from the shafts, at distances of from 90 to 100 feet apart on the inclination of the vein, equivalent to vertical distances of say from 60 to 65 feet apart. The levels are

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usually from 6 to 7 feet high by 5 to 6 feet wide, and are driven by means of power drills, the work being let on contract to gangs of two or four men, according to the size of the drift; the price paid in 1884 varied from 7 to 12 dollars per lineal foot, equal to about £8 to £14 per fathom, according to the character of the ground; the men are charged with the cost of steel, powder, candles, and supplies used by them. The advance per month varies considerably, but may be taken to average from 50 to 100 feet. The shot holes are drilled from 3 to 6 feet deep and from 3 inches to 1½ inch diameter, starting with the larger diameter and finishing with the smaller. The quantity of powder used varies much according to its quality and the character of the ground, but may be taken to range from ½ lb. to 3 lbs. per hole. Two men working one drill will make about 20 feet of drill holes in a shift of 12 hours, in moderately easy ground. The drifts when completed are laid with rails weighing from 12 to 15 lbs. per yard. The rock is trammed along them by hand in small wagons, constructed usually of iron, but sometimes with a wooden body: they weigh from 6 to 10 cwts., and have a capacity of from 1 to 1½ tons.

On arrival at the shaft the wagon is tipped direct into the bucket or skip, the mouth of which is so shaped as to lie flush with the edge of the "tip-plat;" or in other words the skip while lying at the same inclination as the shaft has its mouth horizontal, as shown in Fig. 6, Plate 8. The skip is constructed of iron, weighing about 2 tons and having a capacity of from 1½ to 2 tons. It is kept in position at the tip-plat by a bar of wood placed beneath it transversely across the shaft, and fitted with levers, whereby it can be quickly removed, so as to leave the shaft clear for the skip to travel freely past the level. A common size for a skip is 6 feet long, 3 feet high, and 3½ feet wide. It is fitted with four wheels of 14 inches diameter, and set 3 feet apart, with a gauge of 3 feet 8 inches to 4 feet; the upper or front pair of wheels have a 3-inch tread; and the lower or hind pair, which are set as far back as possible, have a 6-inch tread. The broader tread of the hind wheels is for the purpose of tipping the skip automatically on its arrival at the top of the shaft, which is effected in the simple and ingenious manner illustrated in Figs.

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4 and 5, Plate 8. At the place where it is desired to tip, the inner part of the inclined skip-road, which is laid with rails weighing 25 lbs. per yard, is turned off horizontally, and along this narrower part the front wheels run; whilst the hind wheels on account of their broader tread are caught up by the outer and wider part of the road, which continues to run upwards at its original inclination. In this way the skip is tipped forwards or inverted, swinging on its hind wheels, while to its centre is attached the bale whereby it is connected with the winding rope.

The rock is not unfrequently hoisted from one level to another through the intermediate blind shafts or winzes, in a bucket or small skip wound by a winch, which is sometimes driven by compressed air. Small compressed-air winches have been introduced only of late years, but have proved a very useful adjunct in large mines where air-compressing machinery is employed. They are self-contained, and are fixed on a bedplate 5 to 6 feet long and 2 to 3 feet wide, and can easily be removed on a trolly from place to place; they have a single cylinder 6 to 8 inches diameter, with slot-link reversing motion, and the winding drum is driven through spur gearing; the depth being small, no brake is required. It is estimated that each winch consumes about three times as much air as one drill. The branch from the main air-pipe is simply attached to the winch with a tap.

As soon as the levels have been driven forwards to a sufficient distance from the shafts or winzes, the ground standing between the levels is extracted by overhand stoping, the miners breaking down the rock from the roof or back of the level, and thus working upwards from each lower level towards the one above. This work also is done with power drills. The stoping is started at from 10 to 14 feet distance from the shaft or winze, so as to leave a shaft pillar of that thickness on each side; and it is not carried up higher than from 6 to 10 feet below the bottom of the next level above, so as to leave a floor of that thickness for the upper level. In this way the stopes are worked out along the whole length of each level in a series

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of inverted steps like the underside of a staircase, proceeding in successively rising stages. Each fathom in length is assumed to be one square fathom in cross section, and is known to miners as a "running fathom" of ground.

Timbermen follow on after the miners, and timber up the stopes with rows of large cross timbers or props fixed close together, so as to support the hanging-wall or upper side of the cavity from the foot-wall or under side. In the Calumet and Hecla mines the timbers are placed from 4 to 6 feet apart, instead of close together side by side, and are framed into sills at bottom and caps at top; in this way considerable economy is effected, inasmuch as squared timber of 12 to 14 inches scantling can be used for the props, instead of round timber 2 to 3 feet diameter; there is also a saving in time and labour through the diminished handling of the timber in the mine, special wood-cutting machinery being employed to cut out the necessary joints. The timbering forms one of the heaviest items of cost in the Lake Superior mines, amounting frequently to as much as 10 per cent. of the entire mining cost.

At the Calumet and Hecla mines the mode of contracting for stoping is peculiar; the men are paid from 11 to 13 dollars (46*s.* to 54*s.*) per cubic fathom, the vein being taken to average 2 fathoms, or 12 feet in width; should it widen to 14 feet, the extra 2 feet are not allowed for in the contract price; on the other hand, the men derive an equivalent advantage when the vein narrows up to 10 feet. A running fathom of 216 cubic feet is equivalent to 18 or 19 tons of rock. Blasting is usually done between shifts, namely between six and seven o'clock in the evening; at some mines it is carried out by a special gang of men, and not by the miners.

Winding Engines.—The winding engines are frequently situated at some distance from the shafts, and one engine winds from several different shafts: the rope, which is of steel wire, is carried over a series of sheaves. The engines are not unfrequently fitted with V friction gearing, in place of the ordinary spur gearing; and are always supplied with a powerful steam brake. The most remarkable winding engine in the district, and probably in the world, is that

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lately erected at the Calumet and Hecla mines; it is a compound condensing and rotary beam-engine designed by Mr. E. D. Leavitt, Jun., having a 40-inch high-pressure cylinder working with 135 lbs. steam, and a 70-inch low-pressure cylinder, with 6 feet stroke. At 36 revolutions per minute, it is stated to develop 2500 indicated H.P., and to be capable of increasing to 4100 H.P. at 60 revolutions. The fly-wheels are 32 feet diameter, and weigh 45 tons each. The main shaft on which they are mounted is 18 inches maximum diameter and 14 inches minimum, and 130 feet long. It is coupled to three pairs of air-compressors, one with 36-inch cylinders and 5 feet stroke, and two with 32-inch cylinders and 4 feet stroke; and also to six winding drums of 20 feet diameter, which are fitted with hydraulic clutch gearing. Each drum weighs about 60 tons, and is capable of coiling 4000 feet of $1\frac{1}{4}$-inch steel wire-rope at a speed of 1000 feet per minute.

Rock Houses.—As a rule very little selection of the stone is made in the mine, since it is found not practicable to carry out underground an economical separation of the dead or barren country rock from the copper-bearing veinstone. The whole of the mine stuff is consequently drawn to the surface, and taken direct into the rock house, which wherever practicable is situated in a direct line with the inclined shaft, as shown in Figs. 7 and 8, Plate 8, and close up to its mouth, so that the skip tips directly into it. Generally however the rock house receives the stuff from several shafts situated some distance apart; and at the mouth of each, as shown in Figs. 9 and 10, Plate 9, the skip tips into a wagon, which is run and tipped into the rock house by an endless wire-rope. The stuff thus tipped passes over a sloping screen or griddle G, Fig. 7, Plate 8, of wooden bars from 2 to 3 inches apart; the pieces passing through are small enough to treat at once in the stamp mill. The larger lumps requiring to be reduced in size are broken by Blake crushers B, Figs. 7 and 8, the jaws of which are usually 16 × 24 inches or 10 × 15 inches. The larger size will break per day from 300 to 350 tons of rock when of a soft amygdaloidal character; but of conglomerate rock it would break only about

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half as much. A more or less perfect separation of the stuff is effected in the rock house by breaking up with sledge hammers the pieces too large for the crusher; the poor rock is thrown out into tram wagons, from which it is tipped on the burrow or waste heap. Pieces of nearly pure copper, too large for the stamp mill, are cleaned up by hand with hammers and chisels to about 65 per.cent. of pure copper, and are packed into barrels and sent direct to the smelting works.

Stamp Mills.—Owing to the need of a large supply of water, the stamp mills are generally situated on the banks of Lake Superior, and consequently at some distance from the mines, from which the stuff is brought by railway. The trucks transporting it are fitted with drop bottoms, and have a capacity of from 3 to 4 tons. They are run directly over a series of hoppers or shoots H, Fig. 14, Plate 10, situated immediately behind the mill, into which the rock is discharged by opening the bottom of the truck. Thence it passes down an inclined shoot S into the mortar of the stamp, the feed being regulated by hand.

The "Ball" stamp,* so named because invented by William Ball in 1856, is the one that is in almost universal use throughout the district; it is shown in vertical section in Fig. 16, Plate 11. Being constructed very much on the principle of a steam-hammer, it requires very solid foundations. A pit is dug 12 to 14 feet deep and 26 to 30 feet square, Figs. 14 and 15, which is lined with a stone walling 4½ feet thick at the bottom and 3 feet thick at the top. The bottom of the pit receives a concrete floor from 12 to 14 inches thick, upon which are laid timbers 14 inches square and 19 feet long, leaving spaces of 2 to 3 inches between them, and of 9 to 18 inches at the sides of the pit. The spaces are filled in with small broken rock and floated with cement, a layer being thus laid during the day and allowed to set during the night.

* See Transactions of the American Institute of Mining Engineers, 1877, vol. v, pages 584-611; and Transactions of the American Society of Mechanical Engineers, 1885, vol. vi, pages 370-399.

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A dozen layers are so built up, laying the timbers in alternate directions across the pit; there are thus about 168 timbers in all. On the top layer are fixed, one on each side of the woodwork, two longitudinal cast-iron sills or girders L, Fig. 16, strengthened by knee braces, and secured by about fifty iron holding-down bolts or tie rods of 2½-inch round iron, which pass down between the alternating timbers to the bottom, where they are fastened to a heavy base-plate. Laid across, and bearing on the two longitudinal sills are seven spring timbers T, having each a section of 16 by 14 inches, which are held in position by two transverse cast-iron sills R; these cross sills are laid outside and alongside the spring timbers T, and have their ends bolted to the ends of the two longitudinal sills L. The spring timbers last only from three to six months, and have then to be taken out and replaced by new ones. On the cross sills R four cast-iron head-posts H, inclining towards one another at the top, are framed together by cross pieces; and to the frame so made are fixed the steam cylinder C at top, the mortar M at bottom, and the other parts of the stamp.

The mortar M is made of cast-iron, and stands on a cast-iron bedplate about 20 inches thick, which is placed on the top of the spring timbers; it has thus a slight vertical movement at each blow, whereby the wear and tear of the stamp are diminished. The mortar is a circular pan, about 4 feet diameter outside, and 2½ feet high, the bottom being about 7 inches thick, and the sides 4 inches. In the centre of the mortar is placed the "die" D, on which the ore is stamped; it is a conical cast-iron block about 7 inches high, tapering from about 22 inches diameter at the bottom to 20 inches at the top. Upon it fits a cast-iron ring, about 5 inches thick and 6 inches broad, having an outside conical flange for supporting the bottoms of the "stave liners" V, which line the inside circumference of the mortar and keep the die central within it. The stave liners are cast-iron plates about 18 inches high and 2½ inches thick, curved so as to fit the inside of the mortar, around which they are carefully wedged up tight, leaving a clear internal diameter inside them of about 3½ feet. The die, ring, and stave

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liners last about eighteen months, and have then to be taken out and renewed.

The frame F of the mortar is about 4 feet square at the base, and $3\frac{1}{2}$ feet high, and is inclined so as to project outwards at top about 2 feet from the perpendicular. In the frame are fixed four screens sliding into grooves, each containing four grates G of sheet steel about $3\frac{1}{2}$ feet high and $7\frac{1}{2}$ inches broad, which are punched with holes $\frac{3}{16}$ inch diameter and $\frac{1}{2}$ inch apart horizontally, and $\frac{1}{3}$ inch vertically. At some of the mills oblong holes, $\frac{1}{8} \times \frac{5}{16}$ inch, have been substituted for the $\frac{3}{16}$ inch round holes, to facilitate the passage of flat and oblong pieces of copper. The screens are shielded outside by heavy iron splashboards, which are held in position by an iron crossbar bolted on to the mortar frame. At the bottom and outside each screen there is a discharge pipe 3 or 4 inches diameter, through which the stream of copper sands passes into a series of launders connected with the jigs or washers. On the top of the mortar is fixed the "urn" U, a circular cast-iron cistern into which water is led by a 4-inch pipe to supply the mortar. Alongside is fixed a cast-iron feed-hopper, with a mouth about 16 × 14 inches, through which the rock passes from the shoot S into the mortar, where it is then crushed in a large volume of water, each ton of rock crushed requiring from 25 to 30 tons of water.

The stamp shoe E is made oblong, with straight sides and rounded ends, about 22 inches long, 14 inches wide, and 10 inches thick; and is secured by a dovetail joint on the bottom of the vertical shaft or stamp bar, which is 10 inches diameter and weighs nearly 2000 lbs. The shoe weighs about 630 lbs., and lasts from one to three weeks, according to the material of which it is made and the character of the rock stamped. The best mixture for the shoe is chilled white and grey iron with a certain amount of Franklin spiegel. The time occupied in changing a shoe is about one hour.

The stamp is worked by a vertical steam cylinder C, Plate 11, which varies in diameter in different mills from 15 inches to 19 inches, and is fixed centrally on the top of the stamp frame. Near the top of the head-posts is fixed a pulley P, 20 inches diameter, driven by the horizontal mill-engine, which also works

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all the other machinery in the mill through pulleys, shafts, and belting, Plate 10. The shaft of the pulley carries an elliptical spur-wheel, which gears into a corresponding wheel, and gives motion to an eccentric on the shaft of the second elliptical wheel, whereby the slide-valve of the stamp cylinder is worked in such a manner as to keep the top steam-port fully open for admitting the full pressure of steam during the downstroke, whereas only about one-eighth of the lower steam-port is opened for the upstroke and with a quicker motion of the valve. The piston consequently travels with much greater velocity and force during the downstroke than during the upstroke. The cylinder is made with a counter bore at the bottom, into which the piston will drop if ever the feed of rock be allowed to get too low in the mortar, beneath the stamp shoe; the steam above the piston then escapes past the sides of the piston, and the stamp is immediately brought to rest, thus preventing the bottom of the cylinder from being knocked out or any other damage from being done to the stamp. The piston has a stroke of 2 feet, and the stamp gives from 90 to 100 blows per minute, with a steam pressure of from 80 to 100 lbs. The piston-rod is connected with the stamp shaft by a circular disc or cheese-head fixed on the bottom of the rod, which is encased by an iron bonnet bolted on the top of the stamp shaft; the cheese-head is secured within the bonnet by india-rubber packing above and below. The stamp shaft works through guides fixed between the braces of the head-posts H; and round it is placed a revolving clamp and pulley Y, having feathers which work in splines or grooves cut in the stamp shaft. A belt round the pulley Y rotates the stamp shaft during its up and down strokes, causing the oblong shoe to strike continually in a fresh place, and thus to prevent the rock from packing in the mortar.

The net total falling weight of a Ball stamp ranges from 4000 lbs. to 5000 lbs., performing with the steam pressure a total work of from 100 to 180 foot-tons at each blow. The power developed in full work is from 100 to 180 I.H.P., and the quantity of rock crushed per 24 hours is from 120 to 220 tons. The total weight of the stamp and frame is from 70 to 80 tons, and the cost from £1800 to £2000.

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III.—System of Ore-dressing, and Machinery employed.

The object of ore-dressing is to separate as far as possible the small percentage of valuable metal occurring in the ore from the worthless matrix or gangue with which it is found associated. In the Lake Superior district metallic copper is the only product of value; and the dressing process consists simply in separating it from the gangue, and concentrating it to the highest degree of purity practicable. Thus whilst the average percentage of copper in the rock mined in this district does not generally exceed 1 to 2 per cent., the dressed product sent from the mill to the smelting works contains on an average about 80 per cent. of copper. In describing the system of dressing followed in a Lake Superior copper mill, it will be sufficient to refer to the complement of machinery required to dress the ore from a single stamp, as shown in Fig. 15, Plate 10; and the main feature of the process may be said to consist in applying to copper ore the principles and the machinery already employed elsewhere in the dressing of tin and lead ores.

Hydraulic Separators.—The stream of sands issuing from under the stamp head, and passing through the screens, is carried in wooden launders L inclined at an angle of 5°, Fig. 14, Plate 10, which discharge into three rows of settling troughs T, known in the district as "hydraulic separators." These are placed alongside the first three sets of jigs or washers J, as shown in Plates 10 and 12, and consist of V shaped wooden troughs, Figs. 17 and 18, about 16 feet long for a double set of jigs, and supported on trestles, the top of the trough being about 4½ feet from the ground; they are constructed with two compartments, an inner and an outer, and into the inner is delivered the stream of sands from the stamp launders. The inner trough, Fig. 17, is about 1 foot wide at the top and 1 foot deep; the bottom is 1 inch wide, and has four longitudinal slots cut in it, each 1 inch wide and varying from 4 to 9 inches in length, the longest being situated nearest to the delivery from the stamp launders. The slots open into the outer trough, which extends on each side of the inner, and is about 1¾ foot

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wide at top and $1\frac{3}{4}$ foot deep; it has an angular channel, with four openings in it close to the bottom, which are fitted with 1-inch discharge pipes. The outer trough is kept nearly full of water by a $1\frac{1}{2}$-inch pipe from the water-main; and the rough separation of the larger pieces of mineral from the minuter particles known as "slimes" is effected by the action of the water in the following manner. The height of the water in the outer trough being maintained at a few inches higher level than the stream of sands flowing along the inner trough, the consequent upward current of water through each of the four slots in the bottom of the inner trough permits only those pieces to drop through them which are heavy enough to overcome the resistance encountered from the rising current. The heaviest and coarsest bits fall through the largest slot, the next through the second, and so on for the third and fourth; and all these are discharged from the bottom of the outer trough through the pipes leading to the jigs. The finest particles of sand however, constituting the slimes, being too light to overcome the upward current, flow out from the end of the inner trough into other launders, and thence into settling troughs. A rough separation of the sands into coarse, medium, and fine is thus effected in the first stage of dressing.

Some 75 per cent. of the total amount of rock crushed by one stamp head, or say 150 tons, assuming the stamp to crush 200 tons per day, is thus removed from the stream of sands, and is subsequently dealt with by the jigs. The size of the bits varies from over 1-16th of an inch down to 1-32nd of an inch, more than 40 per cent. being less than 1-25th of an inch. Of the sands thus separated from the slimes, about 65 per cent. are classified as coarse, 22 per cent. as medium, and 13 per cent. as fine.

Jigging.—The process of jigging consists in sorting into layers, according to their varying specific gravity, an aggregation of particles differing both in shape and density, by means of the vertical pulsation produced among them by the aid of water; according to the construction of the machine employed, the pulsation is produced either by the water moving vertically through the stuff, or by the

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stuff moving vertically through the water. In a Lake Superior copper mill the jigs are arranged in sets alongside the hydraulic separators, as shown in Plate 10, the first row in each set being called "head sieves," and the second row in each set "tail sieves." For each stamp-head there are as a rule three sets of head and tail sieves, each set with its own hydraulic separator; and these are known as the "roughing" jigs. They are succeeded by two or more similar sets called "finishing" jigs, which are not directly connected with a hydraulic separator. All the jigs are of similar construction, and are worked in the same way, the only difference being in the fineness of the mesh of the sieves, which varies from 10 to 30 holes per lineal inch or from 100 to 900 holes per square inch.

The jigs in general use in the district, as shown in Figs. 17 and 18, Plate 12, are those commonly known as the "Collom washer," being the invention of Mr. John Collom (see Proceedings 1873, page 135). Each is constructed in a rectangular wooden tank, about 7 feet long, 3½ feet wide, and 2½ feet high, with frames of 2½-inch stuff. Up to about 18 inches from the bottom of the tank it is equally divided into two compartments or "hutches" H, having inclined sides and a 1¼-inch discharge pipe from the bottom. About 6 inches from the top is fixed in each hutch a horizontal wire sieve, 3 feet long and 2 feet wide, which is kept covered with a bed of coarse sized copper, varying in thickness from ½ inch to 1½ inch. The two hutches are kept filled with water by 1-inch pipes entering about 9 inches from the bottom and connected with the 1½-inch water main. In the middle of the upper part of the tank are two other compartments, each 2 feet by 1½ foot and 1 foot deep, the bottom of each being left open to the two hutches respectively. In each compartment works a loosely fitting wooden piston P, on which stands a piston-rod about 18 inches high, steadied in guides; on the upper part of the rod is screwed a nut N, below which is a spiral spring, adjusted to aid in lifting the piston after it has been depressed by the arm of the rocking lever L overhead. The rocking lever L is worked by a connecting-rod and crank from a 20-inch belt pulley, and depresses each piston alternately about half an inch, the extent of depression being regulated by the adjusting nut on the piston-rod. The

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piston is raised again by the joint lifting action of the water beneath it and of the spiral spring above it. The number of pulsations is about 120 revolutions per minute, varying according to the fineness of the stuff to be jigged. Two rocking levers are coupled by a rod, so as to be worked by one pulley.

These jigs are known as "bed jigs"; and their action and mode of working are as follows. The coarse sand issuing from the first spout of the hydraulic separator T flows over an apron on to the head sieve of the first set of roughing jigs. Upon the stratum of copper forming the bed of the sieve, a layer several inches thick is soon deposited of coarse sand, too large to pass through the sieve of 100 meshes per square inch. The layer of sand and copper being agitated by the pulsation of the jig piston, the finer grains of copper which are heavy enough to overcome the resistance of the upward pulsation of the water pass through the copper bed and sieve into the hutch below. The stuff here collecting is conducted by launders to the head sieve in the first set of finishing jigs, where it is re-jigged in a similar manner on the copper bed of a medium sieve having 256 meshes per square inch; and as soon as a sufficient quantity has collected on the top of the bed, it is skimmed off, and put into barrels. The still finer copper which falls through this sieve into the hutch beneath is discharged into a catch-box C outside the jigs, Fig. 14, Plate 10, where it is washed and then put into barrels.

The layer of coarse sand and grains of copper which collects on the copper bed of the head roughing sieve is skimmed off as it accumulates. The lighter and coarser sands at the top of the layer are returned to the mortar to be re-stamped; the finer and heavier copper at the bottom of the layer is collected and put into barrels. The skimming is done by hand, the machine being stopped as often as required for that purpose. The lightest sands jigged on the head roughing machine, which are not heavy enough to pass through the sieve, are discharged over another apron on to the corresponding tail sieve of the roughing jigs in the same set, which has 144 meshes per square inch, and are there re-jigged. The sands collecting on the sieve are returned to the mortar to be re-stamped. The grains of copper falling through the sieve are led by a launder to the head sieve of the finishing jigs,

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where they are jigged a third time on the copper bed of a sieve having 256 meshes per square inch. What collects upon this sieve is removed as it accumulates, and is put into barrels; what passes through runs into the catch-box C, Fig. 14, Plate 10.

The overflow from the tail sieves in the second and third sets of the roughing jigs runs to waste. The overflow from the tail sieves in the first set of the roughing jigs runs into the finishing jigs, where it is re-jigged. In some mills the overflow from the finishing jigs runs into a settling trough, and thence through an opening in the bottom of the trough to another set of finishers, where it is re-jigged. In other mills, as shown in Plate 10, the overflow from the finishers runs through launders into a cistern, and is thence raised by a centrifugal pump P, Fig. 14, through iron pipes into a V shaped settling trough R, preparatory to treating it on a revolving table. The other sets of jigs dressing the medium and fine sands are worked in a similar way, but with finer roughing and finishing sieves.

The copper of the richest grade is obtained from the mortar, and consists of pieces of ore too large to pass the screens, but which, being completely free from gangue, are removed and at once packed in barrels; this is called cover-work. The slimes which overflow from the hydraulic separators are conducted by a launder into wooden V shaped settling troughs, about 10 feet long, 4 feet deep, and 4 feet wide at the top; these are fitted at the bottom with spouts, through which the slimes pass into launders, whereby they are led into the receivers of the rotating tables, better known in Cornwall as "revolving buddles."

Rotating Tables.—In the Lake Superior district Evans' table, shown in Figs. 21 to 23, Plate 13, is in general use. It is similar in the main to the convex revolving table used in Cornwall, but has been improved by the addition of a central stationary apron A, below which revolves on a vertical shaft the annular conical table C, driven at 1½ turns per minute. The machine is constructed in a strong wooden frame. The outer diameter of the table is 19 feet and the inner 8 feet, giving 5½ feet breadth of annular surface, sloping downwards towards the circumference at an inclination of about 12° to the horizontal. The

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open centre of the table is covered by the conical apron, which has the same slope as the table; and its outline, instead of being circular, is a spiral, as shown in the plan, Fig. 23, increasing from 4½ to 6½ feet radius in its complete turn. The apex of the apron is surmounted by an annular basin or receiver B, pierced with holes and divided diametrically by a partition in line with the shortest and longest radius of the spiral. The half basin facing the shorter half of the spiral is supplied from a launder L with slimes, which it feeds upon that side of the apron, whence they flow down upon the annular table as it revolves beneath. The other half basin, facing the longer half of the spiral, is supplied with clear water, which flows thence over that side of the apron, and down upon the annular table, washing out the tailings or lighter and poorer part of the slimes, of which the middles and heads, or heavier and richer portions, remain deposited upon the table, and are carried round towards the longest radius of the spiral apron. As the radius of the apron increases in the same direction in which the table revolves, the slimes and the water are delivered upon the table gradually nearer and nearer to its outer edge. The tailings washed off the table are caught in a circular launder T running round underneath its outer edge. Towards the end of the revolution, shortly before arriving at the longest radius of the apron, a pipe P stretches radially across the table, having its outer end bent back obliquely over the table, and perforated with holes discharging jets of clear water, by which the middles or medium slimes are washed off into a catch-box M near that part of the table. Finally the heads or richest portion of the concentrates, which still cling to the table and succeed in passing these jets, are washed off into a separate catch-box H by a still stronger jet J at the very end of the revolution, leaving the table quite clean for starting upon its next round.

Kieving and Buddling.—The products of the rotating tables are seldom rich enough to be sent straight to the smelting works, and therefore require to undergo further concentration, which is generally effected by means of the two processes usually employed in Cornwall

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and known as "kieving" and "buddling." The same is the case in regard to many of the products of the jigs, more especially the fine sands coming from the hutches of the tail finishing jigs.

In kieving, the fine slimes are put into a kieve or tub, shown in Fig. 11, Plate 9, about 2½ feet diameter and 3 feet deep, together with water enough to reduce them to the state of liquid mud, which is kept slowly moving by means of a steadily revolving stirrer, Figs. 12 and 13. On the conclusion of the stirring, a succession of sharp blows are struck on the sides of the kieve with a mallet or bar. The tremor thus imparted to the semi-liquid mass causes the heavier particles containing copper to settle down to the bottom. After a short time the water is run off from the top, and the upper layer of poor sand is shovelled out, leaving at the bottom the layer of concentrates, which however are frequently not rich enough yet for smelting, and have consequently to be buddled.

In buddling, Figs. 19 and 20, Plate 12, the slimes are again mixed with water, and made to flow in a thin stream over a spreading apron A into a long trough G, the sides of which are over 2 feet high at the head, while the bottom slopes gently downwards at an inclination of 3½ degrees. At the head of the box the rich copper slime settles; and this deposit is usually rich enough for smelting, containing as it does over 30 per cent. of copper; but if still not rich enough, it is kieved a second time over.

Losses in Dressing.—There is a considerable loss of copper in nearly all the Lake Superior mills, in spite of all the attention bestowed upon the treatment of the tailings according to different methods; and it has usually been found that extra expense incurred in that direction for labour and machinery has not been justified by the value of the copper saved. The loss is due principally to the occurrence of copper in the three following forms: (1) Float copper, occurring in very fine grains and flat scales free from gangue, which are carried away by even the weakest current of water that can be employed in the dressing. (2) Included copper, consisting of fine particles included within grains of gangue. (3) Oxide of copper, which may be either included in grains of gangue or found free.

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Conclusion.—The fact illustrated by the St. John del Rey gold mines, the Rio Tinto copper mines, and the Mechernich lead mines, is confirmed by the experience of the Lake Superior copper mines:—namely that the most successful mines are generally such as are capable of economically treating exceptionally large quantities of ore of a comparatively low percentage, rather than those which yield smaller quantities but of a higher percentage.

In the Lake Superior copper mining, the features which appear to the author most worthy of special attention are the following:—

Firstly, the care with which the exploratory workings are kept in advance of the stoping. This is one of the causes which has been most conducive to the prosperity of the district, and is well exemplified in the Calumet and Hecla mines, where the reserves are said to be sufficient for fifteen years' future working at the present rate without further development. The Quincy and Atlantic mines have also similar extensive reserves.

Secondly, the general use of machine drills, which admits of opening up the mines at a rate otherwise impracticable. This is one of the few localities where drills are employed for stoping, and it has been found that two to three times as much rock can be stoped in the same time by drill as by hand. A pare of men with one drill can stope 1,000 tons per month.

Thirdly, the care bestowed upon the separation of the copper from the gangue by dressing. The progressive improvement in dressing in the Lake Superior district has perhaps been more rapid than in any other region of equal extent and importance; and although the ore is of a comparatively simple character, the author doubts whether equal care has been bestowed in other localities, even when dealing with far more complex ores. The most important improvement has undoubtedly been the introduction of the Ball steam-hammer stamp, which nevertheless has not yet succeeded in establishing a footing elsewhere. The value of this appliance for treating large quantities of mineral hardly admits of dispute as regards the Lake Superior district.

To the kindness of the managers of the principal mines the author is in a large measure indebted for the information contained in the present paper.

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Discussion.

Mr. RATHBONE exhibited an extensive collection of specimens in illustration of the paper. One was a piece cut off from one of the large masses of native copper that were met with in mass mining; it showed how the gangue came in between the metal, so that not only was it very difficult work to strip the mass all round, but there was also quite as much difficulty in cutting the mass up into pieces, on account of the gangue being so interspersed throughout it. On this account it was that experience in Lake Superior copper mining had at present shown that the stamp work, in which the copper was disseminated very evenly throughout the rock, was much better to deal with than mass work: in fact the getting out of such very large masses as were mentioned in the paper did not pay as a rule, unless they were of very frequent occurrence, for the amount of dead or unprofitable work necessitated in searching for them was so great as entirely to absorb their value when discovered; whereas work like that at Calumet and Hecla, where the copper was evenly disseminated throughout the veinstone, did pay very well, even though the percentage of copper in the stone might be very low. In another specimen it was seen where the drill had gone in till it struck the copper, when it had to be withdrawn, because it was impossible to go on. Other specimens were copper chisellings, produced in cutting up the big masses into smaller pieces of a size that could be handled. Also crystals of native copper, which were very rare; and cores obtained in prospecting with diamond drills for the purpose of finding large masses of copper or rich portions of veinstone. One of the cores contained a small amount of copper, showing that the drill had got into paying ground; another showed the country rock, which was chiefly epidote and was considered kindly for copper. Occasionally a little native silver was found, but not in sufficient quantity to be of any commercial value; one specimen however, from a recent discovery on the northern shores of Lake Superior, was just as full of silver in a finely divided state as the fine copper stamp-rock was full of copper. Sometimes copper was found in thin plates,

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called leaf copper, separated from one another by intervening portions of gangue. The stone hammer-heads exhibited were frequently found in the Ontonagon district, and were supposed to have been used by the Indians in very early times for pounding up the native copper into war implements such as arrow-heads; the groove round each stone was doubtless where a withe had been bound round it for securing it to the handle.

The PRESIDENT said a letter had been received from Dr. Le Neve Foster, Government Inspector of metalliferous mines in North Wales, who regretted he was not able to be present and to take part personally in the discussion upon this paper.

Dr. C. LE NEVE FOSTER wrote that subsequently to the completion of the paper the production of copper in the United States during last year had been made known; and that it would be well to point out that, though the total output of the whole country had decreased, the Lake Superior mines in 1886 had produced 39,500 tons of 2000 lbs., of which 25,050 tons came from the Calumet and Hecla mines.

In regard to the Ball stamp, was the paper correct in stating (page 96) that the Ball stamp was the one that was in almost universal use throughout the district? He thought not; nay further, was it not a fact that the Calumet and Hecla mines had discarded all their Ball stamps for the Leavitt stamps,* which were not mentioned in the paper? As the date of the author's visit to the Lake Superior district was not given, possibly the introduction of the Leavitt stamp had taken place since he was there.

Mr. RATHBONE replied that his last visit to Lake Superior was certainly long after the adoption of the Leavitt stamp; but he had called it the Ball stamp because the principle of the stamp was just the same, each being a sort of steam-hammer. The improvement introduced by Mr. Leavitt consisted in adding a small lifting cylinder

* See "The Engineering and Mining Journal," New York, 1885, vol. xxxix, page 152; and "Engineering," 26 Feb. 1886, page 201.

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(Mr. Rathbone.)
immediately underneath the main cylinder; the smaller cylinder had no valve, and the boiler steam was constantly acting on the underside of its piston to lift the stamp; and in the main cylinder the steam was admitted only upon the top of the piston for the downstroke, which was made against the lifting force of the smaller cylinder. It was true that at the Calumet and Hecla mines at the present time all the old Ball stamps were being taken away, and replaced by stamps of the improved construction, which had a much greater stamping capacity; they crushed from 200 to 220 tons of rock in twenty-four hours, whereas the old Ball stamp would crush only perhaps 90 to 120 tons. The new stamp was of course much more economical in point of fuel; and at the Atlantic mine, as cord-wood was getting daily more expensive, coal had been used for many years in preference to cord-wood. When last at the Calumet and Hecla mines he had been surprised to see the enormous quantity of cord-wood that had to be kept in stock in order to get it properly seasoned. Green wood of course made a very great difference in the efficiency of the stamp.

Mr. HENRY DAVEY had been struck with one statement in the paper which bore testimony to the great value of mechanical engineering, namely that, while mass mining did not pay, stamp-rock mining did pay, and even paid when there was only 0·75 per cent. of copper in the stone treated (page 89), the whole of the work being done by machinery throughout the successive processes in the treatment which it underwent. Although large rich masses of native copper were met with, ready to go to the smelting mill without any dressing if they could only be got out of the mine, yet all the work of getting them had to be done by hand labour; and consequently, even when almost pure, like the best of the specimens exhibited of pieces broken from them, they did not pay to work. The contrast was very remarkable between such specimens and others of those exhibited, which contained only 0·75 per cent. of copper. It seemed indeed surprising that the latter could be made to pay, especially when it was remembered that there were thousands of tons of refuse from copper mines in Cornwall, lying in heaps all over the county,

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and containing perhaps $1\frac{1}{2}$ and sometimes 2 per cent. of copper. If in America such a low percentage could be made to pay, he wondered some of the Cornish refuse heaps were not worked, as the treatment was the same.

Mr. HILARY BAUERMAN said his own experience of the Lake Superior district had been somewhat earlier than the author's, as he had been there twenty-two years ago, at the time when the great Calumet and Hecla mine was nothing more than a square prospect hole full of water; but sundry other mines of the same kind were beginning to be developed. Since that time there had been many changes in certain respects, but few in others. It would be seen from the map, Plate 6, that the upper promontory of Michigan, or the Keweenaw point as it was called, was a promontory about 120 miles long; and the narrow belt in the middle was a curious belt of amygdaloidal traps and conglomerates, which contained copper. Beyond the Copper Falls mine, where the point of the promontory turned nearly east and west, there was an indent in the coast, called Copper Harbour, where the first discovery was made about 1845; and some of the first ore was worked by the Pittsburg and Boston Company, who took 25 tons out, and then the mine was abandoned. It was a black oxide of copper, of which he exhibited a specimen that he had brought from the spot. In those days that was a very difficult place to get at. Another mine was afterwards started, the famous Cliff mine, which was about six miles southwest of the Central and about eight southwest of Copper Falls, being further from Eagle Harbour; and that was the beginning of what was for a long time the greatest mine of Lake Superior. To the statement in the paper (page 87) that the copper did not occur in true fissure veins, he had to take exception, as all the great mass mines north of Portage Lake, such as the Central and Cliff, were worked upon fissure veins, going about north-west and south-east across the belt. The Minnesota was also on a lode, though of a less regular character. The longitudinal section of the Central mine in Fig. 3, Plate 7, showed a working on a transverse vein; it was not a working on the conglomerates at all nor on the amygdaloids. At a later date

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(Mr. Hilary Bauerman.)
occurred the discoveries about the middle of the promontory, near the towns of Hancock and Houghton on Portage Lake, which was a curious basin running south-east into Keweenaw Bay; and from its north-western end a canal had been cut due north, so as to form a water communication right across the promontory. In the neighbourhood of Hancock and Houghton, the vesicular trap containing copper was worked; it had the same spongy character all through the lake, containing cavities which were being filled with shells or linings of native copper; here and there the cavities were broken through, and then they had streaks and masses and sheets of copper running through them. These mines were first developed in the neighbourhood of the town of Hancock on the north of the lake; and among them were three famous mines—the Quincy, the Pewabic, and the Franklin, which had been very profitable, as he believed some of them still were; they were working on stuff containing about 1½ per cent. of native copper, and were going on still. Three miles north-east of the Franklin came the Albany and Boston mine, the first in which conglomerates were found; they were very like amygdaloids, only that they were masses of pebbles having the spaces between the pebbles filled in either with linings of copper or with a mixture of copper and epidote and other minerals. Sometimes there was also a little native silver, besides oxides and silicates of copper. The Albany and Boston at the time of his visit was a magnificent looking mine, and a great deal of money had subsequently been spent there, though unfortunately without leading to profitable results. But it led a few years afterwards to the discovery of the Calumet and Hecla mines, which had developed another class of conglomerate of the most extraordinary kind; the bed having a comparatively slight dip was worked more like a colliery than a copper mine as ordinarily understood.

Mass mining he believed had never been unprofitable, if only the masses were numerous enough. Originally the mass mines had been the most valuable on the lake, such as the Cliff mine, the Minnesota, and, at the time when he knew it, the Central. Those mines had all been distinguished by enormous masses. For instance, one of the

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largest masses ever found on the lake he believed was at the Central, and that was about 800 tons. When visiting the mine in 1865 he saw solid copper taken out 4½ feet thick, or about three times the thickness of the heaviest armour-plate rolled, with large cavities containing perhaps the finest known crystals of native copper. But even in those days a mass mine did not work upon the masses alone; the Cliff mine had a very large stamp plant, and their stuff returned he believed something under 2 per cent. It was the same with all the other mass mines. Subsequently the stamp-rock mines had been developed, especially the Calumet and Hecla which had ruined almost every other on the promontory; but then the Calumet and Hecla did not yield only ¾ per cent., but something like 4 per cent. as an average of the whole of the stuff. A great production was still kept up from that mine.

With regard to the plant and machinery on Lake Superior, there was no doubt that the Ball stamp was admirably suited for the district. The material was a most peculiar one, as would be seen from an examination of any of the numerous specimens exhibited. There was no knowing what was going to be met with in the stuff; in what looked like a nice piece of rock with copper evenly disseminated through it, there might be found two or three inches of solid copper, which would take any amount of stamping under the steam hammer. The Ball stamp had been in use for a long time, having been invented long before any of the great western mines were discovered. The rotating stamp, such as was used all over the Rocky Mountain states, and in Mexico and California, was admirably suited for its purpose, and he did not think there would be any advantage in getting anything else. As to the dressing machinery on Lake Superior, judging from the mill shown in Plate 10, it was now substantially simplified from what he had formerly seen. The Collom jig was invented by a Cornishman on Lake Superior. In fact in the early days Lake Superior was entirely Cornish, as could be seen by the old kieve, shown in Fig. 11, which still continued to be admirably suited to its purpose. The slime dressing was mainly conducted by the rotating table, Plate 13, which corresponded with what was known in England as the Zenner buddle or the Hunt

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(Mr. Hilary Bauerman.)

buddle, and probably was well suited for the purpose. A great number of more complicated dressing machines had been tried previously, and he was glad to see they had given place to the simpler system here shown.

The PRESIDENT asked what was the mode of working for getting out a mass of copper 4½ feet thick, such as had been mentioned.

Mr. BAUERMAN said the masses were formed where there had been cavities in the lode which had been filled with copper. When a mass was met with, the regular plan was first to cut the rock down all along its underside, nearest the footwall of the lode,—"desuing" the lode, as it was called; and then to go above the mass, and put in a large hole at top, which was filled in with gunpowder and usually tamped with sand. On firing the charge, it made a bigger hole; and the process was repeated until a large piece of the mass was broken off. That was before the days of dynamite. Chisels were next used for further cutting up the piece broken off, by chipping grooves across it; and that was the great difficulty, because it was always necessary to have at hand two sets of chisels of different tempers, on account of the irregular pieces of quartz and other minerals that were found in the mass of copper. The cutting was slow work in consequence. The chisel cuttings exhibited by the author were remarkably clean; and in such cases the difficulty was not so great, because the chisels, being properly tempered for cutting the copper, would stand much longer when they did not suddenly encounter pieces of stone imbedded in the copper. When the broken mass had been cut up into pieces of about a ton or a ton and a half, a chain from the winding engine at the surface was brought down the shaft and along the level, and by means of levers was got round the lump, which was thereby hauled into the level, and along the level to the shaft.

Native silver accompanied the copper, but irregularly, and in no very large proportion. This had always been considered to be very pure; but subsequently to the discovery of mercury in the large crystals of silver at Kongsberg in Norway, that of Lake Superior had

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been examined by Professor Brush, of Yale College, New Haven, Connecticut, and had been found also to contain a little mercury. Even the Lake Superior copper, the purest in the world, was not free from arsenic, of which visible traces could be detected on examination by sufficiently delicate methods. It was also curious to notice that Lake Superior was one of the places, the only other being in Chile, where the native arsenites of copper had been found; it was on the south side of Houghton that they were found some years ago in rather notable quantity, though not enough to affect the native copper near which they were met with. For electric conductivity Lake Superior copper was equal if not superior to the best electrotype copper. The only other metallic mineral found in the district was disulphide of copper, which had been met with at Lac La Belle, in ground apart from that containing the native copper.

Mr. THOMAS SOPWITH congratulated the Institution on the paper that had been read, which he considered would serve as useful reference for engineers who wished for information about the Lake Superior copper district. It showed evidence of much patient labour and careful investigation on the part of the author during the time he had been in that district; and he desired to compliment him also upon the diagrams and the geological specimens by which the paper was illustrated, many of the latter being rare and of great value. Although the subject was essentially one which appealed to mining engineers, it was not difficult to see that mining enterprise conducted on such a scale was largely, if not entirely, dependent upon mechanical engineering; and particulars had been given which were interesting alike to mining and to mechanical engineers. It was evident that no machinery was employed in the mines of Great Britain which could be compared with some of the machines described in the paper, such for instance as the stamping apparatus shown in Plate 11, capable of stamping 150 to 200 tons per day from a large size down to that of particles which would pass through sieves of such fine mesh as those described in the paper; 15 tons in a day would be considered a good performance for the best stamp in use in Cornwall, and from 2 to 3 tons per day for each head of

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(Mr. Thomas Sopwith.)
stamps in ordinary use there. In like manner the rotating table, illustrated in Plate 13, showed marked improvement upon the Zenner and Hunt buddles or tables, which had long been in use in this country. Several of the machines described might well form subjects for interesting papers; and the entire system and arrangement of the mechanical operations as adopted in the Lake Superior copper district elicited his own admiration, as regarded both the mining and extraction of large quantities of material at a minimum cost, and its subsequent treatment, whereby the output of the mine averaging only from 1 to 3 per cent. of copper was separated and classified, until a marketable ore was obtained with a tenure of over 80 per cent. of metallic copper: this difficult operation being conducted on such a scale and with such economy as to leave large profits.

He would take the opportunity of emphasizing the concluding remarks in the paper (page 107), in which attention was called to the fact "that the most successful mines are generally such as are capable of economically treating exceptionally large quantities of ore of a comparatively low percentage, rather than those which yield smaller quantities but of a higher percentage;" to which he would add that, as a rule copper and lead and iron mines had proved more remunerative than gold and silver mines. In this country and on the Continent might be counted by scores copper and lead mines which yielded as much as from 10 to 20 per cent. of the pure metal, as compared with the entire turn-over or output of the mine, and which nevertheless did not pay their working expenses, particularly of late years, when the prices of these metals had been greatly depressed. On the other hand, the Rio Tinto mines in Spain were worked successfully, although the mineral obtained had a tenure of only from 2 to 3 per cent. of copper; and even that small percentage would be reduced by nearly one half, if the entire bulk of overburden which had to be removed was taken into consideration in estimating the whole amount of stuff worked. The successful working of the Lake Superior mines with a similar tenure of copper was described in the paper. At Rio Tinto the pyrites obtained from the mines, in quantities exceeding 1500 tons per day, was all subjected to chemical operations on a gigantic scale, embracing calcination, lixiviation,

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and precipitation, before the copper was obtained; and in the Lake Superior district, where the material to be treated was of a different nature, the valuable product was obtained by purely mechanical operations, as described in the paper. In each case a large margin for profit was left; and taking the value of copper on the spot at £35 per ton, and the average contents of copper in the raw material raised from the mine at 2 per cent., it followed that the raw material could be extracted from the mine, and subsequently concentrated either chemically or mechanically, for less than fourteen shillings per ton. At the Mechernich lead mines in Germany, the largest lead-producing concern in the world, the lead-bearing strata were worked, drawn to surface, and a separation made of lead from material containing only 2 to 3 per cent.; and the operations were on such a scale as to require about 12,000 tons of stuff to be daily transported over the railways in the form of mine matrix, overburden, and waste.

It was evident that such concerns as these could be worked with advantage only by the application of the most perfect mechanical appliances; and the author had done good service to both mining and mechanical engineers in bringing under the notice of the Institution a good typical illustration, such as the Lake Superior copper district, where the most judicious mining operations would fail to ensure success, if they were not followed up with well-contrived mechanical applications, involving, in the ever-varying conditions which existed in different mines, the exercise of mechanical ability of a high order.

It would add to the value of the information furnished in the paper, if the author could further state, in the case of fine copper being produced in the Lake Superior district at a cost of £30 per ton, from mine matrix containing 1½ per cent. of copper, how this cost might be apportioned under each of the four following heads:—firstly, actual mining, that is miners' contract prices for working the ore, inclusive of the cost of current explorations in new galleries, shafts, and winzes; secondly, haulage underground and at surface, and winding; thirdly, dressing or concentration from 1½ per cent. up to 80 per cent.; and fourthly, reduction to fine copper.

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Mr. GEORGE SEYMOUR believed from his own examination that the paper, written by his partner, was thoroughly correct in the details, all of which had been most carefully gone into. The fact alluded to by Mr. Sopwith was perfectly true, namely that the best and most remunerative mines in the world at the present time were those which were working upon a large quantity of material and a relatively low percentage; this was well exemplified by the case mentioned in the paper (page 89) of the Atlantic mine, which was one of the best paying properties on Lake Superior, though its veinstone contained only 0·75 per cent. of copper. That mine contained mineral in very large quantities; and he believed the experience of every mining engineer was that these were the class of mines which paid best. It was easy to find specimens of pure copper, and others that contained high percentages, and even as much as 4 per cent. of silver was not of exceptional occurrence; but the average mine was that which contained a large amount of stuff of a comparatively low percentage. As to the stamps, there were none in this country or in Europe which could compare with the Ball stamps used on Lake Superior; they were the perfection of stamps, and were virtually steam-hammers. Of course the amount of power was very different. In this country a stamp which under favourable circumstances did 1½ tons per day was a good stamp. In America there were stamps which could do as much as from 200 to 220 tons per day; and they did their work perfectly. There was ouly one difficulty which could not be overcome, arising from the circumstance that, while a good deal of the stuff was interspersed with copper, like the specimens exhibited of mineral vein-stuff, there occurred on the other hand large lumps of solid metallic copper also. It was obvious that when these lumps got under the stamp they could not be stamped down to such small sizes as would admit of their passing through the meshes of the gratings; and it was therefore necessary to stop the stamp after a certain time and take the pieces out by hand. The pieces so taken out formed what was called "cover work."

Mr. C. J. APPLEBY, referring to the statement in the paper (page 107) that the Ball stamps did not seem to have been used very

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largely in other districts or at other mines, thought the reason must be that, although these stamps had great crushing power, the yield from the gratings was relatively small, the area of the screens being too limited to admit of the crushed ore passing freely away: so that in fact, although a large mass of ore was crushed, it was churned in the mortar, instead of being rapidly delivered through the gratings. It seemed to him that this objection applied to several kinds of stamping machinery, of less power than the Ball stamp, but based on the same principles of construction. He had frequently watched these machines at work, and had come to the conclusion that the volume of stuff crushed in a very limited area was much too large to pass freely away; and that the defect of the system was that it was almost impossible to provide a surface of grate large enough for the stamping capacity. He had had more experience with machinery for treating gold and silver than with that for crushing copper ore; but the principle was the same in both cases, namely that the pulp should be delivered from the mortars to the amalgamators as quickly as possible. It seemed to him that this result was obtained by the use of a large number of stamps with ample grate-area; and the balance of advantages he felt sure would be found in this system, rather than in that described in the paper. The use of mills of the old Cornish type was not what he advocated; but the revolving gravitation stamps, such as were used in California and Australia. He was surprised to see cast-iron so largely employed in the Ball stamp itself, and still more so that the stamp-shoe and anvil were made of that metal. Having himself been the first he believed to use steel shoes and dies, his experience proved that when these were made of forged steel of proper quality they lasted longer than any others, and were cheaper in the long run, notwithstanding their higher first cost; steel was now being used in many mills in the United States and elsewhere, and he did not know why it should not be used in the Lake Superior district.

The general arrangement of the dressing mill, shown in Plate 10, seemed to him to be almost as perfect as it could be. It had been mentioned by Mr. Sopwith that operations of this kind were

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(Mr. C. J. Appleby.)
carried out on a much larger scale in the United States than in England; and that was equally true in regard to some of the Colonies, where also were to be found some wonderful illustrations of the seemingly paradoxical remark already made by previous speakers, that as a rule poor mines paid the best. Some of the best paying gold mines in Victoria were averaging only 2 or 2½ pennyweights of gold to the ton of stone crushed; and of course therefore the quantity of stuff to be dressed was enormous, amounting to as much as 300,000 times the weight of the gold obtained. The mills employed on those mines were as well laid out for the work they had to do as the copper mill here shown, which he regarded as being almost perfect. The rotating table with the spiral apron appeared to him an admirable contrivance. No doubt the ordinary Cornish buddle was an excellent separator when carefully worked; and it was quite possible that a difficulty in obtaining men who would be sufficiently careful and attentive had led to the ingenious and simple device of the spiral apron.

Professor RYAN asked whether native copper was as hard as the copper produced by metallurgical processes, and whether there was any variation in its hardness. Tools for working copper he understood had been sent from this country to the Lake Superior mines, and had proved unsuitable; and he should be glad to learn whether that was owing to the hardness of the native copper itself. There was a tradition from pre-historic times that some method of hardening copper had been practised among the nations of antiquity; and it would be interesting to know whether native copper, which was presumably the kind they used, ever possessed such a degree of hardness as might account for the origin of that notion. With regard to the stamp-shoes of chilled cast-iron lasting from one to three weeks only, he presumed they failed by fracture, in which case forged steel would be likely to stand the same work much longer. The discovery that some native silver contained traces of mercury seemed to him to suggest that possibly the formation of native silver in those cases had been by the process of amalgamation, and that the mercury had afterwards been evaporated, with the exception only

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of the minute traces now discovered. As to the copper refuse left at mines in Cornwall, he presumed it was regarded as refuse on account of its requiring to undergo the chemical process of smelting, which would be very expensive in comparison with the mere mechanical process of freeing the native copper from the gangue.

The stratigraphical features of the district, as described in the paper and pourtrayed in the map by which it was illustrated, appeared to him to present very many points of interest; but as these hardly came within the scope of mechanical engineering, he felt reluctantly compelled to forego numerous questions which he should otherwise have been tempted to ask.

Mr. RATHBONE, in reply, said the reason why the refuse heaps in Cornwall were not treated in the same way as the poorest stuff at Lake Superior was because they consisted of copper pyrites, which was a sulphide of copper, containing only one-third of metallic copper, and especially requiring moreover to undergo the expensive operation of smelting. Consequently, although the percentage of copper might not be lower than at Lake Superior, the treatment was utterly different. The veinstone at Lake Superior contained native copper, which was practically pure, and did not require any roasting in order to drive off the sulphur or to separate it from the iron pyrites and other impurities which were almost invariably associated with copper pyrites. The native copper was tough, whereas the copper pyrites was brittle; and this was another reason why the Ball stamp was peculiarly suitable for the stone containing native copper.

The question of fissure veins was one about which there had been a considerable amount of discussion; it was a point of great importance, but involving too much geological detail to be now entered into at length.

Having analysed in accordance with Mr. Sopwith's suggestion the details of working expenses in the Lake Superior copper district, in the treatment of ore containing 1½ per cent. of copper, and the production from it of bar copper at a total cost of £30 per ton, he had arrived at the following apportionment of this total cost:—

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(Mr. Rathbone.)
mining £14 4*s.*, surface and general expenses £7 4*s.*, milling £4 10*s.*, smelting £4 2*s.*; total £30 per ton of fine copper.

With regard to the ordinary Californian stamp referred to by Mr. Appleby, it certainly had a much better discharge than the Ball stamp, for the simple reason that the discharging surfaces were so much larger; in other words, a larger number of small stamps being employed, their discharging surfaces bore a larger proportion to the quantity of the stuff stamped. It should be remembered however that their wearing parts were much greater. The Ball stamp was one big stamp, instead of a number, and every wearing part of it could be changed quickly; whereas the Californian stamp, such as that used at the Quincy mill, was continually wearing, and was frequently in the shop for repairs; it was not so suitable as the Ball stamp for the hard rock at Lake Superior, such as the conglomerates, which were so very hard that the wear and tear of the plant was sometimes very great. The only other material for which he thought the Ball stamp would be suitable would be native gold, were there ever to be found sufficiently large deposits of low-grade ores where the metal was evenly disseminated throughout the veinstone. The only objection to its use in such a case would be from the fear of valuable material being lost. Just as there was leaf-gold, so was there also leaf-copper; and this was a source of serious loss at the present time at Lake Superior. At the Calumet and Hecla mines, as much as one per cent. of copper was said to be lost in the leaf-copper that floated off. Some ingenious apparatus had been made for the purpose of rolling the leaf-copper in a sort of pug mill, whereby it was rolled into small pellets, of which specimens were exhibited; the result was that it could then be jigged. Owing to the very large area of surface in leaf-copper, it floated off in the stream of water, and was lost; and although the specific gravity was not increased when it was rolled into pellets, the surface area was diminished, and it then sank easily in the jigs. The adaptation of such an apparatus to leaf-gold would of course require great care, in consideration of the value of the material. At the present time he believed one of the great difficulties at the Transvaal gold mines was to save the flour-gold or leaf-gold, just as it was at Lake Superior with the leaf-copper; blankets had been

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tried, as well as other means, but without success. If a delicate apparatus could be used for rolling the leaf-gold into pellets, he thought the difficulty might be overcome.

In regard to the very numerous points of geological interest in the Lake Superior district, these were elaborately dealt with in the transactions of the Geological Survey of Michigan, in which a special treatise was devoted to the upper peninsula, and the copper-bearing and palæozoic rocks of Lake Superior were elaborately described by Professor Raphael Pumpelly and Dr. C. Rominger.

The PRESIDENT considered the statement made in the concluding portion of the paper was of particular interest to mechanical engineers, namely that it paid to work the mines in question, because such exceptionally large quantities of material containing a comparatively low percentage of copper could be treated economically. This showed that by a sufficient exercise of mechanical ingenuity it might often be possible to utilise what were considered waste materials. The Members he was sure would desire to pass a hearty vote of thanks to Mr. Rathbone for his paper, upon which it was evident he must have expended a large amount of time and thought, as well as upon the preparation of the extensive diagrams by which it was so well illustrated.

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NOTES ON THE PUMPING ENGINES AT THE LINCOLN WATER WORKS.

BY MR. HENRY TEAGUE, ENGINEER OF THE WORKS.

On the occasion of the visit of the Members to the Lincoln Water Works at the Summer Meeting of the Institution in 1885 (Proceedings 1885, page 446), a good deal of interest was manifested in regard to various mechanical details in connection with the Pumping Engines, respecting which numerous enquiries were made both at the time and subsequently. Having been requested to furnish some particulars respecting these details and the reasons for their adoption and the experience of their practical working, the author has much pleasure in complying with the request by offering the following notes.

Sims' Compound Engine.—The first pumping engine was erected in 1848. This is the original compound engine first constructed on Sims' plan, having the high and low pressure cylinders continuous with each other, as shown in Fig. 1, Plate 14. It had been made in 1836 by Messrs. Harvey, Hayle Foundry, Cornwall; and had been working on two Cornish mines before its removal to Lincoln. A 25-inch cylinder is fixed on the top of a 50-inch cylinder, and the two pistons are on one piston-rod, the space between them being at all times open to the condenser. The length of stroke is 8 feet, and the 12-inch plunger-pump at the other end of the beam has a stroke of 7 feet. The valve arrangements are the same as those of an ordinary single-cylinder Cornish engine.

Balance Valve.—The pump works against a pressure equal to 350 feet head of water, the city drawing its supply direct from the pumping main. When a main pipe burst or a hydrant was opened quickly, it was found that the catch-pins came down too heavily

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on the spring-beams. To avoid this, the author in the autumn of 1848 fixed in the main delivery pipe from the pump a balance valve of the construction shown in Fig. 10, Plate 16. The valve D is a flat disc on a vertical spindle, closing upon a seating below; and is held open by two spiral springs S, pressing against a crosshead H upon the spindle above the stuffing-box. The upper end of the spindle is screwed, and fitted with a nut N above the crosshead H, by means of which the compression of the springs is adjusted to the required amount for holding the valve open to the extent desired, against the current of water flowing downwards through it from the pump, as indicated by the arrows. Any increase in the velocity of flow tends to close the valve. On the top of the spindle is a second nut M, which can be adjusted to drop upon the crossbar B, so as either to limit the valve to partial closing, when it is desired to let the engine continue working on, or else to allow the valve to close entirely; in the latter case the lower nut N can be screwed up against the underside of the crossbar B for holding the valve down securely on its seat. The valve-spindle being of brass and only 1½ inches diameter, there is but little friction in the stuffing-box; and the valve has consequently been found to be far more sensitive than the double-beat and treble-beat valves usually adopted, which by their friction on their centre pole or guide pin are caused to be much too slow in action.

Exhaust and Equilibrium Valve Catches.—To be as safe as possible, and hold the engine at either end of the stroke whenever the catch-pins strike the spring-beams, catches were at the same time applied to the shafts of the exhaust and equilibrium valves, as shown in Fig. 11, Plate 17. This view illustrates the case in which either the steam valve or the top delivery clack of the pump has failed to close as promptly as it ought to do, and the pressure of steam has consequently been in excess of the load in the indoor or downstroke of the pistons; the upper tappet T on the plug rod P has consequently depressed the handle of the exhaust shaft E so far that the bottom catch C has caught; and it will so remain, holding the exhaust valve shut, until released by the engine-man. The steam catch is liberated by a rod and lever fixed on the exhaust shaft;

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consequently its liberation is prevented, and the steam valve also is held shut, until the bottom catch C is released. The top catch on the equilibrium shaft Q acts in a similar manner whenever there is a decrease of load in the upstroke of the pistons; the lower tappet on the plug rod then lifts the handle of the shaft Q so high that the catch becomes caught, and holds the equilibrium valve shut until released by hand. These catches the author has found invaluable, the engine being caught and held stationary after the next single outdoor or indoor stroke, until they are released by the engine-man; and ever since 1848 he has applied them to all the pumping engines he has had erected in different towns. Instead of letting the engine make the next single stroke before stopping, there is no difficulty in arranging catches to hold the engine instantly (Proceedings 1853, page 112), and it was so intended at first; but on further consideration it was thought no damage would be done by the engine making the next single stroke in the opposite direction, and this view has held good in practice, the present simple method above described having been found to be all that is required. The opening of the valves is effected in the ordinary way by weights.

Combined Bucket and Plunger Pump.—In 1852 a small auxiliary engine was erected, and the question arose as to the best kind of pump to be adopted. After some consideration a combined bucket and plunger pump was decided upon, having an 11¼-inch bucket and an 8-inch plunger, with a stroke of 2½ feet. In working it was found that, in consequence of the contracted water-way through the bucket clack, it made a great noise both in opening and in closing; and the author therefore determined that, if he ever had to fix another combined pump, he would substitute a piston instead of the bucket, and provide a clear water-way both in the suction clack and in the delivery clack. The idea of the combined bucket and plunger pump he believes to have originated with Smeaton, though claimed by many others subsequently; indeed even as late as three years after the author's own application of it at Lincoln it was twice announced as a new idea. Naturally to an observer watching the delivery head of an ordinary bucket-pump, when the

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large wooden pump-rods were in use, it required no very great stretch of imagination to apply the plunger in combination with the bucket, seeing that in the descent of the rod a volume of water equal to its own bulk was displaced.

Combined Piston and Plunger Pump.—In 1862, being in want of more pumping power, it occurred to the author that, as the city draws its supply direct from the main and only the surplus is delivered into the reservoir, a double-acting fly-wheel engine would not be so much affected by a sudden withdrawal of water as the ordinary single-acting beam engine. A 36-inch single-cylinder double-acting engine with 8 feet stroke, and with six double-beat valves for the steam distribution—two steam, two expansion, and two exhaust,—was accordingly erected, as shown in Fig. 3, Plate 15, having been made by Messrs. Williams, Perran Foundry, Cornwall. To this engine was applied a combined piston and plunger pump, shown in Figs. 4 and 5, possibly the first of the kind, having a 12¾-inch piston and a 9-inch plunger, with a stroke of 7 feet; the valves were Harvey and West's double-beat clacks of 14 inches diameter (Proceedings 1858, Plate 61, Fig. 1). The fly-wheel was placed intermediate between the pump and the beam centre, the crank having a stroke of 4¾ feet. The action of this engine was satisfactory, with the exception of the heavy beating of a single-flap clack in a 15-inch bucket lift with a head of 20 feet for raising the water on to the filter beds.

Relief or Break Clack.—For obviating the annoyance of this concussion, without incurring the expense of a double-beat clack for such a situation, the author began to devise some simple remedy. A 4-inch break-valve he was aware had been applied by Mr. Gribble at the beginning of the present century to a 16-inch exhaust valve in a pumping engine with 91-inch cylinder at the United Mines, Cornwall; it was quite a success, and is sketched from memory in Figs. 6 and 7, Plate 16, showing both valves closed. The long slots in the lugs on the large valve allowed the small valve to open first, which was found a great benefit in relieving the load on the large valve. On the other hand the author knew that the pyramid of

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clacks, sketched from memory in Fig. 8, Plate 16, had practically failed; and no better result had attended the treble clack (Proceedings 1858, Plate 61, Fig. 3) designed by Mr. R. Jenkyn, of Copperhouse Foundry, Hayle, in which three separate rings were hung one upon another, but all hinged on the same side. In regard to the last, it occurred to the author that the reason of the failure lay in the three clacks being all hung on the same side; and that, had they been hung alternately on opposite sides, the desired aim of obviating concussion would have been accomplished. To test the correctness of this view, the 15-inch clack was removed early in 1863, and one-third of its area was cut out in the centre of the flap; the aperture so made was covered with a supplementary leather clack hinged upon the main clack at the edge opposite to the main hinge, as shown in Figs. 12 and 13, Plate 17. By this means the concussion was so completely prevented, that on placing the hand or ear in contact with the clack box not the least tremor or sound was perceptible, and the time of closing could not be detected. The leather of the small supplementary clack continued in constant action for seven years before requiring to be changed, and that of the main clack for thirteen years. In 1866, when the Harvey and West double-beat valves in the 14-inch main pump began to leak, the author replaced them with leather break-clacks of this construction, whereby the action of the pump was greatly improved, as shown by the two pairs of diagrams in Figs. 14 and 15, Plate 17, which were both taken under similar circumstances when the pump was travelling at 160 feet per minute. These diagrams were taken with a McNaught indicator having a spring of 10 lbs. per inch of range. Fig. 14 shows the vacuum above the clacks, which at the commencement of the stroke is 5½ lbs. per square inch for the break-clack, as shown by the full line, and 7 lbs. for the double-beat valve, as shown by the dotted line; Fig. 15 shows the vacuum below the clacks, which began at 4 lbs. per square inch in each case. The suction pipe is 13 inches diameter, and runs 40 feet horizontally from the pump before dipping into the tank, in which the water level at the time of taking the diagrams was 6 feet below the bottom clack. In taking a number of diagrams similar to those

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shown in Figs. 14 and 15, it was found that scarcely any two were exactly alike. This was attributed in most instances to the undulatory motion of the water in the tank from which it was being pumped; the tank was 70 feet long by 40 feet wide, and the undulation was sufficient at times to raise the indicated line above the atmospheric line at the finish, as shown by the thin full line at A in Fig. 15. In some pumps with a vacuum of about 7 lbs. per square inch or 16 feet head of water at the commencement of the upstroke, the indicated line has been raised several feet above the atmospheric line at the finish. To obviate this evil with a long horizontal suction-pipe, it occurred to the author in 1852 to interpose at the foot of the pump a large air-tight box or vacuum vessel, for the long horizontal suction-pipe to deliver into; the vessel contains sufficient vacant space to spare for taking up the fluctuations of the water, which are thereby prevented from affecting the working of the pump. This addition has been found to answer the purpose thoroughly, the pumps working with the greatest ease when so supplemented. The author was led to the introduction of the vacuum vessel in consequence of being consulted about a 4-inch hand-pump, to which had been laid a 2-inch suction-pipe of 480 yards length, with a vertical dip of 8 feet at the well end; although the pipe was filled at starting, the pump would not draw any water, until he added a vacuum vessel of six times the cubic content of the pump. This rendered the action so easy that a boy could work it. On the construction of the Gainsborough Water Works in 1866, the vacuum vessel was called into requisition for a 12-inch plunger-pump, supplied from the river by a 10-inch suction-pipe of 1000 feet length; the pipe runs 425 feet horizontally from the river, then rises 16 feet, and thence runs 575 feet horizontally to the pump. In several other instances the vacuum vessel has been applied with equally good results.

The break-clacks, Figs. 12 and 13, work incessantly for five years without changing a leather, and without showing the least sign of leakage, under 350 feet head of water or 150 lbs. per square inch; and there is not the slightest concussion, the time of closing not being perceptible. For a velocity of 160 feet per minute of the pump the

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author has found the weight of the flap should be about 2 lbs. per square inch. On the top of the second or supplementary clack a third of still smaller diameter can be applied, and even a fourth or more, hung alternately on opposite sides.

In 1884, when it was found that still further pumping power was required, the author decided to revert to the Cornish pumping engine, notwithstanding the consideration which had previously led him to choose a double-acting fly-wheel engine in 1862—namely that the city draws its supply direct from the main. For the experience gained from the working of the Cornish pumping engines which he had erected in the interval at Grantham, Maidstone, and other places, had convinced him that the cost of coals and repairs had been reduced in some instances to as low as only one-sixth of the annual expenditure pertaining to rotatory pumping engines previously in use there. The new Cornish pumping engine accordingly procured from Messrs. Harvey, Hayle Foundry, was started in March 1885, and is shown in Fig. 2, Plate 14; its action has been all that could be desired, while the saving of coal has been no less than 543 tons in ten months. The cylinder is 58 inches diameter and 9½ feet stroke; the plunger is 18 inches diameter and 8 feet stroke, with three of Harvey and West's double-beat clacks. The main girders and spring-beams are of wrought-iron, with india-rubber buffers to receive the catch-pins. Every joint in the cylinder, and in the steam, feed, and other pipes, and also in the pump work, is faced; and all are bolted together, iron to iron, with only thin paint between. The shafts of the exhaust and equilibrium valves are fitted with the useful catches previously mentioned. In the equilibrium pipe is placed a check throttle-valve V, Fig. 11, Plate 17, which is adjusted by a hand-wheel W according to the proper load from time to time upon the engine (Proceedings 1853, page 111, and Plate 25, Fig. 4). This keeps the speed of the engine under perfect control in the outdoor or upstroke of the piston, against any ordinary fluctuations in the load. The valve is opened wider whenever the load is permanently increased, and is closed further if the load is reduced; the range of load is from 220 to 350 feet head

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of water. The delivery main from the pump is fitted with Husband's balance valve, Fig. 9, Plate 16, which is a double-beat valve loaded with an adjustable dead-weight; but owing to the friction of the stuffing-box round the plunger of 8 inches diameter attached to the valve, this is not found to be so sensitive as the balance valve previously adopted by the author, which is adjusted by springs, as already described.

Coal Consumption.—The Sims' compound engine and the 36-inch double-acting fly-wheel engine are found to consume about 4 lbs. of coal per horse-power per hour for actual work done. The 58-inch Cornish engine consumes 3·14 lbs. per horse-power per hour in the ordinary course of working, without any special arrangements being made for a test. The coal used is the Nottinghamshire and Derbyshire slack; its evaporative duty the author believes does not much exceed 7 lbs. of water per lb. of slack, and varies between that amount and only two-thirds as much; its efficiency is therefore not to be compared with that of Welsh coal.

About 1½ miles west of the city, and a mile west of the filter beds and pumping station, is the impounding reservoir of 23 acres area, which forms an ornamental lake in the grounds of Hartsholme Hall. On the Cross o' Cliff hill, 1¼ mile south of the pumping station and near the county asylum, is an open service reservoir holding 1½ million gallons. On the opposite hill, 2 miles north of the pumping station and near the cathedral, is another open service reservoir holding 800,000 gallons, into which the pumping main delivers over a standpipe. When the consumption below hill is greater than the quantity pumped by the main engines, no water will rise over the standpipe; this occurs not only in extremely hot weather, but also on very cold days, when taps are left running to waste in order to prevent freezing. A 6 HP. gas engine is therefore provided for pumping back over the standpipe out of the reservoir, to supply the upper part of the houses situated on the top of the hill; and there is a back-pressure valve on the crown of the hill, for preventing the water so pumped back from flowing down the main below hill.

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Sewage Pumping Engines.—At the sewage pumping station, situated in the valley about half a mile east of the city, the sewage is pumped up and delivered on to the corporation farm by a pair of vertical compound engines made by Messrs. Hathorn Davey and Co., Leeds. The high-pressure cylinders are 15 inches diameter, and the low-pressure 30 inches diameter, the length of stroke being 5 feet. The plunger pumps are 22 inches diameter with 5 feet stroke. The feature that recommended these engines was the differential gear for catching the engine in case of the fouling of the clacks or bursting of a main.

Discussion.

Mr. WILLIAM B. BRYAN, engineer of the East London Water Works, said that he had under his care at Old Ford the first Cornish engine ever made for waterworks purposes. It had now been at work forty-nine years, and not a single improvement as regarded efficiency had been made upon it in any subsequent Cornish engines for waterworks, including the new Cornish pumping engine described in the paper and started in 1885 at the Lincoln Water Works. He had himself thought that Cornish engines had become things of the past for waterworks purposes. Having under his care Cornish engines capable of lifting 108 million gallons daily, he was in a position to say that they were sources of very great anxiety. It was true they worked very well, magnificently in some respects; but the engine-driver was never allowed to leave his post. The work was very economical; nominally 21 lbs. of feed-water per horse-power per hour was the average quantity used, working the week through. From some tests lately taken he had found 320 heat-units per minute per horse-power were passing away from the hot-well of the condenser. The duty was very deceptive, because while pumping

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into mains the pressure would often fall 30 or 40 per cent. The load was precisely the same for a high lift as for a low lift; consequently the nominal consumption of 21 lbs. of feed-water, if estimated in the work actually done, might become 28 or 30 lbs. per horse-power per hour. The intermittent action of the flow was also very trying to the joints in the water-pipes. No matter how carefully it was endeavoured to prevent this by means of air-vessels or stand-pipes, it still would occur. With regard to the suction-boxes upon the long suction-mains, referred to in the paper (page 129), he knew of some suction-pipes 4000 feet long, which were without suction-boxes, and they worked very well; the pumps were three-throw pumps drawing direct from the pipes, and to his own knowledge there had been no difficulty within the last ten years. It appeared to him that one of the most perfect pumping engines for pumping direct into the mains was the high-duty Worthington engine, in which the steam used was always exactly proportional to the weight of water to be lifted. For lifting water from deep wells, he thought the compound direct-acting engine of Mr. Davey was also one of the best. The Cornish engine had no doubt done very fine duty; but he was much astonished to find that a new one had been put to work in the year 1885.

With regard to the combined bucket and plunger pump, with which it was mentioned in the paper (page 126) that a difficulty had been experienced in getting sufficient water-way through the bucket clack, he had himself found that if a double-beat valve was used on the bucket, instead of a clack, there was not the slightest difficulty. Under his own care two compound engines with bucket and plunger pumps, built by Messrs. Simpson ten years ago, were working splendidly at a very high piston-speed, and no such difficulty as that experienced by the author had ever occurred. Of the valves shown in the drawings, he thought some were rather crude. The double-beat valve and the four-beat valve, used by Messrs. Harvey and West, and invented by Mr. Husband or Mr. West, acted most perfectly in all the engines under his own charge, and no difficulty had ever occurred; he considered them the best kind of valve for very large pumping engines.

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Mr. J. W. RESTLER, engineer of the Southwark and Vauxhall Water Works, had thirteen Cornish engines with cylinders varying from 36 to 112 inches diameter and working against heads varying from 80 to 350 feet. Where the pressures remained constant, they were of course working at their best; but in the case of eight of the engines, the head against which they had to pump varied about 80 feet in the 24 hours, owing to the exigencies of the supply; and as the engines had to be weighted sufficiently to overcome the maximum head, there must in such cases be always a considerable loss of efficiency. They were thus he thought unsuited for districts where the supply was taken direct from the pumping mains, in which the draught and consequently the pressure were continually fluctuating. To keep the pressure constant, it was necessary that the speed of the engines should be continually varying; and in order to accomplish this object in the most economical manner, he was now having fitted to the expansion gear of two pairs of 600 H.P. direct-acting compound engines a governor actuated by the pressure in the main, which would automatically vary the degree of expansion in exact proportion to the work the engine was at the moment called upon to perform. These engines were working with a steam pressure of 100 lbs. per square inch, and were taking over the work formerly done by a pair of 80-inch Cornish beam-engines working with a boiler pressure of 40 lbs. The duty obtained from the compound engines showed a saving equal to at least 50 per cent. over the Cornish. The satisfactory nature of these results had led him to design for the new works now under construction a pair of quadruple-expansion engines, which were intended to work with a steam pressure of 200 lbs. per square inch. They were to draw the supply for their pumps directly from a main in which the pressure varied from 50 to 200 feet head; and to deliver against a head varying from 250 to 400 feet. This wide range of work would be automatically adjusted by a governor, which would be actuated by the pressure in both suction and delivery mains, and which would act on the expansion gear in the same manner as the governor used for the compound engines. In both cases ordinary high-speed governors driven from the crank-shafts were also fitted

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to act upon a throttle-valve, so as to check the engines in the event of accident to either main.

Mr. EDMUND L. MORRIS, engine superintendent of the New River Water Works, observed that the plan of fitting safety-catches to the exhaust and equilibrium valves, for preventing the engine from going in or out too violently, was mentioned in the paper (page 125) as having been adopted about the year 1848 for the Sims compound engine at Lincoln. Some engines under his charge at the New River Water Works, which had been built by Boulton and Watt in 1812, and altered before 1850, had had those safety-catches fitted on them at the time of the alteration. Previously they had cataracts for controlling both the outdoor and the indoor stroke; that for the outdoor stroke was removed, and a safety-catch put on in its place. The man who came from Boulton and Watt to fit the catches did not quite know how to do it, and went down to the East London Water Works to see how it should be done; the safety-catches must therefore have been in regular use there at that time. There was also under his care an engine put up in 1824, and another in 1847, fitted with vacuum-vessels on the suction-pipes, exactly similar to that described in the paper (page 129); so it would appear that these devices were already in use before their adoption by the author.

With regard to the experience gained by the author from Cornish pumping engines at Grantham, Maidstone, and other places, which had convinced him that the cost of coals and repairs had been reduced to only one-sixth of the annual expenditure pertaining to rotatory pumping engines previously in use there (page 130), it was difficult without seeing the actual figures to understand how such a conclusion could have been arrived at. Later on it appeared (page 131) that, while the rotatory engine at Lincoln used 4 lbs. of coal per horse-power per hour, the Cornish engine used only 3·14 lbs.; but this was not even 25 per cent. difference, much less did it approach a saving of five-sixths. It would seem as though the rotatory pumping engines replaced by the author at the towns referred to must have been defective in their pump-valves, and must have been attended with considerable expense in consequence of

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(Mr. Edmund L. Morris.)
break-downs; otherwise he did not see how the expense could have been so much more. From his experience he had found rotatory engines cheaper to work than Cornish. He considered Boulton and Watt engines better for pumping into mains than Cornish, on account of the former having only to pump against the actual head at any given time, instead of having—as was necessary in the case of the Cornish engine—to raise always a weight sufficient to overcome the greatest head, which might be required for only a portion of each day's work. But a direct-acting rotatory engine he thought was better than either, because, in addition to its greater economy in working, it could generally be stopped before it sustained any damage when a burst occurred in the pumping main. A pair of single-cylinder rotative engines of 400 horse-power, erected at the New River Works over thirty years ago, which were very celebrated at the time, had had cylinders 60 inches diameter and 8 feet stroke, using steam of 40 lbs. pressure cut off at 1–14th of the stroke. It could be imagined at what a pace they would have come in, had it not been for the cranks and the fly-wheel, and what an enormous blow there must have been on the piston at the beginning of the stroke. The result had been that the crank shaft had gradually given way, and when taken out was found to be twisted like a bundle of sticks. The weight of the fly-wheel was excessive; and to this, coupled with the high initial blow of the steam in the cylinders, the failure of the shaft might no doubt be attributed. This instance showed that, apart from other reasons, it was not advisable to carry expansion too far in one cylinder. These cylinders were now being taken out, and the engines compounded, and fitted with a lighter fly-wheel and a starting engine; and very satisfactory results were anticipated from the alteration. Some compound engines erected at the same time as those just mentioned had worked well ever since, and in comparison with their horse-power had fly-wheels of half the weight that was at the time considered necessary for the single-cylinder engines. Instead of the quadruple-expansion engines that had been mentioned, he should himself prefer a triple-expansion engine with three bucket-and-plunger or piston-and-plunger pumps, which he believed would give a more favourable flow for the water.

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Mr. EDWARD B. MARTEN, Member of Council, thought it was a very useful thing that when the Members went to the summer meetings of the Institution they were furnished at the time with descriptions of the works that were to be visited. It was the description so furnished of the Lincoln Water Works that had induced him to go and visit them on the occasion of the summer meeting there in 1885; and he had been surprised to find the sequence of the engines as they stood there, and could not quite see the reason of that sequence. He could understand well enough why the Sims engine had been difficult to pump with into the main, and why the author had subsequently adopted the rotatory pumping engine; but afterwards it did not seem so clear why he should have reverted to the Cornish engine, with all the difficulties that were so well known to belong to it where the main was constantly subject to being drawn upon, in consequence of the reservoir being on the opposite side of the town to the engines. The present paper was the result of questions which he had asked after visiting the works, and which had elicited the interesting details and practical records so obligingly furnished by the author from his long and varied experience. He was glad to have in the paper so good an illustration and description of what a Cornish engine could do, and also what it could not do.

Mr. JOHN G. MAIR thought the clearest statement that the Cornish engine was unfitted for pumping under varying pressures —as in cases where the service supplies were being drawn from the main — was to be found in a lecture by Sir Frederick Bramwell on the steam engine and its work:* in which it was said that, except for the purpose of pumping into a reservoir, where the head of water was nearly constant, and the engine was then in the same condition as in pumping from a deep well, he was of opinion that the employment of the Cornish engine for waterworks purposes was an entire mistake. In conformity with that opinion, he thought that, where the author had to pump into a main in which there was a varying pressure—as was evidenced by the fact that he had

* Science Lectures at South Kensington, vol. 1, 1878, page 154.

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(Mr. John G. Mair.)
to put a balance-valve to pump through, and that he was also obliged to put a throttle-valve into the equilibrium-pipe leading from the top to the bottom of the cylinder—it would have been better to adopt a different type of engine. But it appeared from the paper that his experience with the rotative engine had not been very satisfactory—a result totally different from the usual experience.

With regard to the quantity of feed-water used, it had been stated by Mr. Bryan that the Cornish engines at Old Ford used 21 lbs. of feed-water per indicated horse-power per hour; and Mr. Greaves' valuable paper read before the Institution twenty-five years ago (Proceedings 1862, page 157) gave 26 lbs. per hour, per horse-power measured in the main, as the amount of feed-water used by the Cornish engine pumping into the mains at Old Ford over long periods of working, exclusive of the jacket condensation, which was returned by gravity to the boiler. A rotative engine doing the same work would use from 18 to 20 lbs. of feed-water per hour, per horse-power in the main: so that there was a saving of at least from 25 to 30 per cent. At the West Middlesex Water Works, where Cornish engines had been working for some time, three compound engines had lately been put up with 47½-inch cylinders and 8-feet stroke; and with each compound engine there was a saving in coals of about £350 a year over the consumption with the previous Cornish engines.

No doubt the Cornish engine was exceedingly valuable for pumping out a deep mine; but for surface pumping, especially for pumping into a main, it was better to pump with an engine that gave a more uniform flow. Any form of single-acting engine, used by itself alone for doing the work, gave necessarily an intermittent flow; and in such a case uniformity of flow must be made up simply by means of an air-vessel. Though not properly intermittent, the flow from a rotative engine was a varying one; the motion of the pump piston was exactly the same as the motion of the steam piston, and, both being controlled by the fly-wheel, the curve representing the velocity of flow was simply a curve of sines, as shown in Fig. 16, Plate 18. The only kind of engine that he knew of, which would deliver anything

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like a uniform flow of water, was that which had now been introduced into this country under the name of the Worthington engine, consisting of a pair of engines laid side by side, in which the steam-valve of each in turn was actuated by its fellow. The flow of water coming from these engines was represented in Fig. 18, Plate 18, from which it would be seen that, when the flow from one engine was beginning to die away, the other engine took up its share of the work, and went on with it until its own turn came for dying away, when the first engine again followed suit; the moment the pressure in the main began to be relieved from one engine, the other engine went on again and maintained it. It was often alleged that two rotative engines coupled by cranks at right angles would give a uniform flow of water; but it would be seen from Fig. 17 that the mere superimposed reduplication thus obtained of the curve of flow from a single rotative engine (Fig. 16) simply gave a succession of humps of rather smaller magnitude for the double quantity of water delivered; and these inequalities had still to be taken up by the air-vessel. The Worthington engine he had seen pumping through 30 miles of main, where the friction alone amounted to 1000 lbs. per square inch on the pump. Now if the flow of water were to vary at all in so long a main, considering that nearly the whole pressure was due to friction, the slightest increase in speed would cause the pressure to increase to such an extent that the result would be to burst the mains; and this was exactly what had been found to be the case, when engines of other types than the Worthington had been used.

Mr. HENRY DAVEY, in connection with the uniform flow of water through a main from a pumping engine, referred to the pair of pumping engines he had put up thirteen years ago at the Clay Cross colliery near Chesterfield, which were placed at the bottom of the Morton pit for forcing water in one direct lift of 950 feet to the surface (Proceedings 1874, page 270). Those engines had been working almost night and day from that time to the present. The theory that he had advanced in connection with them to the late Mr. Howe, the engineer of the colliery, was that without any air-

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(Mr. Henry Davey.)
vessel they would deliver a uniform flow of water through the main to the surface, provided they were not coupled in any way whatever beyond merely delivering into the main at the same level; and they had been found to do exactly as predicted. They were in fact direct-acting steam-pumps; their valve-gears were not coupled in any way whatever, but they were left free to take what course they chose; there was a separate steam stop-valve for each engine. At first the engines began to work as if they hesitated about it, but they soon took up a motion following the line of least resistance, and so fell into a way of working which gave a perfectly uniform flow. It was easily seen why it should be so: both pistons were exposed to the same steam-pressure, and if one engine moved a good deal faster than the other it imposed an extra resistance on the second engine, which consequently lagged; and so, left to themselves, of their own free will they took the line of least resistance. The second engine began to move before the first engine had completed its stroke; and the action described as produced by the Worthington engine was obtained without any coupling of the valve-gears. The result would not be so perfect with an air-vessel; and in his own practice in putting pumping engines underground to force the water to the surface he had never used air-vessels, except in the case of rotative engines.

The PRESIDENT was sure the Members would join with him, not only in passing a vote of thanks to the author, but also in regretting that he was prevented by illness from being present. In his unavoidable absence he was very glad that the engineers of some of the extensive waterworks in London had been able to come and join in the discussion. He had great pleasure in proposing a hearty vote of thanks to Mr. Teague for his interesting paper.

Mr. HENRY J. MARTEN wrote that from the statements given in the paper (page 130) he inferred that the rotatory pumping engines which the author had replaced by Cornish engines with so great an economy

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in fuel and repairs must have been of a very inferior kind, and certainly not fairly comparable with properly constructed rotatory engines such as those turned out by the best makers. In his own experience he had found only a very slight difference in the duty performed by the two classes of engines; and his preference for either one or the other was guided by the special circumstances connected with each case.

With regard to the combined bucket and plunger pump mentioned (page 126) as having been applied by the author to an auxiliary engine at Lincoln in 1852, it was a curious coincidence that in the same year a pump of that description had been constructed for the Bridgnorth Corporation Water Works by himself and his brother, Mr. Edward B. Marten, having been designed by them about a year previously. The idea, as in Mr. Teague's case, had been taken from the little lift-pump sketched in Smeaton's experimental enquiry into water wheels, in which the area of the pump-rod was shown to be half that of the bucket, with the object of securing uniform delivery from the pump spout over the model water-wheel. By allowing the half-area rod to work through a stuffing-box in a close lid fitted over the lift-pump barrel, the uniform-throwing lift-pump was converted into the uniform-throwing force-pump, now in every-day use and known as the combined bucket-and-plunger pump.

Mr. JOHN W. GRAY, engineer of the Birmingham Water Works, wrote that he had not found any pumping engine yet to come at all near to a genuine Cornish engine for economy in working, taking all the year round. As for a six hours' trial or any sort of racing, he did not believe in the results so obtained. The pumping engines at Whitacre, near Birmingham, were compound high and low pressure; the advantage of a double-acting Cornish engine was thereby obtained. The load was the same as in a single-acting Cornish engine; the steam worked expansively on the load, in a similar manner to a Cornish engine. Rotatory engines he considered were not to be compared with Cornish, or with a compound such as now described. An advantage of the compound over the Cornish was that a greater quantity of water was raised by the same weight of

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(Mr. John W. Gray.)
engine; and also the expansion was not so sudden, and was therefore less straining to the machine. The differential gear was a great improvement for both Cornish and compound, and the cut-off was beautifully arranged by that means.

Mr. WILLIAM VAWDREY, engineer of the South Staffordshire Water Works, wrote that, although he had a decided partiality for Cornish pumping engines, he had never found them so much more economical in their working as the author appeared to have done; and he could only suppose that the rotatory engines with which the comparison mentioned in the paper had been made had not been in as good working order as the new Cornish engines by which they had been superseded. Although he did find the Cornish engines work cheaper in regard to fuel than the fly-wheel and double-acting engines, yet there was not such a large difference. These remarks referred simply to coal, otherwise steam; but as regarded oil &c. and renewals, he had no doubt that a Cornish engine, well erected and with its gears well balanced, would be found, as the author said he had found it, much the most economical class of pumping engine; and in cases similar to that dealt with at Lincoln, where the engine was working direct into the supply main, it was in his opinion much safer than a rotatory engine. For eight years he had had a Cornish engine supplying a district direct, without a reservoir or tank or any outlets whatever beyond the consumers' draw-taps; it was kept at work night and day, and pumped at various speeds between half a million and a million gallons a day under a head of 220 feet or 95 lbs. per square inch; and during the whole time there had been no trouble or accident of any kind. During that period of eight years, nearly the entire cost of the engine had been saved in the cheaper pumping of the water, as compared with what it had previously cost when two 50 H.P. high-pressure horizontal engines had been employed for doing the same work, but pumping under a fixed head into a reservoir. In all the Cornish engines which he had had erected, safety catches as described in the paper were fitted on the gear shafts, thereby reducing to a minimum the chances of much damage arising in case of a main bursting into which the engines

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were working; whereas in the fly-wheel engines, unless very sensitive governors were provided, great damage was generally done in such a case, if the engine-man did not fortunately happen to be near the gear at the moment of the accident occurring.

Mr. TEAGUE wrote in reply that he had not found the intermittent action of the Cornish engine, when pumping direct into the main with an air-vessel of the proper size and properly charged, to vary more, even under a pressure of 350 feet head of water, than from 6 to 10 feet of head; and when the water was being pumped direct into a reservoir, not the slightest variation was perceptible at the delivery end. Instances had been met with where the variation had been as great as 40 feet, but where complete satisfaction had nevertheless been felt that all was right. The Cornish engine had not been found by himself to require constant attendance; it worked for hours without alteration, except in case of a main bursting, or the sudden opening of a hydrant, and even in such cases it was stopped by the safety-catches. In his own experience it had proved quite as safe as the rotatory engine, if not safer; and the difference of pressure consequent upon the constant draw-off from the delivery main was but slightly felt.

With respect to the rotatory engines which he had replaced by Cornish (page 130), had they not in his own opinion been defective he should not have advised their discontinuance. At Lincoln however the difference in coal consumption between the Cornish and the rotatory engine had not been found greater than stated in the paper (page 131); and if both engines had been started new together, the difference would no doubt have been even less.

A few hours' test he quite agreed was not to be relied on; and those, who like himself, could remember the excitement that prevailed from fifty-five to sixty years ago respecting the duty of engines, did not care much for such short trials.

The results mentioned in page 130 were not given as representing a comparison between good Cornish and good rotatory engines; but to show the great loss that had been occurring with some engines in actual use, which had previously been held in very good estimation

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(Mr. Teague.)
by others than himself. He should be sorry for it to be thought that he undervalued the rotatory engine; there were places where he had used it in preference to the Cornish, and others where he had preferred the direct-acting Tangye engine to either. But where the situation would admit, and looking at the yearly cost of repairs, lubricants, coals, &c., he greatly inclined towards the Cornish engine: especially as he had not found the rotatory engine to be attended by the great benefit and saving which were said to be derived from its use in connection with a variable head.

In 1843, while he was in charge of the Bowden Hill manganese mine, about a mile northwest of Brent Tor near Tavistock, one of the Sims compound rotatory engines, which had cylinders without steam-jackets, was used both for pumping and for winding. The empty skip was lowered to a depth of 40 fathoms by a brake on the winding drum. When full it contained 6 cwts., in addition to its own weight and that of the chain; and the number of skip-loads raised was at the rate of ten per hour. When starting to wind this load, the boiler steam was each time admitted direct into the low-pressure cylinder for a few strokes; and the consequence was that, after the skip had been wound to surface, the steam required for pumping alone was found to be less than in the ordinary continuous pumping when no winding had to be done. For ascertaining the coal consumption during the eight hours of winding as well as pumping in each day and also during the sixteen hours of pumping alone, the coal was weighed during the two periods, and the difference per hour was found to be but small, whether pumping alone or winding as well. No doubt the explanation was that much of the heat absorbed from the boiler steam by the low-pressure cylinder and its surroundings was given off again afterwards in the intervals when working compound; and also that the friction in the low-pressure cylinder was reduced during the time that the direct supply of boiler steam was continued.

In an instance that had occurred a short time ago, where there was a good single-cylinder rotatory engine and it was found desirable to increase the pumping power, it had been decided to replace it by a compound engine, which it was thought would be attended with a

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great saving of coal &c. The result of twelve months' working however had shown that but little saving had been realised.

Just as the Cornish and rotatory and other engines were severally suited for different kinds of work, and the same kind of engine was not the one for every position, so was it also with the invaluable Harvey and West double-beat clack. There were places where it was not applicable, and where the leather clack was the one more suitable. In such cases the break-clack described in the paper was of value and much used.

To a three-throw pump he presumed no one would think of fixing a vacuum vessel: although it might even there be of advantage at starting. The benefit or otherwise would be easily seen by fixing a gauge on the suction-pipe.

The cylinders of the Cornish engines referred to in the paper were without steam-jackets.

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MEMOIRS.

JAMES DAVIDSON was born in Edinburgh on 6th July 1836, and after having served for three and a half years at the works of Messrs. Robert Napier and Sons, Glasgow, he went to Canada, and served two years with Mr. John Gartshore, Dundas Foundry. He was employed for two years by Messrs. Kinmond Brothers, locomotive builders, Montreal; and for two years on the Grand Trunk Railway at Point St. Charles, under Mr. Richard Eaton, locomotive superintendent. For three years he worked the Coburg foundry and machine shops. In 1865 he went to New Zealand, and in 1868 became proprietor of engineering works in Dunedin, Otago, which he carried on for some years in partnership with Mr. William Conyers. At the time of his death he was acting as local managing director of the City of Dunedin Suburban Gas Company. He died on 28th December 1886, at the age of fifty. He became a Member of this Institution in 1881.

PETER HAGGIE, principal in the firm of Messrs. Haggie Brothers, was the son of Mr. David Haggie, rope manufacturer, Gateshead, and was born there on 11th June 1821. He was educated at Newcastle, and on leaving school was apprenticed in 1838 to his father. On the death of his father in 1846, his brother David and himself succeeded to the business, which under their management acquired an extensive connection in the colliery districts of Durham, Northumberland, Yorkshire, and Wales. Whilst on a commercial visit to Ulverston he died there very suddenly on 5th November 1886, at the age of sixty-five. He became a Member of this Institution in 1861, and in the following year took part in the discussion upon the paper on the manufacture of hemp and wire rope (Proceedings 1862, pages 203–9.)

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THOMAS JOHN HAYNES was born at Cadiz, Spain, in April 1837, and died at Gibraltar on 11th January 1887, at the age of forty-nine. He was the eldest son of the late Thomas Haynes, of Puntales, Cadiz, who was the founder of the extensive forges and repairing establishments at Puntales and Gibraltar. After having passed the usual term of apprenticeship with his father at Puntales, he removed in 1865 to Gibraltar, where he thenceforth conducted the management of the Calpe Foundry and Forge, and the Gibraltar branch of the shipping business carried on in conjunction with his brothers from 1865 with their own steamers plying between Cadiz, Gibraltar, and the Spanish and Italian ports. During this period the firm took part in the successful salvage of a large number of steamers and other vessels, in addition to carrying out extensive repairs in many critical cases; and at the time of his death they had just concluded engagements to carry out important works at Cadiz for the Spanish government, and also for extensive dredging operations at the harbour at Huelva. In most of the commercial enterprises of the district he took a leading part. The universal esteem in which his business character and other qualities were held was attested by the large concourse attending his funeral, which included the highest officers of the government and of the principal public bodies, together with the leading merchants. He became a Member of this Institution in 1862.

THOMAS MOFFAT was born in the parish of Newton in the county of Edinburgh on 29th May 1830. After some practical experience in coal mines, he entered in 1849 the office of the late Mr. William Logan, then manager of the Edmonstone Collieries, near Edinburgh, where he remained as apprentice and assistant until 1856, when he took charge of the Elphingstone Collieries in East Lothian. In 1857 he took charge of the extensive collieries and iron-stone mines of the Coltness Iron Co., Newmains, Lanarkshire, which he considerably improved and developed. In 1874 he removed to Cleator Moor, Cumberland, to take charge of the Montreal Hæmatite iron ore mines; and continued there till his death, which took place on 15th November 1886, at the age of fifty-six, after a prolonged

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illness. He was frequently consulted in mining cases, and reported extensively on various mining fields throughout Scotland, Ireland, and the north-west of England. He became a Member of this Institution in 1879.

WILLIAM EDMUND RICH, a descendant of an old Wiltshire family, and son of Mr. Edmund Rich of Willesley near Tetbury, was born on 19th May 1844, commenced his education in a private school at Chippenham, and in 1858 was transferred to the Cheltenham Grammar School. In October 1861 he became apprenticed to Messrs. Palmer of Jarrow, where he passed in the usual way through the shops and drawing offices; but having convinced himself by actual experience that exact scientific knowledge was indispensable to engineers, he gave up his immediate prospects of occupation and advancement, and enrolled himself in 1866 as a student in the engineering school of Glasgow University under Professor Rankine, through whose influence, in consideration of his talents and previous training, he was permitted to complete his course in one year instead of two. Sir William Thomson, professor of natural philosophy, was equally interested in him; and both these eminent men continued to the last to take a lively interest in his career. While at Glasgow, he took the Walker prize in engineering, the second prize for natural philosophy, the prize for work in the physical laboratory, and the university medal for an essay on the doctrine of uniformity. On leaving the University he became candidate for a chair of engineering, but fortunately abandoned his purpose in order to join the firm of Messrs. Easton and Anderson, as one of their assistant engineers. His connection with this firm lasted till his death. He soon became their chief engineer and scientific adviser, and in 1878 was received as a partner. The duties he was engaged in were very varied. His extensive knowledge of geology, especially with reference to the water-bearing strata, found ample employment in the numerous water works for towns and domestic supplies on which his firm was continually engaged; among the more important of these may be mentioned Brighton, South Hants, Antwerp, Seville, and Littlehampton. Steam

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engines, especially those used in pumping operations, occupied a great deal of his attention; and as might be expected of a pupil of Rankine, his knowledge of them was accurately scientific. As an assistant at the trials of the Royal Agricultural Society he brought to bear upon them the skill he had attained at Glasgow in manipulating various measuring instruments; and his knowledge of mathematics enabled him materially to improve the testing apparatus of the Society, on which he contributed a paper to this Institution in 1876 (Proceedings, page 199.) In the construction of gun carriages also, especially those on the Moncrieff or disappearing principle, he showed much originality of method in solving the complicated problems involved. He was much engaged in the erection of hydraulic cranes and lifts, the last work of his life being the design and execution of the Mersey Tunnel lifts, the largest hitherto erected for passenger traffic. For a paper descriptive of these lifts he was awarded in 1886 the Telford premium of the Institution of Civil Engineers, of which he was a member. His work was distinguished by great originality and boldness, arising from the confidence he felt in the scientific basis on which he worked; few men were less guided by precedent, though he was by no means blind to the commercial advantages of establishing well considered standards. His death took place from brain fever on 22nd December 1886 in his forty-third year. He became a Member of this Institution in 1875.

JEAN LOUIS TRASENSTER was born at Beaufays, near Liége, Belgium, on 10th February 1816. After receiving a good general education at the Liége public school, he entered the science classes in the University, where in 1836 he and one other were the first two students in the newly established department of mining engineering. In 1838 he gained by examination the rank of mine manager, and in 1842 was the first to win the title of government mining engineer. In 1840, before he had yet taken all his diplomas, he was placed in charge of the class of elementary statics in the University of Liége. In 1844 he was appointed lecturer on mining, and continued to hold that post till 1879. In 1845 he became inspector of the junior

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department of the Mining School. In 1846 he was made inspector of the practical department and professor of the faculty of sciences; and rose by successive promotions to the highest rank in 1855, having meanwhile in 1849 been also appointed secretary to the University. In 1880 he was made Rector of the University; and in 1883 this appointment was renewed for a further period of three years. During the thirty-five years that he lectured on mining he had the training of nearly fifteen hundred mining engineers, of whom nearly three hundred were foreigners. When the "Association des Ingénieurs sortis de l'École de Liége" was founded in 1847 by twenty-nine of his former pupils, he was elected their first President; and he was re-elected annually for thirty-nine successive years until 1886, when he retired in consequence of failing health, the Association then numbering nearly a thousand members. His retirement from the presidency was coincident with the jubilee of the mining engineering department of the University; and the occasion was celebrated on 24th October 1886 by a large gathering of the members of the Association, all of whom had received their professional training from himself. At the commencement of his career he acted as consulting engineer to the John Cockerill Company, Seraing. He was also chairman of the Ougrée Coal and Iron Works, near Liége, being re-elected for thirty-eight years; and was a director of the Alstaden Collieries in Prussia, the Maestricht Paper Mills, and the Herve Railways near Liége. In 1844 was published his treatise on ventilating machines, and in 1852 that on rotary ventilators; in 1848 and 1872 appeared his works on the draining of mines, and in 1872 and 1878 those on the use of compressed air, and of water pressure. It was at his instigation that dressed stone was first employed as tubbing for lining the shafts of coal-pits at Alstaden and Seraing; and he got various improvements carried out, both in the employment of compressed air for sinking pits through watery measures, and in the construction of man-engines. In the government educational work he took an active part, and occupied a responsible and prominent position in connection with that department from 1850. He was one of the editing committee of the "Annales des Travaux publics," and of

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the "Revue universelle des Mines," to both of which publications he contributed important articles. At the international exhibitions of 1862 in London, 1867 in Paris, and 1873 in Vienna, he was a juror; and to him was due the introduction in Liége of public baths and wash-houses. On the occasion of the Summer Meeting of this Institution in Belgium in 1883, he was nominated an Honorary Life Member of the Institution (see Proceedings 1883, pages 310–311); and when the Association of Engineers from Liége University were in return invited to the Summer Meeting of the Institution in London in 1886, he would have accompanied them as their President, had he not been unfortunately detained at home by his wife's illness, which terminated shortly afterwards in her death; and he himself died on 1st January 1887, in the seventy-first year of his age.

THOMAS TURTON, who came of an old Yorkshire family, was born at Sheffield on 21st August 1833, being the son of Mr. Joseph Turton, one of the second generation of partners in the steel firm of Messrs. Thomas Turton and Sons. Entering the works at an early age, he was sent on business, when about seventeen years old, to the United States and afterwards to Russia, in both of which countries he did valuable service, and acquired an extensive general knowledge of the manufacture of steel and iron. On the business of Messrs. Thomas Turton and Sons being disposed of in 1861–62, he commenced business with his brothers as Messrs. Turton Brothers, steel manufacturers; and he invented and perfected two machines for use in file-making, one for shaping the blanks for files, and the other for cutting the teeth on the blanks. In 1867 he removed to Liverpool, and became managing partner in the Liverpool Forge Co., making forgings of all kinds, mainly for ships, besides doing general engineering work and building ships. Here he invented and worked out to successful use a spring equilibrium safety-valve, a hydraulic propeller for ships, and a built-up marine and locomotive crank-shaft now largely employed; also a second built-up crank-shaft, having eccentric ends, which was the joint invention of himself and the late Mr. George Allibon. Other devices of his were a long-

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stroke engine, and a road and tram locomotive. His death took place on 28th June 1886, in the fifty-third year of his age. He became a Member of this Institution in 1872.

SIR JOSEPH WHITWORTH, Bart., D.C.L., LL.D., F.R.S., was born on 21st December 1803, at Stockport, and received his early education in a school kept there by his father, Mr. Charles Whitworth. When twelve years of age he was sent to Mr. Wint's school at Idle near Bradford; and two years later went to his uncle in Derbyshire to learn the business of a cotton spinner, where he stayed four years and attained the position of manager. In 1821 he went to Manchester, and worked four years in the shops of Crighton, Marsden, Walker, and other employers. In 1825 he went to London, and worked during the next eight years in the shops successively of Maudslay and Holtzapffel and Wright; and also for Clements, who was associated with Babbage in the construction of his calculating machine. While working at Messrs. Maudslay's he succeeded in producing his set of three true-plane surface-plates made by scraping. On this mode of producing a true plane he afterwards read a paper to the British Association in Glasgow in 1840.

Returning in 1833 to Manchester at the age of thirty, he started on his own account as a tool-maker in premises in Chorlton Street. The next twenty years were devoted principally to the improvement of machine-tools, and during that period the whole series of machines known by his name were designed and perfected. The duplex lathe, the reversing tool of the planing machine, and the standard gauges of size, were the results of his labours between 1840 and 1850. He also devised and constructed a street-sweeping machine, which was introduced into Birmingham and other large towns, where it proved highly efficient. At the Great Exhibition of 1851 his collection of engineering tools attracted great attention on account of their excellent design and admirable workmanship. In 1853 he was appointed one of the Royal Commissioners to the New York Exhibition; and his subsequent report on American manufactures directed special attention to the suitability of the machinery which

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he had seen at the State Armoury, Springfield, Massachusetts, for the production of fire-arms.

Impressed with the evils of the unsystematic and wasteful modes of procedure then prevalent in most engineering establishments, he saw that the cure lay in the general acceptance of uniform standards of measurement, and in such accuracy of workmanship as would render objects of professedly similar dimensions exactly correspondent with one another within certain determined limits of error, and would ensure that facility of interchange of parts which experience has since proved to be an essential feature of successful engineering practice. His views respecting the value of true planes and correct measurement, and their influence on mechanical production, were set forth in the presidential address which he delivered at the Glasgow meeting of this Institution in 1856 (Proceedings 1856, page 125). He carried them out by supplying his workmen with more delicate gauges than they had previously used, and enforced the observance of these more exact measurements. In 1857 he gave a paper on a standard decimal measure of length for mechanical engineering work (Proceedings 1857, page 134), in which he proposed an equivalent decimal scale in thousandths of an inch, for doing away with the confusion attending the existing anomalous wire and plate gauges; and also a corresponding series of standards of size for taps and dies. In connection with this paper he presented to the Institution a standard decimal 30-inch steel measure, and a decimal wire gauge. Already in 1855, during the Crimean war, the production in ninety days of the engines for ninety gunboats had constituted a feat which had been rendered possible only by the general adoption of the Whitworth standards, and by the consequent power of obtaining from different engineering shops the separate parts of the engines: each firm reproducing ninety copies of one or more individual patterns, with such accuracy that the several parts could be put together at once on delivery, without having to undergo any further fitting for completing the erection of the engines.

The system of standards he gradually elaborated in connection with his famous measuring machine, in which by means of the gravity-piece the sense of touch is enabled to take precedence of

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sight, and by the use of an accurate screw-motion and a graduated index-wheel differences of only the one-hundred-thousandth of an inch are readily detected. A still more delicate machine subsequently made, capable of rendering perceptible a difference of even one two-millionth of an inch, was described by him and its working exhibited at a meeting of this Institution (Proceedings 1859, page 121). Another engineering matter of vast importance, with which his name is intimately associated, is the introduction of a uniform system of screw threads. By collecting an extensive assortment of screw bolts from the principal English workshops, he deduced as a compromise an average pitch of thread for different diameters; and also a mean angle of 55°, which he adopted all through the scale of sizes.* The Whitworth system of screw threads so established was rapidly adopted into general use throughout the United Kingdom and in many foreign countries.

In 1855, with a view to furnishing the government with designs for a complete set of new machinery for the manufacture of small-arms at Enfield, he was requested to carry out practical experiments on the various forms and proportions for rifle barrels and projectiles. For this purpose a shooting gallery 1500 feet long by 16 feet wide and 20 feet high was built at Fallowfield, Manchester; and experiments were there carried out for determining the best size of bore, the kind of rifling, the length of projectile, and other points requiring attention for ensuring good shooting. The Whitworth rifle, which was the result of these experiments, was first tried at Hythe in April 1857, and at all ranges proved greatly superior to all its competitors. At the first meeting of the National Rifle Association at Wimbledon on 1st July 1860, the first shot was fired by Her Majesty the Queen from a Whitworth rifle rest at 400 yards, and hit the target within 1½ inch of the centre; and at most of the subsequent annual meetings the Queen's prize of £250 was shot for with the Whitworth muzzle-loading rifle, until superseded by the Martini-Henry rifle in 1871.

His experiments with small-arms led him on to the construction of big guns and projectiles, in both of which he effected remarkable

* See Proceedings of the Institution of Civil Engineers, vol. i (1841), page 157.

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improvements, and attained a world-wide reputation as a maker of ordnance of extraordinary range and accuracy. In this connection he gave a paper in 1866 on the proof of guns by measurement, with description of the instrument employed (Proceedings 1866, page 105). His steel guns throwing flat-headed and conoidal shot were largely supplied to foreign governments, especially to South America, where they are said to have been used more effectively than any other kind. Experiments at Shoeburyness in 1868 with a 9-inch Whitworth gun gave a maximum range of 11,243 yards (6·38 miles) with a 250-lbs. shell at an elevation of 33 degrees. For making guns of the toughest material possible, and obtaining steel of the requisite hardness and freedom from flaws, he subjected the molten metal to intense hydraulic pressure during the time of its setting. This fluid-compressed steel and its application to the manufacture of guns were described in a paper to this Institution in 1875 (Proceedings, page 268). In 1883 the Gun Foundry Board of the United States, after paying a visit to his extensive works at Openshaw, near Manchester, gave it as their opinion that the system there carried out surpassed all other methods of forging, and afforded better promise than any other of securing the uniformity so indispensable in metal for guns. Gun-tubes he manufactured of hollow cylindrical castings, drawn out to the desired length; even for muzzle-loading guns he preferred to make a hollow tube, and to close the breech with a screw, rather than to bore out a solid forging. For armour he advocated steel plates, studded with hard steel screws or rings, with the twofold object of breaking the shot and of limiting the extension of any cracks developed by the blow; the "Polyphemus" armoured ram and torpedo vessel is covered with plates of Whitworth chilled steel.

In 1857 he was elected a Fellow of the Royal Society; and received the honorary degrees of LL.D. of Trinity College, Dublin, and D.C.L. of Oxford University. For his display of ordnance and of engineering tools at the Paris Exhibition in 1867 he was awarded one of the five great prizes allotted to England; and in 1868 he was appointed by the French Emperor to the Legion of Honour on account of his great services in the improvement of artillery. In

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the same year he received the Albert Medal of the Society of Arts. In 1868 he presented to the country the sum of £100,000 for the establishment of thirty annual scholarships of £100 each for the encouragement of practical science and mechanical art (Proceedings 1868, page 163); and in the following year he was created a baronet.

He was a Member of this Institution from the commencement in 1847, and occupied the position of President in the three years 1856, 1857, and 1866. On the occasion of the summer meeting held in Manchester in 1866, the Members on his invitation visited his residence, Stancliffe Hall, Darley Dale, Derbyshire, where his later years were mainly spent.

His death took place at Monte Carlo on 22nd January 1887, at the age of eighty-three. A letter of condolence from the President and Council on behalf of this Institution was addressed to Lady Whitworth (*ante* pages 33–34). A bequest of forty shares in his works was left to the Institution by his will.

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Institution of Mechanical Engineers.

PROCEEDINGS.

MAY 1887.

The SPRING MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Monday, the 16th of May 1887, at Half-past Seven o'clock p.m.; EDWARD H. CARBUTT, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-nine candidates were found to be duly elected:—

MEMBERS.

JAMES BARNINGHAM,	Manchester.
HERBERT BARRINGER,	London.
WILLIAM BERTRAM,	Edinburgh.
WALTER BUCKTON,	Leeds.
ALFRED CRAWHALL CHAPMAN,	Newcastle-on-Tyne.
GEORGE COCHRANE,	London.
GEORGE CECIL DYMOND,	Liverpool.
HERBERT WILLIAM EDLIN,	London.
JOHN BREEDON EVERARD,	Leicester.
NELSON FOLEY,	Naples.
ANDREW GIBB,	London.
ERNEST HOUGHTON-BROWN,	London.
CUTHBERT RIDLEY LEE,	London.
BENJAMIN MARSDEN,	Manchester.

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THOMAS LODWICK MILLER,	Liverpool.
DONALD BARNS MORISON,	Hartlepool.
BENJAMIN THOMPSON O'BRIEN,	Liverpool.
ROBERT READHEAD,	South Shields.
THOMAS RICHARDSON, JUN.,	Hartlepool.
FRANK SALTER,	London.
SHAPURJI SORABJI,	Bombay.
FRANK HOLMES STONE,	Thaiping.
JAMES TAYLOR,	Oldham.
JOHN WADDELL,	Edinburgh.
ALFRED GEORGE WHITE,	Huelva.
WILLIAM ANDREW YOUNG,	Leith.

GRADUATES.

WILLIAM HENRY ENGLAND,	Leeds.
EDWARD EBDEN JONES,	Plumstead.
HAROLD MILTON MAY,	Carlisle.

The PRESIDENT announced that since the last Meeting a vacancy had occurred in the Council through the lamented death of Mr. William Denny; and that this vacancy had been supplied by the Council, in accordance with No. 28 of the articles of association of the Institution, by the appointment of Mr. R. Price-Williams as a Member of Council.

The PRESIDENT then delivered his inaugural Address: after which the following Paper was read and partly discussed :—

On the Construction of Canadian Locomotives; by Mr. FRANCIS R. F. BROWN, Mechanical Superintendent of the Canadian Pacific Railway, Montreal.

At Twenty minutes past Ten o'clock the Meeting was adjourned to the following afternoon. The attendance was 91 Members and 67 Visitors.

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The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Tuesday, the 17th of May 1887, at Half-past Two o'clock p.m.; EDWARD H. CARBUTT, Esq., President, in the chair. On his having to leave the Meeting before its close, in order to attend officially as President of this Institution a committee meeting of the Royal Society for administering the £4000 voted annually by Parliament in aid of original scientific research, the chair was then taken by DANIEL ADAMSON, Esq., Vice-President.

The Discussion on Mr. Brown's Paper on the Construction of Canadian Locomotives, commenced on the previous evening, was resumed and completed; and the following Paper was then read and partly discussed:—

Experiments on the Distribution of Heat in a Stationary Steam-Engine; by Major THOMAS ENGLISH, R.E., of the War Office.

At Half-past Four o'clock the Discussion was adjourned; the publication of the Paper is accordingly deferred for the completion of the Discussion.

On the motion of the Chairman a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 78 Members and 23 Visitors.

In the evening the Annual Dinner of the Institution was held at the Criterion, Piccadilly, the President occupying the chair, and was largely attended by the Members and their friends. The Dinner was honoured by the presence of His Royal Highness the Duke of Cambridge, K.G., Field Marshal Commanding-in-Chief; and the

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following Guests also accepted the invitations sent to them, several of whom however were prevented from being present in consequence of parliamentary and other engagements. The Right Hon. Lord Colville of Culross, K.T., Chairman of the Great Northern Railway; the Right Hon. Lord Stanley of Preston, G.C.B., President of the Board of Trade; the Right Hon. J. H. A. Macdonald, C.B., Q.C., M.P., Lord Advocate for Scotland; the Hon. Charles W. Fremantle, C.B., Deputy Master of the Mint; Sir Edward W. Watkin, Bart., M.P., Chairman of the South Eastern Railway; Sir Frederick A. Abel, C.B., F.R.S., Chemist to the War Department; Sir James Allport, Director of the Midland Railway; Sir Henry E. Roscoe, M.P., F.R.S., President Elect of the British Association; Sir Graham Berry, K.C.M.G., Agent-General for Victoria; Sir Arthur Blyth, K.C.M.G., C.B., Agent-General for South Australia; Sir James Garrick, K.C.M.G., Q.C., Agent-General for Queensland; Sir Charles Mills, K.C.M.G., C.B., Agent-General for the Cape of Good Hope; Sir Saul Samuel, K.C.M.G., C.B., Agent-General for New South Wales; Mr. H. Coppinger Beeton, Agent-General for British Columbia; Mr. Adye Douglas, Q.C., Agent-General for Tasmania; Major-General Webber, C.B., R.E.; Colonel Martindale, C.B., R.E., General Manager of the London and St. Katharine Docks; Captain Andrew Noble, C.B., F.R.S.; Mr. Thomas Gray, C.B., Assistant Secretary, Marine Department, Board of Trade; Mr. W. S. Caine, M.P.; Mr. Arthur B. Forwood, M.P., Secretary to the Admiralty; Mr. W. Lavies Jackson, M.P., Financial Secretary to the Treasury; Colonel Makins, M.P., Chairman of the Gas Light and Coke Company; Mr. J. P. B. Robertson, Q.C., M.P., Solicitor-General for Scotland; Mr. Edward R. Russell, M.P.; Mr. Thomas Sutherland, M.P., Chairman of the Peninsular and Oriental Steam Navigation Co.; Mr. William Woodall, M.P.; Major-General Bateson; Colonel H. T. Arbuthnot, R.A., Superintendent, Royal Small Arms Factory, Enfield; Colonel W. R. Barlow, R.A., Superintendent, Royal Laboratory, Woolwich; Colonel E. Maitland, R.A., Superintendent, Royal Gun Factory, Woolwich; Captain J. Sydney Webb, Deputy Master, Trinity House; Major Thomas English, R.E.; Mr. W. H. White, Director of Naval Construction to the Admiralty; Professor

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G. G. Stokes, D.C.L., F.R.S., President of the Royal Society; Mr. Edward Woods, President of the Institution of Civil Engineers; Mr. A. D. Lewis, Master of the Shipwrights' Company; Mr. John Mews, Master of the Clothworkers' Company; Mr. John Aird; Mr. Benjamin Baker; Mr. Crawford P. Barlow; Mr. James S. Beale, Honorary Solicitor; Mr. John Benson; Mr. C. T. D. Crews; Mr. George Findlay, General Manager of the London and North Western Railway; Mr. Joseph Gordon, Borough Surveyor, Leicester; Mr. Henry W. Lucy, Editor of the *Daily News;* Mr. Robert A. McLean, Auditor; Mr. H. L. Millar, Treasurer; Mr. E. C. Nepean; Mr. Henry Nelson; Mr. John Noble, General Manager of the Midland Railway; Mr. Henry Oakley, General Manager of the Great Northern Railway; Mr. H. J. Parnall; Mr. H. G. Reid; Mr. John Rhodes; Mr. Owen Roberts; Mr. William Saunders; and Mr. A. F. Yarrow.

The President was supported by the following Officers of the Institution:—Sir William G. Armstrong, C.B., F.R.S., Mr. Thomas Hawksley, F.R.S., and Mr. Jeremiah Head, Past-Presidents; Mr. Daniel Adamson, Mr. David Greig, Mr. Arthur Paget, and Mr. Joseph Tomlinson, Jun., Vice-Presidents; Mr. Benjamin A. Dobson, Sir James N. Douglass, Mr. Samuel W. Johnson, Professor Alexander B. W. Kennedy, Mr. Edward B. Marten (Stourbridge), Mr. Edward P. Martin (Dowlais), Mr. Richard Price-Williams, Mr. E. Windsor Richards, Mr. T. Hurry Riches, Mr. Benjamin Walker, Mr. J. Hartley Wicksteed, and Mr. Thomas W. Worsdell, Members of Council.

After the usual loyal toasts, the President proposed "The Army, the Navy, and the Reserve Forces," which was acknowledged by His Royal Highness the Duke of Cambridge, K.G. The toast of "The Houses of Parliament," proposed by the President, was acknowledged by the Right Hon. Lord Stanley of Preston, G.C.B., President of the Board of Trade, on behalf of the House of Lords; and for the House of Commons by Mr. William Woodall, M.P. The President proposed "The Colonies and Commerce," which was acknowledged by Mr. Adye Douglas, Q.C., Agent-General for Tasmania. "The Institution of Mechanical Engineers" was

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proposed by Colonel E. Maitland, R.A., Superintendent of the Royal Gun Factory, Woolwich, and was acknowledged by the President. The concluding toast of "The Visitors," proposed by Mr. Daniel Adamson, Vice-President, was acknowledged by Sir Arthur Blyth, K.C.M.G., C.B., Agent-General for South Australia.

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ADDRESS OF THE PRESIDENT,

EDWARD H. CARBUTT, ESQ.

On Fifty Years' Progress in Gun Making.

GENTLEMEN,

This being the Jubilee Year of Her Majesty's reign, it naturally occurs to every one to look back and see what progress has been made during the past fifty years, not only in the growth of the nation in territory, wealth, and population, but also in the advancement of art, science, and manufacture. This has already been done to a large extent by the leading men in other Societies:—notably by Mr. Edward Woods, in his presidential address to the Institution of Civil Engineers, wherein he passed under review the railway system and the employment of locomotives all over the world; by Mr. W. H. White, Director of Naval Construction, in his lecture at the Mansion House on modern war ships; by Mr. Thomas Gray, in his lecture there on shipping legislation; by Capt. Douglas Galton, in his paper at the Society of Arts on sanitary legislation and improvements; and by Sir Bernhard Samuelson, in his address to the Chamber of Commerce.

In his striking and spirited address to the representatives of our Colonial Empire, Sir Henry Holland brought out very forcibly the extent to which the prosperity of the Empire depends upon the reality of the available defensive power. He considered it was not too much to say that the whole fabric of the commercial system of the Empire, on which the well-being and even the existence of the colonies in a great measure depend, is ultimately based upon the defensive power capable of being exerted in time of war. The value of British ships and of the freight they carry annually was estimated

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in 1881 to be not less than £900,000,000, and must now be £1,000,000,000, of which it is estimated that in the direct trade of the United Kingdom alone £144,000,000 is afloat at any one time; but British interests in sea-borne commerce are really larger, for much of what appears to be foreign trade is either British property, or security for British advances. In a war with a maritime power he therefore concluded that British interests would be exposed to risk to the extent of two-thirds of the sea-borne trade of the world.

As Mr. W. H. White, in his lecture above mentioned, has given an account of the very great progress made in what is called our first line of defence, namely in our war ships, I have therefore thought an account of the advance made in our Guns, and in the means of their manufacture, would not be inappropriate to lay before the Institution of Mechanical Engineers.

Except in the superior composition of the metal, cannon cast in the reigns of the Georges exhibited little improvement upon those of the time of Elizabeth. The guns in use at the beginning of the present reign, in 1837, were principally the cast-iron smooth-bore 24-pounder and 32-pounder, with spherical shot. Some larger guns had been made before Her Majesty's accession, but apparently as an experiment, namely six of 60 cwts. and four of 65 cwts. They were tried on board the "Excellent" later in 1837, and it was not until 1838 that two hundred of them were ordered for the navy. The highest service charge was 10 lbs. of powder, and the guns cost £65 to £78 each. The highest service charge of the 32-pounder was 8 lbs. of powder. At that time all iron guns were bought by contract, many coming from the Low Moor Iron Works. It was not till 1857 that the Royal Gun Factory at Woolwich was instituted for the manufacture of the Armstrong rifled gun.

No improvement was attempted in the mechanical construction of cannon until it was found necessary to supply the infantry with better arms. In his book on guns, Sir J. E. Tennant states that up to that time they used the "Brown Bess," which was not effective beyond 200 yards; and even then it was said that, before a soldier could bring down his man, he must fire the full weight of his body

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in lead. The want of accuracy in shooting is well illustrated by the fact that in 1812 at the battle of Salamanca 3½ million cartridges and 6000 cannon balls were fired, with the result of only 8000 men being put *hors de combat*. And as late as 1857 during the Kaffir war 80,000 cartridges were fired in a single engagement in which only 25 of the enemy were killed.

The Crimean war directed attention to the fact that our guns must be improved, and a great amount of inventive talent was brought into the field. The ordnance then used was the same as ordered for the navy in 1833, namely cast-iron muzzle-loading guns with cast-iron spherical shot. With these it was impossible to secure accuracy of aim, or great range or rapidity of fire. They had wooden gun-carriages, and no means of moving them except the handspike, or rope and pulley-blocks. Eight or ten men were required to manage each gun; and there was much more danger in loading, as the men had to stand in front of the gun to ram home the shot. This also prevented them from being fired quickly.

The gun of today is made entirely of steel, and is provided with mechanical appliances for every movement in forts, in turrets, or on shipboard. Accuracy of aim is ensured by rifling, that is, by causing the shot to rotate on its axis in order to keep it in its line of flight. The length of range is increased by having an elongated shot which exposes as small an area of cross section as possible to the retarding resistance of the air; and also by the increased powder-charges which the enlarged powder-chamber has made it possible to utilise. Breech loading has led to increased speed in firing, and has also rendered it possible for our large guns, which are 35 ft. to 40 ft. long, to be used on board ship. The men in charge are considerably protected, by not being exposed in front of the gun. Even the loading is self-acting in the smaller field-guns; while arrangements are made on forts or on board ship to lower the gun altogether out of sight while loading. The guns are made to revolve, load, return to position, and train to firing point, by hydraulic power: so that one man can carry out the whole operation, and fire the gun the instant it is necessary.

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While the ability of many inventors has rendered all this progress possible, a good deal of it is due to the genius and energy of two of the Past-Presidents of this Institution—Sir William Armstrong and the late Sir Joseph Whitworth. In 1854 Sir William Armstrong obtained leave from the Duke of Newcastle to make six rifled guns. In these the general principle of construction was nearly the same as at present, namely a central barrel of steel strengthened by hoops. He states that he desired to have steel hoops; but steel not being sufficiently reliable in those days he used wrought-iron coils. The guns were breech-loading, a system which was at first received with favour, then abandoned, and now universally adopted. The objection made by the naval authorities to breech-loading was that the sailors could not manage the requisite mechanism; but the sailors proved themselves better mechanics than was expected: indeed I think we may take it that every Englishman is a born engineer.

In 1854 Lord Hardinge applied to Sir Joseph Whitworth to make the machinery for the production of the barrels for the Enfield rifle. This he declined to do until he could make experiments with a view to determine the proper form of rifling and the length of barrel and of shot. The government agreed he should build a shooting gallery, in which an exhaustive set of experiments was carried out. These showed conclusively (as stated in the *Times* in January 1885) what was the best pitch of rifling, what was the best form or method of rifling, what was the best length of projectile, what shape of projectile afforded the greatest power of penetration, and a variety of similar matters; all these things were removed from the region of speculation. In Plate 19 is shown the series of projectiles tried, and the particulars are added of the effect produced on their flight by the relation between the pitch of rifling and the length of projectile. The experiments proved moreover that what was true of small arms was equally true, *mutatis mutandis*, of cannon.

In 1856 France used some rifled field-guns in the Italian campaign, and this was the signal for the re-construction of artillery in Europe. In 1858 the English government appointed

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a committee to examine and report on rifled field-guns. Seven different designs were submitted; and eventually the committee reported that it was expedient to continue the experiments on two, namely the Armstrong and Whitworth guns. The government became thoroughly committed to the Armstrong system, firstly by appointing Sir William Armstrong as head of Woolwich, and secondly by giving a guarantee to a private firm at Elswick to manufacture his guns. This was in the year 1859; but in 1862 Sir William gave up his appointment at Woolwich, and the government gave up their guarantee to Elswick, which has ever since been conducted as a private firm.

The introduction of the mechanical improvements in guns necessitated the use of much stronger material than either cast iron, brass, wrought iron, or the steel which could then be supplied; and Sir Joseph Whitworth now turned his attention to the manufacture of steel. Crucible steel alone was used; but the comparatively small ingots that could be produced, and in many cases the want of soundness when made, were almost fatal objections to its use for guns. This gave place to the open-hearth process with Siemens-Martin furnaces, which at once increased the power of producing larger ingots. The want of soundness in the hoops and tubes still continued. Sir Joseph Whitworth overcame it by consolidating the steel ingots while fluid under hydraulic pressure. In this system, which is still in use, a gradually increasing pressure up to 6 or 8 tons per square inch is applied, and within half an hour or less after the application of the pressure the column of fluid steel is shortened 1½ inch per foot or one-eighth of its length; the pressure is then kept on for several hours, the result being that the metal is compressed into a perfectly solid and homogeneous material. The government factories continued the use of wrought-iron coils and steel tubes; and it was not until 1880 that steel was adopted in the construction of the large Woolwich guns, although in 1872 Sir Joseph Whitworth had made four guns of 12-inch calibre and 35 tons weight, wholly of steel, for the "Neptune," which were able to fire a projectile of over 1000 lbs. weight.

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In 1868 Sir Joseph Whitworth advocated the use of flat-headed projectiles for penetrating armour under water and at angles. From the first he also advocated the adoption of long projectiles, even five and six diameters in length. This theory is now accepted to a certain extent, the length of the service projectiles having increased from 1·5 and 1·8 calibres up to nearly four calibres long. The flat head has never been adopted; but in these days of compound hard armour the racking effect of flat-headed projectiles may be worth trial. A piece of wrought-iron plate 1·7 inch thick is here shown, by the kindness of the Whitworth Co., which has been penetrated at an angle of 45 degrees by a flat-headed steel shot, nearly five diameters long and weighing 5 lbs., which is also shown; it was fired with a charge of 10 ounces from a three-pounder Whitworth gun of 1·85 inch calibre, weighing 315 lbs.

In 1882 four breech-loading Whitworth guns of 9 inches calibre were made for the Brazilian iron-clad "Riachuelo," which were adapted to fire the modern slow-burning powder. The weight of the charge was 200 lbs., and the projectile weighed 400 lbs. A steel shell from one of these guns was fired through the target shown in Fig. 5, Plate 20, consisting of 18 inches of wrought-iron armour with heavy timber and steel backing, and was dug out of the sand at P, 17 feet behind the face of the target, the shell being still intact, as shown in Fig. 4. The effect on the armour-plate is shown in Figs. 2 and 3. This is the greatest penetration recorded up to that date from any 9-inch gun.

To Sir William Armstrong is greatly due the immense improvement in appliances for working guns. He has introduced innumerable mechanical contrivances for manipulating the heavy ordnance, so that now it is easier to manipulate a 20-ton gun even without mechanical power than it was formerly to handle a 30-cwt. gun. The working, loading, training, and aiming of these heavy guns are all carried out by hydraulic mechanism; and in the most recent cases arrangements are being made for the guns to be loaded at any angle of training, without having to come to one fixed loading position.

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Major Moncrieff invented the disappearing carriage, utilising the recoil of the gun, originally by means of a heavy counterweight, and now by means of a hydro-pneumatic cylinder, to bring the gun back into the position for firing after it has been loaded underground. This system is illustrated in Figs. 6 and 7, Plate 21, and is employed on guns of 5 inches bore and upwards to the 68-ton gun of 13½ inches bore. A model of the hydro-pneumatic carriage is also shown from the Elswick Works, by the kindness of Capt. Noble.

In a new fort on the south bank of the Tyne, Mr. Maxim is trying a new plan of disappearing gun, by mounting it on a kind of gasometer, which is raised by air pressure and sinks by its own weight.

In the fort at Dover the turret carries two 80-ton muzzle-loading guns, and is rotated by steam power. It is the only fort of the kind on our shores; I think we ought to have more.

At Elswick much larger turrets are being constructed for the Italian government, to carry a pair of 120-ton guns, which are to be worked and loaded by hydraulic machinery; the turrets are to be rotated by hydraulic power, and the magazine cranes to be worked in the same way. These turrets have the very unusual advantage of enabling the guns to be loaded in any position of training: so that either the loading can take place immediately after firing, without training to a loading station; or, should it be desired to train the guns and embrasures away from an enemy's fire during the time of loading, they can be turned to any position which will give the desired protection, and there be loaded. With these very large turrets the arrangements are such as will give at least twelve rounds per hour from each gun, or twenty-four rounds per hour per turret.

Mr. Longridge's wire gun is coming into favour, its great advantage being that large steel forgings are not required. By adopting steel ribbon that will withstand 80 to 90 tons tensile strain per square inch of section, and winding this under tension upon the barrel, a gun is obtained possessing very great circumferential strength.

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Mr. Vavasseur has greatly improved the naval gun-carriage, and utilised the hydraulic buffer with a water cataract to take up the recoil of the gun.

After Sir William Armstrong left Woolwich, the government pushed on with the manufacture of the wrought-iron coil guns. A large number of new tools were designed by our best tool-makers, aided by our late Member, Sir John Anderson, who had been appointed Inspector of Machinery. To give an idea of the amount of work turned out, I may say that, since the introduction of rifled guns in 1859–60 down to the present time, upwards of 11,000 rifled guns have been issued from the Royal Gun Factory, varying from the 7-pounder of 150 lbs. weight to the 17¾-inch muzzle-loading gun, and from the 6-pounder rifled breech-loader to the 13½-inch breech-loading 69-ton gun. For fifteen years Woolwich was practically the only manufactory in the country making guns for the nation, as the guns ordered from outsiders did not amount to more than £1500 a year throughout that period. The threatened war in 1878, the year of the £6,000,000 vote of credit, made the government review their position, and led them to apply to our private manufacturers. I must however refer our Members to a very important paper read by Colonel Maitland on 28 June 1884, before the Royal United Service Institution, which gives a short history of gun-making down to that date. He sets forth the reasons for the necessity of re-armament. Down to 1875–76 the British artillery he says was as good as that of any other nation; but he admits that a period of stagnation then followed, and we fell to leeward; and it was fortunate we were not caught napping by an important war. To the fact that we fell behindhand I believe the government are now fully alive, and are endeavouring to make up the leeway. They have given out large orders, so that the work can go on steadily and regularly; and are not waiting for another panic to drive them into abnormal expenditure.

Now let us compare the gun of 1837 with that of 1887.

1837. Muzzle-loading cast-iron gun, weighing 65 cwts. and increased afterwards to 95 cwts., and firing a 68-lbs. shot with

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10 lbs. of powder, taking ten men to fire one shot per minute, each shot fired costing 11*s.* 9*d.*

1887. Breech-loading steel gun with a total length of 44 ft., weighing 110 tons, and firing a shot 16¼ inches diameter weighing 1800 lbs., which is calculated to penetrate a 34-inch iron armour-plate. This gun can be trained and fired by one man with the aid of hydraulic power; and the cost of every shot fired is £190. The time occupied in making one of these guns is from twelve to eighteen months.

The accompanying diagrams, Figs. 8 and 10, Plate 22, show the difference in size of these two guns; and in the following Table 1 are given particulars of the 65-cwt. gun, and of the 45-ton, the 69-ton, and the 110-ton gun.

TABLE 1.—*Comparison of Guns in* 1837 *and* 1887.

Year	1837.	1887.	1887.	1887.
Weight of Gun	65 cwts. / 95 cwts.	45 tons.	69 tons.	110 tons.
See Plate 22.	*Fig.* 8.		*Fig.* 9.	*Fig.* 10.
Diameter of Bore . . inches	8·12	12	13·5	16·25
Length of Bore . diameters	13·3	21·2	30	30
Total Length of Gun, ft. ins.	10 ft. 10 ins.	...	36 ft. 1 in.	43 ft. 8 ins.
Powder charge . . . lbs.	10	295	630	1,000
Projectile . . . . . lbs.	68	714	1,250	1,800
Velocity at muzzle, ft. per sec.	1,600	1,900	2,020	2,128
Energy at muzzle . foot-tons	1,100	18,000	35,367	55,040
Perforation at muzzle through wrought-iron ins.	...	22·6	30·1	34
Range at 15° elevation yards	...	...	12,300 (7 miles)	...
Cost of Gun	£65	£7,050	£12,000	£19,500
Cost of Charge . . £ *s.* *d.*	0 8 0	18 12 0	36 0 0	55 10 0
Cost of Shot* . . . £ *s.* *d.*	C 0 3 9	S 54 0 0 P 5 9 10	S 93 15 0 P 12 0 0	S 135 0 0 P 16 6 6
Number of Guns made or in progress	...	35	32	7

* Cast-iron shot is denoted by C, Steel by S, and Palliser shot by P.

Shot made wholly of Cast Steel is officially stated to have been first proposed in April 1882; but I am informed that cast-steel shot had already been supplied as early as 1877 from Hadfield's Steel Foundry, Sheffield; while forged steel shot had been tested long before, round steel shot as early as 1866.

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The following were the results of the testing of the 110-ton gun at Woolwich in March last, the charges being by far the heaviest ever fired in this or any other country:—

TABLE 2.—*Testing of* 110-*ton Gun.*

Round.	Description of Powder.	Weight of Charge.	Velocity at Muzzle.	Pressure in Bore.
No.		Lbs.	Feet per sec.	Tons per sq. in.
1	Prism brown . .	600	1,699	9·65
2	Prism brown . .	700	1,843	12·05
3	Prism brown . .	800	2,007	15·1
4	Prism brown . .	850	2,078	18·7
5	Prism brown . .	850	2,142	19·5
6	Waltham slow .	950	2,104	15·7
7	Prism brown . .	850	2,150	19·9
8	Waltham slow .	1,000	2,128	16·1
9	Waltham slow .	1,000	2,128	16·2

I have already stated how inaccurate was the firing with the old cast-iron gun and spherical shot; and I intended to ascertain the latest performance with our new rifled guns. But a great authority on the subject, Major G. Mackinlay, R.A., having read on 30th April before the Royal United Service Institution a paper on the "Accuracy of Artillery Fire," I cannot do better than recommend its perusal; and he has kindly lent me the accompanying diagram, Fig. 11, Plate 22, which shows the accuracy of shooting with a 9·2 inch breech-loading gun at 1000 yards at Shoeburyness in 1883. The result of firing ten shots is here seen to be that the point M of mean impact was only 10 inches from the point A aimed at, which must be admitted to be very good practice. Increased velocity gives the shot a lower trajectory, that is it travels in a straighter line, thereby enabling it to take effect over a greater distance. This is of vital importance, as it is so difficult to judge the exact distance of the object aimed at. Suppose a gun be sighted to fire at a ship of a certain height 1000 yards off. If the velocity were 1950 feet per second, the shot would hit the ship at any distance between 1000 yards and say 1100 yards. If the velocity were increased to 2200 feet per second, the shot would hit the ship up to 1200 yards.

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So that increased velocity of shot gives, in addition to increased penetration, a greater margin for judging distance.

Colonel Maitland has kindly lent me a photograph of the 110-ton gun, engraved in Fig. 12, Plate 23; and also a 68-lbs. spherical shot with dummy cartridge containing 10 lbs. of coal dust instead of powder, which represents the highest service charge for the 65-cwt. gun of 1837. In comparison with this spherical shot of barely 8⅛ inches diameter, the shell of the 110-ton gun is 16¼ inches diameter and 55 inches long.

Our largest ironclad costing some £600,000 or £700,000 carries only two of these 110-ton guns; but in addition it has a large number of quick-firing machine-guns. The "Benbow" has an armament consisting of two 110-ton guns, twelve rapid-firing guns, and fourteen machine-guns. There are also four torpedo-ports on the broadside, and one at the stern, all above water. Each of the two large guns is mounted in a barbette at one end of the citadel. It is fixed on a turntable, and is surrounded by a breastwork of plates, over which it fires. Its angular range extends over 230 degrees, from 25 degrees abaft the beam on one side to the same angle on the other side, the two guns being able to converge on an object 50 yards distant from the broadside.

To give another type of ship, let me refer to the armament of the "Colossus," which comprises four 45-ton breech-loading rifled guns, two in each turret, firing projectiles of 714 lbs. weight with a charge of 295 lbs. of powder, and penetrating 20½ inches of iron at 1000 yards; also five 6-inch breech-loading guns, weighing 89 cwts., and firing a projectile of 100 lbs. with 42 lbs. of powder, and penetrating 9·7 inches of iron at 1000 yards; also four 6-pounder Hotchkiss quick-firing guns of oil-hardened steel, weighing 7·3 cwts.; ten four-barrelled 1-inch Nordenfelt guns of 4 cwts.; one two-barrelled Nordenfelt of 181 lbs.; two 9-pounder muzzle-loading guns of 8 cwts.; two 7-pounder muzzle-loading guns of 200 lbs.; and four five-barrelled Gardners of 280 lbs., firing 330 shots in half-a-minute.

It will be remembered that an accident happened to one of the former guns of the "Colossus," when 6 feet of the muzzle was blown

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off during the trial. In the new 45-ton guns the muzzle was hooped; and reports have been received of further practice with these guns off Malta on 28th April, the object being to ascertain the rapidity with which accurate fire could be delivered while the ship was in motion. This is the first occasion in naval gunnery of such a trial being made with heavy breech-loading guns worked entirely by hydraulic power. The ship steamed at eight knots per hour along a measured base, of which the extremities were at a distance from the target of rather more than 1600 yards, or nearly one mile. Notwithstanding the speed in passing and a slight rolling motion, the results were highly satisfactory. The heaviest charge of powder was used throughout, and all the machinery stood the severe and unusual test admirably. So carefully and quickly was the hydraulic apparatus manipulated by the seamen working the guns that the fire was far more rapid than had been expected. In several instances a gun was fired, loaded again, pointed, and fired a second time in one minute and three-quarters; and on one occasion four discharges of the same gun were accomplished in six minutes. The accuracy was remarkable; every shot hit the target, except in one series of four very rapid shots, of which three struck it.

Quick-firing Machine-Guns.

These machine-guns are breech-loading, and are loaded with brass or copper cartridge-cases, so that no difficulty occurs in making the breech to close gas-tight. The mechanism extracts the empty cartridge-case, and re-loads with a new cartridge containing the powder and shot, and fires it off; and this is repeated as long as cartridges are supplied and the lever or crank is worked. The cartridges are generally supplied from a hopper and magazine.

Gardner Gun.—This gun is made of three different kinds, namely with one or two or five barrels of 0·45 inch diameter, firing rifle ammunition. It is worked by a hand crank, which gives a continuous rotary motion. Two men can easily fire 200 shots per minute; and the highest rate of fire has been 312 shots per minute. The British government have some 600 of these guns.

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Nordenfelt Gun.—This is worked by a backward and forward motion of a lever. The smallest size has one barrel 0·3 inch calibre, and weighs only 15 lbs.; it can fire 200 rounds per minute. Those made for the British government, and used principally in the navy, have three and five barrels of rifle calibre, namely 0·45 inch, to fire respectively 450 and 650 rounds per minute. The largest size made is a 40-pounder of 4¼ inch calibre for shipboard and fortifications, firing seven to ten rounds per minute at a muzzle velocity of 2050 feet per second. There are works in London for the manufacture of this gun.

Maxim Gun.—Since the paper read to this Institution two years ago on his automatic self-loading and self-firing gun, Mr. Maxim has so greatly simplified it that it is now constructed with only one-sixth as much work in it. His latest result is that with a gun weighing only 42 lbs. he fires 1000 rounds of rifle ammunition in one minute and a half, and has completed 2115 rounds in four minutes. The largest size he has made is a three-pounder which perforates 3 inches of steel at 100 yards. An automatic gun is being made in France to perforate 9 inches of steel, and to fire about 20 times a minute. There are works in London for the manufacture of this gun.

Gatling Gun.—Three kinds are made, having six, eight, and ten barrels, which revolve inside a case round a longitudinal axis. The gun is worked by a hand-crank, at each turn of which it fires either as many shots as there are barrels, or only half that number. These guns are made at Elswick.

Hotchkiss Revolving Cannon.—These guns are not for firing rifle bullets, but for shell-firing. They are not yet used in England; but 4000 of them are already employed by other nations. They are made in three sizes, to fire 1 lb., 2½ lbs., and 4 lbs. shells at the rate of 86 shots per minute. The penetration of the steel shell at the muzzle through a steel plate is respectively 1 inch and 2¼ inches and 3¼ inches; at a range of 1000 yards the penetration is about one-third less.

Hotchkiss Rapid-Firing Gun.—Of these some 400 or 500 have been supplied to the British government. The 3-inch gun with three men can fire 20 times a minute. These guns are making at Elswick.

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Quick-firing guns combine rapidity of fire with accuracy, long range, penetration, and shell fire. A six-pounder with steel shot can penetrate 2 inches of steel at 500 yards. The largest sized rapid-firing gun yet made is a $4\frac{3}{4}$ inch calibre, firing a 30-lbs. shell with 9 lbs. of powder, and weighing 34 cwts. It is fired by electricity, and can fire 8 to 10 rounds per minute.

CONCLUSION.

I have shown how superior the guns of the present day are to those made at the beginning of Her Majesty's reign. It would open up too large a question to make a comparison of our position with that of other nations; those who wish to do so I should advise to read a very interesting and elaborate report made in 1886 by a United States Committee on Ordnance and War Ships, of which Mr. Hawley was Chairman and Lieutenant W. H. Jaques was Secretary. This Committee spent many months in England and on the Continent, and gathered together the latest information on the subject. The object of their visit to Europe was to advise the United States what steps to take for obtaining the best supply of guns. They quote the case of France, which before the Franco-German war depended entirely upon government factories for her guns. That system failed, and she has now encouraged private firms to put up plant, so that in case of again going to war she will have large manufacturing resources to fall back on.*

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* The following is an extract from the Report of the U. S. Select Committee on Ordnance and War Ships, page 126:—"As an example of depending alone on government works France was a perfect instance before the Franco-German war. During the period referred to, the government factories were the sole source of supply of the armament of the country; the officers charged with the work formed a close corporation; their action was never exposed to the public; their ideas were never subjected to criticism: the ingenuity and inventive talent of the country were ignored and resisted; and no precaution was thought necessary to provide a supply in case of need of re-armament. The result is well known: a great crisis came; the government works were inadequate to meet the additional demands made upon them, and the patriotic efforts of private establishments were inadequate to produce all the material that was

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What is our own means of supply? First we have the arsenal at Woolwich, which the Members of the Institution were kindly invited to visit last summer. Then we have practically two other arsenals, which, although private works, would in case of war no doubt be at the disposal of the government. Fortunately they are separated by long distances; for should an enemy come up the Thames and destroy Woolwich, we should still have Elswick left on the east, close to the seaboard, and an inland arsenal at Manchester, namely the Whitworth works, communicating with the west coast.

I have here for comparison two plans, Figs. 13 and 14, Plate 24, illustrating the growth of Woolwich Arsenal: Fig. 13 showing it in 1837, when employing 136 men; and Fig. 14 showing its extent at the present time, when employing 12,550 men. In 1843 they had some gun-boring machines which were driven by horses, and were bought in Holland. The arsenal is controlled by the Director of Artillery and Stores, General Alderson, and is divided into three manufacturing departments:—firstly, the gun factory, with Colonel Maitland at its head and Mr. Edmonds as mechanical manager, employing from 2000 to 2200 men, where the guns are made; secondly, the carriage department, with Colonel Close as superintendent and Mr. Butter as mechanical manager, employing 2500 to 2600 men, where are made naval and military gun-carriages, torpedo tubes, &c.; thirdly, the laboratory, superintended by Colonel Barlow with Mr. Robert Low as mechanical manager, employing 6100 to 6250 men in the manufacture of cartridges, rifled shells, fuzes, rockets, electric stores, and torpedoes. There is also a chemical department under Sir Frederick Abel; and a department under Mr. J. A. C. Hay, inspector of machinery for out stations. The arsenal

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needed. How entirely France has now altered her system is shown in a previous part of this report; her present practice is theoretically perfect, and it has proved to be practically efficient. Her government establishments are still retained, but as gun *factories* simply, in which the parts are machined and assembled; but for *foundry* work"—that is, steel—"she depends upon the private industries of the country, and many of these works have found it to their profit to establish gun factories which supplement the government factories to a great extent."

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possesses all the newest machinery for making guns, gun-carriages, projectiles, cartridges, and torpedoes. The latest turning shop consists of five bays of 50 feet span and 150 feet length, each of which is served by an overhead travelling crane. The largest of these cranes is 46 feet span, with steam traverse, and is capable of lifting by hydraulic power 100 tons at 12 inches per minute. For building up the gun and shrinking the hoops on, a revolving radial travelling crane is used, covering an area of about one-fifth of an acre, and capable of lifting 200 tons at 18 inches per minute; the extreme dimensions are, height over all 69 feet, traverse 67 feet, height of lift 45 feet, radial traverse for lifting from 17 to 60 feet. The largest lathes have 72-inch centres and 60 feet bed, and cost about £6000 each. The largest boring machines have 78-inch centres and 130 feet bed, and cost about £4000. A combined gun-boring, turning, rifling, and lapping machine, with 130 feet bed, cost about £7000. This gives an idea of the expensive machinery which it is necessary to employ in making the present large guns. Hitherto they have not made any gun larger than 69 tons; but they state they are prepared to make up to 150 tons. They have turned out nearly 2000 tons of finished guns in a year. Only a portion of the steel forgings are made at Woolwich. They have however a steel casting plant with several open-hearth furnaces, whereby they can make about 3500 tons of castings in a year. They have only one hammer as large as 40 tons, made some years ago by Messrs. Nasmyth for welding coils. I understand they have turned out 2000 tons of forgings in a year, the progress having been as follows:—1564 tons in 1883–4; 1698 tons in 1884–5; and 2279 tons in 1885–6. In this connection I would direct attention to the very exhaustive paper by Colonel Maitland on the treatment of gun steel, which he read to the Institution of Civil Engineers on the 15th March last.*

The well-known Elswick Works, originated and developed by Sir William Armstrong, are situated on the banks of the Tyne with a shore frontage of over a mile, and employ 13,000 hands. They smelt their own iron and carry on every operation requisite for

* Institution of Civil Engineers, Proceedings March 1887, vol. lxxxix, page 114.

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turning out the largest ironclad complete with guns. Between 9,000 and 10,000 guns of all sizes up to 110 tons have already been made. In addition to a 35-ton steam-hammer by Messrs. Thwaites and Co., they use also a hydraulic forging press. The success of the trials in the gun department is due to the scientific attainments of Captain Noble. The hydraulic machinery has been developed by Mr. Westmacott, while the steel department is under the charge of Colonel Dyer.

The Whitworth Works at Openshaw near Manchester are entirely new within the last few years, and consequently embody all the latest improvements; they also enjoy the advantage of being built on level ground of 30 acres extent, and were designed and laid out by the late Mr. Leece in conjunction with Mr. Gledhill. The tools are of the latest type; one of the largest lathes has eight cutting tools, and is capable of turning and boring nearly two tons of steel per hour off a gun forging. There are seven hydraulic presses in the steel works, which are capable of turning out the largest steel forgings. All the forgings for the 110-ton gun were made here. The American Commission, reporting upon these works in 1884, after having visited the chief steel factories in France and Russia and Sheffield, spoke of the Whitworth establishment as unique, and the process of manufacture as a revelation, especially in regard to the operation of hydraulic forging.

In making large guns the great difficulty has been the production of steel forgings. My previous statement that Sir Joseph Whitworth had made improvements in the manufacture of steel is by no means intended to imply that other steel-makers were not endeavouring to turn out large masses of steel perfectly sound. Messrs. Firth and Messrs. Vickers of Sheffield I believe had put down new plant, and were making all the forgings which were required of them at the time. In March 1884 Lord Hartington stated that the main difficulty was to get sufficiently large steel forgings; they could be got from France and Germany, but up to that time the demand had been a new one in this country, and there had been great difficulty in obtaining from English works steel forgings of the size and quality

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required. Mr. Brand also stated that the Sheffield works could not supply steel ingots of the size and quality required. I replied at the time in the House of Commons that if the government would encourage our own manufacturers they would soon supply the steel; and the manufacturers were then promised orders if they would put down the necessary plant. Many firms have put down new plant in order to be in a position to supply the government wants, no doubt relying on the promise then made. I am glad to find the government were justified in placing reliance on private enterprise. I lately visited most of these works with Lord Morley and his Committee, for whose appointment I had moved. The information imparted to us during our visit was private; but I may state that the following firms were either prepared or making preparations to supply steel forgings, in addition to Sir William Armstrong and Sir Joseph Whitworth:—Messrs. Firth and Sons, Messrs. Vickers Sons and Co., Messrs. John Brown and Co., and Messrs. Charles Cammell and Co. All of them have either a hydraulic forging press or a very large steam-hammer, with either crucible or open-hearth steel plant, and cranes capable of lifting up to 150 to 200 tons. Each works can turn out from 3500 to 7500 tons of gun forgings per annum; consequently the government can now obtain an ample supply of forgings.

The mode of working is as follows:—an ingot of the requisite size up to 65 tons is cast either round or square or hexagonal, according to the views and experience of each steel-maker. The hexagonal form, with sides slightly curved concave, is to my mind preferable, because the sides can then follow the shrinkage of the material in cooling, and thus prevent internal rupture of the metal. The ingot, being upright during casting, is cast longer than necessary, so as to get the effect of a head to allow for the steel shrinking as it cools; the head is afterwards cut off in a lathe. The ingot in cooling drives the carbon to the centre: so that when cold it is found that, although the steel on the outside is mild enough for a gun forging, the centre is hard enough for tool steel, containing 0·8 per cent. of carbon, while the outer ring contains only 0·3 per cent. of carbon. This hard centre is then bored out of the ingot, until the test shows that the inside of the annular ring contains the

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same percentage of carbon as the outside. The centre being bored out allows an internal as well as an external examination of the ingot. The hydraulic press is then brought into play on the annular ring, with the full advantage of being able to forge on a mandril. The amount of material which is cut off and bored out of the ingot is so large that it leaves the forging only one-half to two-thirds the weight of the ingot. This loss of material accordingly adds to the cost of the forging. Many of the Sheffield works have tools of the largest size for turning the gun-hoops. For turning and boring gun-hoops, the government have also availed themselves of the tools and plant of several large works on the Thames, notably those of Messrs. Easton and Anderson of Erith, and Messrs. John Penn and Sons of Greenwich. In addition to assisting in the manufacture of guns, Mr. Anderson has turned his attention to making and improving the gun-carriages.

The hydraulic forging presses vary in power, working at 2½ to 3 tons pressure per square inch, and having steel cylinders from 35 to 40 inches diameter with 4½ to 7¼ feet stroke. In several of them the head which contains the cylinder is moveable, so that in forging a large mass the cylinder is lifted up and only a short stroke is necessary. The presses are worked direct by large pumping engines, without the intervention of an accumulator, the engines running only while the press is at work. The cranes all have an arrangement for turning the porter-bar, so that the forging is rotated between the blows of the press. There can be no question that the introduction of the hydraulic forging press has been a great means of overcoming the difficulty of making large steel forgings. The pressure is so great and so equal throughout that the steel in the centre of the ingot is worked at the same rate as the outside: that is, while an ordinary steam-hammer would draw the outside only and leave the centre unworked, thus bringing about internal strains in the steel, the press acts on the whole mass equally throughout. To whom the credit of this invention is due it is not necessary to enquire; no one doubts that it was Sir Joseph Whitworth who first got the hydraulic press to work for steel forging. Many of the steel works have made their own hydraulic forging presses. Messrs. John Brown and Co.'s press

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was made by Messrs. Tannett Walker and Co. of Leeds, and is arranged to be used for bending the largest steel armour-plates of 30 inches thickness, in addition to being used as a forging press.

On the 30th of April last, in referring to General Sir Edward B. Hamley's address to the London Chamber of Commerce on the defence of London and the commercial ports of Great Britain, the 'Times' remarked that when we are told more guns are required it is natural to ask who is to supply them. You will doubtless agree with me that, if the government will only give the orders, this question will soon be answered; for I think I have shown that we have both works and men sufficient for furnishing soon an adequate supply of guns, if only the nation will determine to have our defences put in a proper position.

The change from wrought-iron to compound armour has necessitated a complete change in the projectiles for piercing the latter. Palliser chilled shells are of no use, and steel projectiles for this purpose have yet to be developed as a regular manufacture. Chromium seems to be likely to play an important part in the composition of shells for this purpose. Some trials have taken place at Shoeburyness, but so far the English manufacturers have not done so well as the French. The difficulty in making hardened steel projectiles is that if too soft they will not penetrate the armour and will upset; and if too hard they will fly to pieces when standing in store, days after being made. Among others Messrs. Firth and Sons are I believe at the present time engaged in endeavouring to make good shells of hardened steel that will be free from both these objections.

Trials are continually taking place, and lately a steel shot fired from the 43-ton 12-inch gun went through a 16-inch compound armour-plate and 12 feet of oak backing, and buried itself 6 inches in a wrought-iron plate. It is expensive work however, as it is calculated each trial costs £700, including the cost of the armour-plate damaged. But we must proceed; we have the richest country in the world to defend, and if the skill of our engineers is utilised

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during the time of peace, we shall avert a temporary defeat should we unfortunately have to defend our shores. It is surely advisable to work steadily on, rather than to suffer from the wasteful extravagance invariably associated with panic in trying to make up for lost time.

As the President's address will not be replied to, I have avoided expressing any opinion on the structural merits of the various guns to which reference has been made, my only object being to review what has been done during the past fifty years, and to record our present position in relation to this matter, I trust without wounding any susceptibilities. In conclusion I desire to express my thanks to the several authorities and manufacturers who have so obligingly aided me by furnishing information in connection with this important subject, especially to General Alderson, Colonel Maitland, Captain Noble, and Mr. Gledhill.

Mr. EDWARD WOODS, President of the Institution of Civil Engineers, said he had all the more pleasure in proposing a vote of thanks to the President of the Institution of Mechanical Engineers for his most able Address, in consequence of the two Institutions being so closely affiliated as was happily the case. It was of great use, he thought, that from time to time the progress of the mechanical arts should be reviewed; and all would agree that the last fifty years had witnessed a most wonderful development, not only in artillery, but in every branch of mechanical science. The subject so ably handled in the present Address, which had been listened to with so much interest, had a most important bearing upon the welfare of the nation. The President, as was well known, had for many years devoted close attention to the improvement of guns, and during his

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(Mr. Edward Woods.)
career in parliament had impressed upon their rulers the great importance of obtaining the assistance and aid of private firms as supplementing the government factories. The meeting he was sure would heartily join him in passing a cordial vote of thanks to the President for the Address he had just delivered.

Sir LOWTHIAN BELL, Bart., Past-President, said he had gladly undertaken, as a matter of form, the otherwise unnecessary task of seconding the vote of thanks which had just been proposed. No one who had listened to the Address could be otherwise than grateful to the President for the large amount of trouble he had taken in bringing this very important subject so prominently before the members of the Institution. He had not only laid very clearly before them the vast progress which had been made in the construction of ordnance, but had also drawn attention to a matter which could not be considered altogether devoid of interest, namely the enormous cost at which the advances in gunnery were being carried on. When the cost of firing away shot from one of the present large guns had now risen to as much as £190 per round, one might be tempted perhaps to say the fewer of such shots were fired the better. But however costly each shot might be, this cost fell very far short of the other expenses connected with the firing. For he remembered, just after the conclusion of the Crimean war, being informed by Capt. King Hall, who had conducted the storming of Bomarsund by the Baltic squadron, that every ton of shot fired during that cruise cost the country something like £100,000; so that whether each shot cost £190 or £1900 was a very small matter, seeing that the means which had to be adopted for taking the ships to the place and getting them into position might bring up the cost to so formidable a total for each ton fired that the expense of each round sank into insignificance.

Without questioning the accuracy of the statement contained in the Address, that fluid steel under the pressure applied to it by Sir Joseph Whitworth of 6 to 8 tons per square inch was found to be compressed to the extent of 1½ inch in every foot, he must confess that such an amount of compression was certainly novel to himself, implying as it seemed to do that the specific gravity

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of the steel so compressed must be increased something like one-eighth. The specific gravity of the steel, which in round numbers might be taken before compression at 8, would thereby become raised to something like 9. Such a result was very surprising to himself.

The vote of thanks to the President for his Address was carried by acclamation.

The PRESIDENT said he was very much obliged to the President of the Institution of Civil Engineers and to Sir Lowthian Bell for the very kind way in which they had spoken of his Address. The expense of firing shots which cost £190 each might also be looked at in another way; for whereas with the old cast-iron guns the old broadside ships had something like 800 or 900 men on board, the present largest war-ship carried only about half that number, so that actually there were a considerably less number of lives risked than in former years; and he thought any expense was worth incurring whereby loss of life could be saved.

As to the contraction of fluid-compressed steel to the extent of one-eighth, he could only say that it was Sir Joseph Whitworth's own statement (see Proceedings 1875, page 290); and as far as he had been able to see in visiting works, but without having the possibility of remaining there to take the measurements for himself, he should say the statement was accurate.

He thanked the meeting most heartily for the kind manner in which they had received his Address.

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ON THE CONSTRUCTION OF CANADIAN LOCOMOTIVES.

BY MR. FRANCIS R. F. BROWN, OF MONTREAL.

In the present paper the writer purposes dealing more particularly with those classes of Locomotives which have been built from his designs and under his personal supervision at the shops of the Canadian Pacific Railway, Montreal. A few preliminary remarks are desirable, in order to present the subject on a fairer basis for comparison with English practice.

The permanent way in Canada consists generally of flat-bottomed rails, weighing from 56 lbs. to 72 lbs. per yard according to class of service and age of road. The rails are spiked to flattened ties or sleepers at about 2 feet centres, or closer if necessary. Either common or angle fish-plates are used; and brace castings are placed against the outside rails at curves as required.

Grades are usually expressed in percentage, or in ft. per mile; and curvature in degrees of the angle subtended by a 100-ft. chord on the curve; thus a curve of 1° has a radius of 5,730 feet, and a curve of 6° has a radius of $\frac{5730}{6} = 955$ feet. The maximum grades on main lines are commonly 1 per cent. or 52·8 feet per mile, and the sharpest curvature 6° or 955 feet radius; these limits of course do not apply to mountain sections.

The classes of service comprise:—way or stopping freight, that is, goods trains; through or fast freight; mixed, that is, one or more passenger coaches attached to freight trains for local country service; local passenger; and express. All these have to run on single track, and are operated by telegraph from the "train despatcher's" office. In order to get the traffic through, it is considered of more importance that the engines should haul the

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largest possible loads with such economy as can be obtained, than that they should haul smaller loads at a cheaper rate per ton in regard to fuel.

The passenger service on main lines is more often a combination of express and local than either one of these chiefly. Thus the majority of through express trains have to stop at nearly all stations either by time-table or by signal. Special care is therefore required in designing the engines so as to combine free running with the quickest possible starting power; and a continuous brake is also rendered necessary as well as expedient for economising time in stopping.

In all classes of service the dead or non-paying weight hauled forms a much greater percentage of the total train than on an English railway. This is partly due to the fact of the freight cars having to be protected against the climate, and to the employment of specially designed refrigerator cars and ventilated cars for the carriage over long distances of perishable goods, such as fresh meat, fish, butter, cheese, &c. It is also partly owing to the strength of the passenger coaches being greatly increased with a view to the safety and comfort of the passengers; for it must be borne in mind that a through transcontinental train in Canada carries with it all the conveniences of a first-class hotel. The through trains on the Canadian Pacific Railway from the Atlantic to the Pacific ocean carry parlour, sleeping, dining and buffet coaches, with sofas, easy chairs, state rooms, smoking room, bath room, lavatories, &c.; all of which accessories to comfort necessarily add to the dead weight per passenger.

A portion of the traffic is worked by wood-burning engines, which require a special form of grate, and arrangements of wire-netting for the ash-pan and chimney in order to prevent setting fire to the surrounding country. For coal-burning engines the quality of the fuel is very variable; some of the coal is of such a kind as to necessitate rocking grates with dumping arrangements, sharp blast, and netting for arresting sparks; all of these appliances have to be used for maintaining efficiency, but they are somewhat detrimental to economy, inasmuch as to some extent they react upon each other.

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In England the express engines, some of them burning the best Welsh coal, have a very different array of circumstances to contend with: which is usually overlooked when comparing the relative performances of the two types of locomotives.

The general designs of the engines which form the subject of this paper are of the American type, as being the best adapted for overcoming climatic difficulties, giving as it does a flexible wheel-base to suit the road when disturbed by frost and thaw, affording easy access to all parts of the mechanism, and enabling necessary repairs to be effected with the greatest facility: all of which points are of great moment for enabling the traffic to be carried on without stoppage for repairs.

S.A. Light Engines for Freight and Mixed traffic.—The lightest class of engine which will be described is designated S.A.; of which a longitudinal section and plan are shown in Figs. 1 and 2, and cross sections in Figs. 3 and 4, Plates 25 to 28. This class was specially designed by the writer with a view to condense the stock of patterns, and at the same time to give the best and most satisfactory results, whether working on the Atlantic or Pacific coast or on the prairie or rocky sections intervening, with all the extreme variations in class of coal from anthracite to almost lignite, and of water from lime to alkali, which are encountered in operating a railway across 3,000 miles of country: so that a locomotive of this class might be transferred to any portion of the line and give equal satisfaction. This system also reduces to a minimum the stock of duplicates for repairs; and enables the repairs to be effected without loss of time, and at a low cost.

For obtaining the requisite adhesion with this class of wheel-base —consisting of a four-wheeled lateral-motion truck in front, and two pairs of coupled drivers behind—and for economising weight, great care has been exercised to reduce the weight of the front end of the engine without impairing its strength, or diminishing the protection in case of collision; and the maximum weight obtainable has been placed on the driving wheels. Equalising bars are placed between each pair of truck wheels and also between each pair of driving

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wheels, in order to minimise all disturbance from inequalities of road and to equalise the wear on the tires as much as possible. This system virtually carries the rigid portions of this engine on three points, namely the centre of truck and the centre of each equaliser between the driving wheels, thus giving the most stable form of support that can be attained.

The S.A. class of engine has 17 × 24 ins. cylinders and 5 ft. 2 ins. driving wheels. The weight of the engine in working order, that is with two gauges of water (*i.e.* above the second try-cock) and with fire in the fire-box, is distributed as follows:—on truck 30,900 lbs., on drivers 53,900 lbs.; total weight 84,800 lbs. = 37·85 tons. According to the usual formula the tractive force is nearly 112 lbs. per lb. of average steam-pressure in the cylinders.

S.C. Light Passenger Engines.—For light passenger service a similar engine is built, classed as S. C., but having driving wheels of 5 ft. 9 ins. diameter; and a casting is inserted above the truck centre to raise the front end correspondingly. The distribution of weight is as follows:—on truck 31,600 lbs., on drivers 58,100 lbs.; total weight 89,700 lbs. = 40·04 tons. The tractive force is 100½ lbs. per lb. of average steam-pressure in the cylinders.

The capacity of tender for both these classes is 2,800 gallons of water and 10 tons of coal if required. The water supply along the line is stored in frost-proof tanks, which have a capacity of about 40,000 gallons, and are distributed at intervals varying from 10 to 25 miles and averaging about 16 miles. The tender capacity is sufficient to carry water enough for running two of these intervals, in case the supply at any tank should be stopped from external causes. As the railways are worked in divisions of about 110 to 140 miles, the coal capacity of the tender allows of carrying enough to serve for a round trip, wherever the exigencies of the coal supply render this advisable.

S.A. Light Engines.— Boiler.—The first point which attracts attention is the "wagon-top," as it is called, which is 8½ inches high above the top line of the barrel, Plate 25. The object of this

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construction is primarily to obtain by increased height of fire-box a sufficient area in the fire-box tube-plate for inserting such a number of tubes as will give the most efficient proportion of heating surface in the tubes. The size of tube which is almost universally adopted is 2 inches outside diameter. A smaller diameter causes a diminution of efficiency at the front end of the tube, owing to the comparative absence of flame from the class of coal used; and on account of sagging it is unwise to attempt to use smaller tubes, unless the barrel of the boiler is short. Moreover the adoption of a single size for general use facilitates repairs, and reduces the number of tools necessary to be kept, as well as the stock of tubes kept in the stores. For a given diameter of boiler the number of tubes, and therefore the efficient tube surface, is much increased by the height of the wagon-top. Other very important advantages are also gained by the wagon-top. As the dome must be placed on the wagon-top, the regulator can thus be elevated by that amount above the surface of the water, thereby assisting to avoid priming, which is most troublesome with some kinds of water. This arrangement concentrates the heavier portions of the boiler over the driving wheels, and thereby adds largely to the adhesive weight. Moreover the barrel of the boiler is kept from being unnecessarily large, and the average water-level approaches very nearly to filling the barrel. One advantage of this is that, when driving hard into a snow bank (or "snow bucking," as it is called), it is almost impossible for the water to leave the top of the fire-box uncovered, since the barrel requires but a small quantity to fill its vacant space; and the same remark applies when the engine is going down an incline.

Fire-box.—As the upper portion of the fire-box is wider than the shell between the frames, Plate 27, this necessitates putting in the inside box in a special manner. The writer's practice is to put it in from the front, before riveting in the throat sheet or front plate of the shell, which is put in afterwards, the connection being made between barrel and fire-box by a double-riveted joint; this practice gives entire satisfaction. The foundation ring is 2½ inches deep, and 3 inches wide at sides and back, and 3½ inches wide at front; it is single-riveted all round, with ¼ inch projection below the plates to allow

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for solid caulking. It is forged from scrap-iron, and welded together at the centre of each end. It is then machined all round, inside and outside; and the corners are tapered for the scarfing on the plates. The outer plates are scarfed very carefully to extend about $2\frac{1}{2}$ to 3 inches beyond the edge of the plate, sufficient material being left on the edge of the plate to give this length of scarf. This allows of three rivets for holding the plates close to the outer corner of the ring, and effectually prevents the plates at the corner from being sprung away by the caulking. The inside corners of the fire-box tube and back plates have $\frac{7}{8}$ inch internal radius, and the scarfing on the side plates is brought well round the outside of the tube and back plates. There has not been a single instance of one of these corners giving trouble by leaking.

The fire-hole is elliptic in form, 16 inches long by 14 inches high, Plate 25. It is formed by flanging the two back plates outwards, and a welded sleeve of Yorkshire iron, $5\frac{5}{16}$ inches wide by $\frac{3}{8}$ inch thick, is inserted between them, which is riveted to the inside box before the box is put in place. The flange of the outer plate extends beyond the sleeve, to form a backing for caulking the sleeve, and to allow the fire-door to fit against it. This form of fire-hole gives no trouble by leaking; and its flexibility allows the inside box perfect freedom for vertical expansion and contraction.

The fire-box crown is not quite flat, Plate 27, having $\frac{1}{2}$ inch rise in the centre from each side for preventing deposit of scale from occurring through deflection of the roof-plate in the centre, which sometimes happens with flat tops. The front portion is supported by ten transverse crown-bars or roof-girders; and the after portion by five rows of direct stays, with ten in each row. The crown-bars BB consist of two wrought-iron plates, 5 inches $\times$ $\frac{5}{8}$ inch, set 1 inch apart; and have cast-iron blocks between the ends, forming feet to fit the curve of the crown-plate and to rest on the top edge of the side-plates of the fire-box. Each crown-bar is secured to the roof-plate by ten bolts of $\frac{7}{8}$-inch diameter with taper fit, driven upwards through the crown-plate, and having a fluted head below, with a copper washer between the head and the plate; the head is fluted round the bolt for the purpose of leaving room for any burr on the edge of the plate, and

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for enabling the annular face of the head to fit up solidly against the plate and make a perfect joint with the copper washer. The head is of the snap or cup form, in order to give as little projection for deposit as possible. The crown-bar is $2\frac{1}{2}$ inches above the plate, giving ample water-space between, in which are placed cast-iron ferrules on each bolt, having the bottom face of the same diameter as the bolt-head below the plate, while the upper face is made large enough to give the crown-bar a solid bearing on it. The washer on the top of the crown-bar has its edges bent down at front and back, so as to clip the two plates of the bar and keep them from any tendency to spread. These bars are spaced equally with the rows of direct stays, at a uniform pitch of $4\frac{5}{16}$ inches longitudinally, leaving $2\frac{1}{2}$ inches between the lap of the joint and the front row. The bars are hung in pairs from the external shell by a series of braces on each side, which are connected by a stirrup and pin to the crown-bars and to brackets on the boiler; three brackets are riveted in the dome on each side, and two on the shell on each side; those riveted to the dome assist materially in preventing any deformation of the shell owing to the large size of the hole cut in the shell plate. Allowance is made in all the braces for upward expansion of the fire-box. The direct stays are $1\frac{1}{8}$ inch diameter, screwed with eleven threads per inch, and riveted over the plates on the outside of the shell and on the inside of the fire-box, excepting only the outer row on each side, which are not tapped through the shell, but are screwed into hangers in pairs; the hangers are secured by pins to brackets on the shell, similar to those which carry the crown-bars; the brackets are all of mild cast-steel, and of light pattern. The hangers have allowance for upward expansion of the side-plates of the fire-box.

This system of staying presents advantages. Crown-bars are preferable to direct stays for the forward part of the roof-plate, inasmuch as they allow considerable movement of the fire-box while firing up, and the grip of the roof bolts prevents the roof from buckling, which invariably occurs from the direct contact of flame. This does not apply to the back end of the crown, where there is very little flame contact; and the absence of crown-bars on this

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portion materially assists in keeping the crown of the box free from deposit, and in removing it when formed.

The back plate of the shell and the smoke-box tube-plate are supported by gusset-stays attached to the top of the shell and barrel. Those on the back plate have the angle-irons continued down to relieve the strain on the top row of stays to the inside box. The taper plate of the wagon top is prevented from extending by four braces from the line of the bottom joint of the taper to the gusset-stays on the back plate, as shown in Fig 1, Plate 25.

A row of cross stays $1\frac{1}{8}$ inch diameter, screwed eleven threads per inch, are tapped into the shell from side to side between each crown-bar and each row of crown-stays, and are placed $2\frac{1}{2}$ inches clear above the crown. These cross stays prevent the flat sides of the wagon top from bulging out, and relieve the top row of side stays from undue strain, thus avoiding trouble from broken stays. Three cross stays Y are placed for the same purpose in the taper course above the back end of the tubes, each being connected by pins to a pair of stiffening angle-irons which are riveted to the oval sides of this course.

All side, front, and back stays for the fire-box are $\frac{7}{8}$ inch diameter, screwed eleven threads per inch, and riveted outside and inside. The tube-plate is stayed to the barrel below the tubes by four barrel-stays with studs through the tube-plate.

Dome.—The dome is 2 feet 4 inches diameter outside by 2 feet 6 inches high to joint, Plate 27. It is flanged out to the shell, and double-riveted; and the shell is strengthened by an extra thickness of plate which also takes the dome rivets; this plate and the shell project inside the dome far enough for a row of rivets, thus reducing the hole in the shell to 2 feet $\frac{1}{2}$ inch diameter, and tending to prevent priming from being started by splashing. The top ring of the dome is of cast-iron, and has a cast-iron cover studded on with ground or copper-wire joint. Provision is made in the dome cover for whistle and safety-valve connections.

Boiler shell.—Plate 25. The boiler is built entirely of Siemens-Martin mild-steel plate imported from Scotland. The barrel is $52\frac{1}{2}$ inches diameter outside at the smallest course, and 11 feet $4\frac{1}{4}$ inches

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long, the plates being $\frac{7}{16}$ inch thick. The fire-box shell is 6 feet $7\frac{5}{8}$ inches long by 3 feet $6\frac{1}{2}$ inches wide outside between the frames; and inside 5 feet $11\frac{5}{16}$ inches long by 2 feet 11 inches wide at bottom and 3 feet $6\frac{1}{2}$ inches at top. The depth below the centre line of the boiler is 4 feet 8 inches to edge of plate, and the height above the centre line is 11 inches at sides and $11\frac{1}{2}$ inches at centre. The thicknesses of plates are as follows:—front and back tube-plates $\frac{1}{2}$ inch; back and side plates inside $\frac{5}{16}$ inch; back plate and top of shell $\frac{1}{2}$ inch; sides of shell $\frac{7}{16}$ inch; top of inside box $\frac{3}{8}$ inch; dome $\frac{7}{16}$ inch; smoke-box $\frac{3}{8}$ inch. Cleaning plugs are inserted as follows:—one in each corner at bottom of box; two in each side in accessible positions; one in front of shell at bottom, and one close under the barrel; five across the back plate just above line of crown; six in front tube-plate, namely two above tubes, two at sides, and two at bottom. Two hand-holes $2\frac{1}{4}$ inches diameter are placed on the taper plate, to afford access to the back end of the tubes, and to wash the deposit down into the leg of the fire-box.

The boiler work is all sheared, punched, and riveted by hydraulic machinery on Tweddell's plan, the rivets being all of very mild Siemens-Martin steel: except in the foundation ring and where hand-riveting is necessary, in which case Lowmoor rivets are used. The crown stay-bolts and all screwed stays are of the same quality of steel as the rivets. The flanging is done by hand on special blocks, and the plates are heated in a furnace, and annealed after flanging whenever they have been locally heated. The edges of all plates are planed to an angle of 75° before being put together. The longitudinal seams are double-riveted zigzag with lap joints; and the circumferential seams are single-riveted, except the connection between fire-box and barrel which is double-riveted. The tubes are wrought-iron lap-welded, of German or American make, 185 in number, 2 inches outside diameter, No. 12 B.W.G. thick (0·110 inch), 11 ft. $8\frac{1}{4}$ ins. long between tube-plates; and are arranged in vertical rows, all being kept clear of the $\frac{7}{8}$-inch internal radius of fire-box tube-plate. The smoke-box tube-plate is drilled $\frac{1}{16}$ inch larger than the tubes, and the fire-box tube-plate to net size; the tubes are swaged down at the back end through about an inch length,

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sufficiently to receive a copper ferrule 2 inches outside diameter and No. 18 B.W.G. thick (0·050 inch), which is driven on, and the tubes are then inserted in place, and rolled tight at both ends with a Dudgeon expander, and beaded at the back end only.

Smoke-box.—The smoke-box is formed by a continuation of the barrel, the front tube-plate being circular, Plate 28, and flanged forward to fit inside the front barrel course, which is also riveted to the smoke-box barrel. The front end of the smoke-box is stiffened by an angle-iron ring, to which is bolted the circular door-frame or front of cast iron; this is fitted with a round cast-iron door, which is hinged at the side and secured by three tapped bolts, and makes a conical joint with the frame. The conical joint makes a much tighter door than the flat joint, as the door is less easily sprung out of shape while being machined. The door has a number-plate bolted on in the centre.

The boiler is rigidly secured at the front end only, where the saddle and cylinders are cast to shape and chipped to fit, Plate 28; and the smoke-box is secured by turned driving bolts, with a thickening plate on the inside of the box. As shown in Plates 25 and 27, the fire-box end is provided with four angle-iron supports to slide on the top of the frame, and with four strap-brackets to clip the top bar of frame, which have liners sufficiently thick to allow of only $\frac{1}{16}$ inch lateral play on each side. Four clips are placed on the sides of the box, to slide on the bottom bar of the frame and prevent twisting of the frame. As the fulcrum of the spring equaliser or compensating lever is bolted to the centre of the top bar of the frame, the weight of the fire-box is transferred almost directly to the centre of the equaliser. No other connection is made between boiler and frame, so that the boiler is perfectly free to expand and contract.

Heating Surface.—The heating surface is as follows:—tubes (external) 1132 square feet; fire-box 112·5; total 1244·5 square feet. The grate area is 17·3 square feet.

Testing.—These boilers are built to carry a pressure of 150 lbs. per square inch, and are tested with steam to 165 lbs. The hydraulic test is not generally used by the writer, as it is considered by some engineers that the structure is damaged to some extent by the

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excessive pressure. Hydraulic pressure has however been applied up to 220 lbs. per square inch, in order to test the soundness of the design; and the result was very satisfactory.

Regulator and Steam Pipes.—The regulator, Plate 25, is of the common balanced double-seat type and is of cast-iron, as is also the valve-box, both being designed so as to reduce the strains of expansion and contraction, and to enable the valve to be kept tight without attention. It will be noticed that the seats form very sharp cones, and are very wide compared with English practice; they are found to give the best results for durability and tightness. The regulator rod slides in the stuffing-box, being actuated by a horizontal lever provided with a sector, similar to a reversing lever. The driver sits on the right-hand side; and all handles are brought close to him, so as to be worked easily and quickly without losing sight of the track.

The regulator pipe is carried in the dome by a wrought-iron strap; and has a drooping flange or collar cast on near the top, to prevent water from creeping up the pipe and causing priming to start. The main steam-pipe S is of wrought-iron lap-welded, 5½ inches diameter inside, and ¼ inch thick; it has a cast-iron sleeve riveted on at each end, with a copper joint for caulking. The joints at each end are ball shaped and ground tight; the back face of the front sleeve forms a ball joint to the tube-plate, and the T pipe studs make the two joints at this end. The joints between the branch pipes and the T pipe are made with a brass ring, having a ball joint at one side and a flat joint at the other, and both joints are ground. Similar joints are made between the branch pipes and the cylinder casting, which projects inside the smoke-box for convenience, Plates 25 and 28. These joints are all painted with black varnish before being finally put together. The branch pipes are 4½ inches diameter at each end, and the centre portion is made of oval section so as to leave the space in front of the tubes as open as possible.

Exhaust and Petticoat Pipes.—The exhaust pipes are in one casting, Plates 25 and 28, so made as to get the exit as low as possible; each exit is on the top of the pipe, and forms a semi-ellipse divided by a web of metal; on this face is bolted the nozzle N, which is 7 inches high, and the tip is 3¾ inches diameter, being very slightly larger

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than the exit from each pipe. Thus the nozzle does not contract the steam passage, and therefore avoids "blowing over" into the other cylinder; but it serves to convey the jet of steam to the centre of the petticoat pipe and chimney, thus producing the maximum effect as an ejector. The petticoat pipe P is in effect a continuation downwards of the chimney, the two acting similarly to a Friedman injector with two admissions, one above the petticoat and the other below it. The petticoat pipe is smaller in diameter than the chimney, being about 13 inches diameter; it has a cone-shaped bottom spreading out to about 17 inches diameter, and an extension sleeve at the top; it is held in place by a cross stay in the middle and a pair of stays at the top to prevent vibration. Thus the areas of the openings at top and bottom are both adjustable, so that the smoke-box can be kept clear of cinders, and the draught through the tubes can be equalised top and bottom, to obtain the best results.

Chimney.—The chimney or stack for coal burning is 16½ inches diameter inside, and has the base casting made in two parts, Plate 28, one bolted permanently to the smoke-box, and the other riveted to the barrel of the stack, with a turned joint between them. This admits of the stack being readily changed for repairs, or for wood burning if required. The stack is of the "diamond" type, that is, it has a double-cone top of cast iron to admit a sheet of steel-wire netting for spark arresting, the netting being inserted in the joint between the two portions of the cone. This netting is 3½ × 3½ meshes per square inch with wire No. 12 B.W.G. thick (0·110 inch), and is protected in the centre by a cast-iron cone with curved faces to deflect the sparks aside, the cone being held by three vertical stays from the barrel of the stack. The barrel is of Bessemer steel No. 12 B.W.G. thick (0·110 inch), and is parallel in form.

The wood-burning chimney is made somewhat similar, except that it is all of steel No. 12 B.W.G. thick (0·110 inch); and the netting is made in the form of a flattened ⌓ in section, and is dropped in from the top to rest on a ring riveted to the inside of the stack; it is protected by a cone, as in the former case. The netting used is much finer, being 11 × 11 meshes per square inch, and made of steel wire No. 19 B.W.G. thick (0·040 inch).

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Ashpan.—This is constructed with dampers at each end, which are worked from the foot-plate; the bottom is slightly curved up at each end, Plate 25, to hold water if required. It is carried by studs tapped into the foundation ring, and is secured by cotters for easy removal. Ashpans for wood-burning engines have a fine netting screen inserted inside each damper, to prevent the ashes from being blown out.

Grate.—For coal-burning the grate consists of cast-iron crossbars, which are pivoted at each end on side bearers carried by studs in the foundation ring, Plates 25 and 26. The crossbars have a series of alternate fingers at each side, placed so that the fingers of one bar extend between those of the next, and leave $\frac{5}{8}$ inch air-space all round; the body of the bar is also perforated with air-spaces. The bars have levers below, connected with a coupling-rod R which is worked by a lever L from the footplate, so that they can be rocked on their bearings to break up all clinkers which may be forming, shake down the ashes, and clear the fire. The two front bars are replaced by a dump, where required, so that any clinkers which may be formed can be dropped into the ashpan without dropping the fire; the dump is also worked from the footplate.

The wood-burning grate is formed by two rectangular shelves running round the fire-box, the upper about 10 inches wide and the lower about 6 inches, each sloping down towards the centre, and open in the centre; a third similar shelf below is closed in the centre, forming a sort of tray which is the bottom of the grate. A vertical space of 3 inches for admission of air separates each. The two lower shelves are each carried from the one above, and the top shelf by side bearers in the fire-box.

Boiler Mountings.—Two Richardson "pop" safety-valves V, $2\frac{1}{4}$ inches diameter, are secured to the dome cover, Plate 27; one or both are locked so that they cannot be tampered with. Both are set to blow off at 150 lbs. pressure, and will do so within $\frac{1}{2}$ lb., thus effectually preventing any increase above that pressure. When carefully adjusted they will close as soon as the pressure drops $\frac{1}{2}$ lb. below the blowing-off pressure; they therefore prevent any waste of steam.

The whistle is screwed on a stem fixed in the centre of the dome cover. It is of the low-toned class, the bell being $5\frac{3}{8}$ inches diameter

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and 8 inches long outside; it is worked by a horizontal lever under the cab roof above the driver's hand.

A globe mounting is placed on the top of the fire-box inside the cab; the joint to the boiler is made with a loose ring, forming a ball joint to the plate and a flat joint to the mounting; both are ground joints, and are secured by three studs. This globe supplies steam to injectors, blower, heater, Westinghouse pump when used, and steam-gauge; the various cocks are screwed in symmetrically round the globe. A main stop-valve is placed inside the globe, so that the steam can be shut off from all of these, and any temporary repairs effected at once. This mounting also holds the steam-gauge and its lamp.

Tallow cups or lubricators are fixed on each side of the fire-box with blow-through valves; and are connected to the steam-chest by copper tubes carried along the inside of the boiler clothing, for the purpose of lubricating the cylinders and valves.

On the back of the fire-box are fixed a glass water-gauge and lamp, and a set of three try-cocks; the latter suffice to ascertain the water-level if the glass gauge should get broken or stopped by dirt. All these cocks are of the compression type, that is, having a screw spindle with conical end to screw down tight on the seat; and the glass-gauge cocks are designed so that they can be closed and the glass removed, and the whole space round their stems can be cleaned out, while steam is in the boiler. These gauges and the tallow cups are all screwed into the fire-box shell, no mountings being put on with flat joints and studs. All mountings are provided with wooden handles. A cast-iron plate is fixed above the fire-door, to hold oil cans &c. while running. Two handles are placed in convenient positions on the back of the fire-box, which are connected with the feed-cocks between the tender and the injector or pump.

The fire-door is of the Stirling type, secured by a hinge bracket on the back of the fire-box, and fastened by a latch; the centre of the door has a swinging panel, which is adjustable to admit air. Steel castings are now being used for this door by the writer, in place of forgings.

A blow-off cock is placed centrally at the bottom of the back plate, and is worked by a handle from the foot-plate.

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Cylinders and Saddle.—The saddle D, Plate 28, between the frames is an independent casting, bolted to the smoke-box, and fitting the frames with flanges on inside and on top. Each cylinder is fitted to the outside face of the frame, and is bolted with driving bolts, which also secure the inside flange of the saddle. The cylinders fit between lugs on the top of the frame, and on the top flange of the saddle; and the cylinders and saddle are keyed in position. The cylinder casting has an extension, forming the steam and exhaust passages, and connecting the cylinders with the smoke-box; this extension is securely bolted to the smoke-box and the saddle. This plan admits of either cylinder being taken off for repair or renewal, without interfering with the saddle or frame, enabling the work to be done in the shortest possible time and at the lowest cost.

The steam-chests are placed on the top of the cylinders, Plate 28, and are removable, so that refacing or repairs to the valve-seats can be done rapidly and conveniently. The joints at top and bottom are made with copper wire; and the studs which hold the cover also secure the chest in place. The steam passage being cast in the cylinder enters the chest at the bottom, behind the valve-seat. The chests are placed as close in as the smoke-box will admit, to afford protection. The steam ports are $16 \times 1\frac{1}{4}$ inch, and the exhaust port $16 \times 2\frac{5}{8}$ inches. The valves are of the Allen type with $\frac{7}{16}$ inch supplementary port in four sections; the lap is $\frac{15}{16}$ inch, and the lead $\frac{1}{8}$ inch bare. The travel in full gear is $5\frac{1}{8}$ inches, the throw of the eccentrics being 5 inches. Very satisfactory results are being obtained for economy, efficiency, and speed. All the valves are of cast-iron of the same quality as the cylinders; and no scraping is done on the faces, because the surfaces, when care is taken at first, become quite polished and hardened, showing that valves of this metal run with a very small amount of friction or wear.

The cylinders and steam-chests are lagged with wood over a sheet of asbestos cloth, and are sheeted with stiff Russian iron, Plate 28. The cylinder and steam-chest covers have casings of cast-iron.

Frames.—Plate 25. These are forged from selected scrap-iron under a 30-cwt. Davy hammer; and are each made in two parts, the

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splice being placed in front of the driving axle and secured with keys and driving bolts. The mode of manufacture of the main frame is to forge the top bar in one piece from end to end, then weld on the horns or pedestals with a split scarf, the welding being done under a 12-cwt. hammer; the bottom bar is then veed in, and the inclined bar at the back end is dabbed on at the top and veed in at the bottom; the lower jaw of the splice is forged, together with a portion of the pedestal. The front end or extension frame is made as straight as possible, to obtain economy in forging and machining; and is provided with lugs on the top only, to receive the saddle-flange and the cylinder.

Across the front end of the frame, and behind the buffer beam, a heavy plate F, 8 inches wide and $\frac{3}{4}$ inch thick, is secured by being checked into the frame and riveted with angle-irons to the buffer-beam plate and to the front foot-plate. This gives protection to the cylinders in case of accident, and has proved to be of great service. Stays are placed to connect the smoke-box with the front end of the frame, so as to add vertical stiffness to the latter.

The back end of the frame is secured by a heavy cast-iron foot-plate, which is accurately planed and well bolted in place. This casting carries a wedge arrangement, for taking up all slack motion in the coupling between engine and tender. Side brackets are bolted to the frame and foot-plate, for supporting the back end of the running boards and cab.

Motion.—The pistons are of the built-up class with two packing-rings, bull ring, and junk ring, all of cast-iron. The advantage of this plan is that the packing rings can be examined and replaced without disconnecting the piston-rod from the crosshead. The piston-head is put on the rod with a taper of 1 in 16, and is made sufficiently tight to shrink on, and is then secured by a fine-threaded nut. The piston-rods and slide-bars are forged of mild Bessemer steel.

"United States" metallic packing-rings are used for the piston-rods and valve-stems, and give full satisfaction; the rods continue in first-class condition, and a set of packing-rings lasts about twelve months.

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The cross-heads are of the four-bar type, and are of mild cast-steel, fitted with cast-iron gibs of cylinder metal.

The connecting-rods are of Siemens-Martin mild steel, with the oil cups forged solid on the straps. The coupling-rods are forged from best selected scrap-iron, without welding, and with solid eyes and oil cups forged on. Half-brasses and cotters are used in all these rods, on account of extreme cold in winter.

The motion proper is of the indirect kind, in the American style, for allowing free access to the steam-chest. The eccentric straps, expansion links, lifting links, reversing handle, and rocker arms, are all of mild cast-steel of English manufacture. All pins work in bushed ends where required. The weight of the motion is counterbalanced by a semi-elliptic spring S, Plate 26, bearing in front of the motion plate, and coupled to a short lever on the reversing shaft. The motion plate is of rolled mild steel, and the valve-rods are of forged mild steel.

Axles and Crank-Pins.—All axles are of Siemens-Martin mild steel, and are parallel, except in the centre between eccentrics &c. The crank-pins are of Lowmoor or Bowling hammered bars, and are case-hardened on the journals; the wheels are heated, and the crank-pins being turned parallel are driven in with a large tup and riveted over on the inside. The crank-pins have to be of the best material and extra strong, to withstand the effect of frost in winter, as cases have been known where all four have broken off suddenly when the engine was left standing long.

Wheels.—The driving wheels are of strong cast-iron, Plate 27, with hollow spokes of egg-shaped section and hollow rim. The counterbalance weight is cast in solid, the rim being cut at each end of the weight in order to prevent damaging the wheel by contraction. The counterbalance is calculated to balance the total revolving weights and one half of the reciprocating weights. The wheels are pressed on the axles with a hydraulic pressure of 80 tons, and then keyed tightly.

The tires are of crucible steel 3 inches thick, and are secured on the centres by shrinkage only; no other attachments are necessary to secure them, and they can be safely worn down to

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$1\frac{1}{2}$ inch thickness in winter and $1\frac{1}{4}$ inch in summer, without becoming loose or breaking.

The axle-boxes are of cast-iron with brass bearings babbitted. The back horn-block is wedge-shaped, with setting-up and locking bolts.

Truck.—The frame of the truck, shown in Figs. 5 to 7, Plate 29, consists of a cast-iron plate or saddle D, strongly ribbed and resting on the top bars of the side frames F; it has a lateral space in the centre, to allow the swinging casting G to move sideways on four links L hung on pins through the saddle. The swinging casting is free to revolve on a centre bolted to the underside of the saddle between the cylinders, thus forming the sole support for the front end of the engine.

Each side-frame F of the truck consists of two straight wrought-iron bars, connected at each end by a pair of horn-blocks or pedestals. The springs S, one on each side of the truck, are placed in the interstices of the frame in an inverted position, so that the weight is transferred direct from the centre of the top frame to the spring buckle, thus relieving the side-frame of the truck from any strain due to weight. The ends of the springs are connected to equalising bars H, one on either side of each spring, which rest on the tops of the axle-boxes.

The axle-boxes are of cast-iron, with loose brass bearings babbitted; so that by removing the sponge box and lifting the truck about half an inch the bearing can be removed with the fingers and a new one substituted. The collars on the axles are loose, to permit of this being done.

The axles have journals 5 inches diameter by 8 inches long. The wheels are Krupp wrought-iron coiled discs, 30 inches diameter, with $2\frac{1}{2}$ inch crucible-steel tires and Mansell clip-rings. They are put on the axles with a hydraulic pressure of 40 tons.

Cab.—The cab is of ash, open at the back in the centre, and having doors in front to pass out on the running boards. There are two windows on each side, one sliding and one fixed. The roof is double, and extends back over the front of the tender. Seats are placed on each side, the right-hand being the driver's. The central opening at back is provided with thick canvas curtains for winter use only.

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Pilot or Cow-catcher.—This is of oak, strongly bound with iron, and bolted on the front of the buffer beam, as shown in Plates 25 and 26. The point is supported by rods from the push casting C on the buffer beam, and by stays from the bottom back beam to the saddle between the cylinders; so that it cannot be broken down by the weight of an animal encountered on the line.

Clothing and Furniture.—The boiler is lagged with wood, so as to leave an air space of about an inch; and is then covered with heavy Russian iron, with bands of the same. The dome is similarly covered, with the addition of cast-iron base and cap.

The sand-box H has 9½ cubic feet capacity, and is placed on the top of the boiler for dryness, with a brass pipe at each side to the driving wheels; both valves are worked by one handle from the cab. It is finished in Russian iron, with castings for base and cap, similar to those on the dome.

A bell is placed on all engines, to be rung at crossings and on entering stations, in conformity with the law.

A pump is placed on the left-hand side of the engine, and a No. 8 non-lifting injector of Gresham pattern on the right-hand.

A gong is fixed in the roof of the cab, with a cord running the full length of train, for signalling stops by the conductor, or in cases of necessity or alarm.

These engines are occasionally equipped with Westinghouse pump and reservoir, for extra service as passenger engines.

Tender.—The tank has a capacity of 2,800 gallons of water and 10 tons of coal. It is mounted upon a wooden frame of white oak, which is strongly braced longitudinally and laterally, and is carried on two four-wheeled rigid-centre trucks, Plate 30. The two springs on the front truck are placed laterally on the cross frame, and of the four springs on the back truck two are placed longitudinally on the side frames and two laterally on the cross frame; thus the tender is carried on three points, and rides very steadily in consequence. The cross frames of the two trucks are of I beams, 10 inches deep by 5 inches wide and weighing about 40 lbs. per foot, secured at the ends by wrought-iron plates and to the side frames by driving bolts. The side frames are of two flat bars 3 × 1¼ inch and

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one 3×1 inch; the second 3×1¼ inch bar is gibbed at the ends to form a truss with the top bar, all three bars being secured to the axle-boxes at the ends. The axle-boxes are the standard freight-car boxes with removable bearings, so that duplication is carried as far as possible. The axles are of Siemens-Martin steel and are duplicates of those used under coaches and freight cars. The wheels are 33 inches diameter, of cast-iron with chilled treads. Hand-brakes are applied to both trucks, so as to equalise the brake power on all the wheels.

Painting.—The writer's practice is to paint the engines black, without stripe or ornament of any sort. The letters and figures are put on in gold leaf for passenger engines, and in yellow paint for freight engines. Extra large figures are put on the tender for the convenience of the traffic and operating departments.

S.C. Light Passenger Engines.—The foregoing S.A. class of freight engines are equipped as S.C. engines for light passenger service by substituting driving wheels of 5 ft. 9 ins. diameter, and adding Westinghouse automatic brake equipment complete, with improved brakes on the driving wheels, arranged to compress each wheel between two shoes, as shown in Plate 31, so as to neutralise the thrust on the axle. Extra care was taken in calculating and placing the counterbalance weights in the wheels, and a corresponding satisfactory result in steadiness has been obtained. The tender has also the automatic brake, arranged to admit of being worked by hand if necessary; and instead of cast-iron wheels, Krupp wrought-iron coiled disc-wheels of 33 inches diameter are used, with Martin-steel tires 2½ inches thick. The feed water is supplied by two No. 8 injectors, one non-lifting on the left-hand side, and the other lifting on the right-hand side.

S.B. Heavy Passenger Engines.—These are built on similar lines to the preceding classes, as regards type of wheel-base and general features. They are especially designed for working very heavy and fast trains, up to ten coaches weighing 60,000 to 80,000 lbs. each, and at speeds of 45 miles per hour between stations. Their weight

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in working order with two gauges of water and with fire in the fire-box is distributed as follows:—on truck 31,000 lbs., on drivers 64,800 lbs.; total weight 95,800 lbs. = 42·77 tons.

The cylinders are 19 inches diameter and 22 inches stroke, and the driving wheels are 5 ft. 9 ins. diameter. The tractive force is thus 115 lbs. per lb. of average steam-pressure in the cylinders.

The wheel-base is 23 ft. 6½ ins., and the distance between the driving wheels 8 ft. 9 ins. The coupling-rods are made of I section, for the sake of lightness and stiffness. The distance from the centre of the driving axle to the centre of the cylinders is 11 ft. 8 ins.

The springs are underhung, instead of overhead as in the preceding classes, thereby enabling the boiler centre to be placed lower; and the riding qualities are very satisfactory.

The boiler is 54 inches diameter outside the barrel, which is all in one sheet from the taper course to the front end, where it is connected with a solid wrought-iron ring, 10½ inches wide and ½ inch thick, in which the front tube-plate is riveted, thus dispensing with a longitudinal joint crossing the tube-plate flange. The barrel is 11 ft. 0¾ inch long, and 11 ft. 4¾ ins. between the tube-plates. The fire-box is 7 ft. by 3 ft. 6½ ins. outside, 5 ft. 4½ ins. deep from centre line, and 11¾ ins. above centre line at sides, to 12¼ ins. above at centre. The details of construction are otherwise exactly the same as in the preceding classes, except that the longitudinal seams of the barrel are here double-welted butt-joints, with the inside welt narrow and the outside one wide, the latter being double-riveted with wider pitch in the outer row of rivets. The tubes are exactly the same as in the preceding classes, except for length; and are 204 in number. The working pressure is 160 lbs. per square inch. The heating surface is as follows:—tubes (external) 1,235 square feet, fire-box 134·8; total 1369·8 square feet. The grate surface is 18·4 square feet.

The main steam-pipe is 7½ inches diameter inside and $\frac{5}{16}$ inch thick, and the branch pipes are 6 inches diameter. The steam ports are 18 × 1⅝ inch, and the exhaust port 18 × 3¼ inches. Allen valves are used with the Morse balancing arrangement; the latter consists of four cast-iron strips set on the back of the valve, jointed

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at the corners, and held up by springs against the inner face of the steam-chest cover, which is planed; a small hole in the back of the valve communicates with the exhaust. The average travel of the valve is $5\frac{11}{16}$ inches; the lap is $\frac{15}{16}$ inch, and the lead $\frac{3}{32}$ inch. The steam-chest cover is hollow for the steam to pass to the front end of the valve.

The truck has a wrought-iron frame, and the cross frame carrying the weight is of a truss form; the whole being rather lighter and stronger than in the preceding classes. The wheels are 36 inches diameter, of Krupp make, namely a wrought-iron coiled disc with steel tire; the axles, axle-boxes, and hornblocks are duplicates of those in the preceding classes.

The outside finish is considerably different, in consequence of the running boards being placed lower down, in a line with the top of the tender frame and foot-plate; a box splasher and sand box are put on the driving wheels. The feed-water is supplied by two No. 9 injectors, one non-lifting on the left hand and one lifting on the right hand; in Figs. 14 and 15, Plate 32, is shown the way in which the lifting injector is worked, which being more rapid and simple in action is considered preferable to the ordinary style. The engines are equipped with Westinghouse automatic brakes, similarly to the S.C. class; and also with a double sight-feed lubricator.

The tender has a capacity of 2,800 gallons and 10 tons of coal, and is built in a similar manner to the preceding, except in having 40-inch Krupp wrought-iron coiled disc-wheels with Martin-steel tires.

S. D. Consolidation Engines.—Plates 33 to 35. The term "consolidation" is simply used to denote that the engine has four pairs of driving wheels coupled and a two-wheeled truck or bogey in front. These engines have been designed for special service on the north shore of Lake Superior, where the grades and curves are frequent and heavy, and the service is almost entirely composed of through trains. They are intended to haul freight in summer, and passenger trains in winter when bad weather or the exigencies of traffic render this necessary; they thus require to possess the qualities

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of rapid steaming and steady free running, with a minimum internal friction and wear and tear from the high number of revolutions per minute. Their weight in working order is about 104,000 lbs. or 46½ tons.

Boiler.—The boiler barrel, as shown in Plate 33, is 54 inches diameter by 11 ft. 10½ ins. long, and is similar in design to that of the S.B. class of heavy passenger engines (page 206); but the longitudinal seams are all double-riveted lap-joints. The fire-box is made from the same class of bending blocks, but its shape is shallow and wide, so as to spread over the top of the frames; the boiler centre being 7 ft. 3 ins. high gives a depth of 3 ft. 9 ins. from centre to bottom of fire-box, or about 1 ft. 5 ins. depth of leg below the barrel. The fire-box is 8 ft. 9 ins. long by 4 ft. 2¼ ins. wide outside, and the thicknesses of plates and width of water spaces are similar to those in the former classes; but the top of the box slopes down from 12¼ inches above the centre line at the front to 4¼ inches at the back, in order to avoid burning the fire-box crown on descending grades. The system of staying &c. is the same as that in the former classes. The fire-box is carried on the top of the frames by four cast-steel slippers secured to the foundation ring and having lips to prevent side play. Two strong Lowmoor iron plates are secured to the outside of the box near the front end, and are bent under the frame and bolted; and at back end two heavy Lowmoor iron links connect the box with the frame, so that it is perfectly free to expand and contract but is allowed no other movement. The boiler is fixed only by being bolted at the front end to the cylinders; the motion plate, though having an extension to fit the underside, is not fixed to it. The tubes are 208 in number, 2 inches outside diameter, and No. 12 B.W.G. thick (0·110 inch). The pressure is set at 160 lbs.

Smoke-box.—This is of the "extension" type, as shown in Plate 33, with high exhaust-pipe and straight stack. In it is fitted a horizontal plate F, extending from the tube-plate to the front of the exhaust-pipe, above the line of the top tubes and below the tip of the exhaust, and fitted closely round all pipes; to the underside of this horizontal plate, and in front of the exhaust, is riveted a vertical

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baffle-plate L, with an extension piece at bottom which is capable of adjustment to regulate the draught through the tubes. From the front end of the horizontal plate a netting extends to the front of the smoke-box, and is made secure all round. The netting is similar to that in use for diamond stacks. The deposit of cinders in the extension of the smoke-box is dropped through a hopper P attached to the underside, the hopper being made air-tight when not in operation. The exhaust nozzle N is single; and the dividing partition inside the pipe is carried up as high as possible, Plate 34, to prevent "blowing over." This arrangement gives very free steaming qualities, with a decreased back-pressure in the cylinders.

Heating Surface.—The heating surface is as follows:—tubes (external) 1329·5 square feet; fire-box 118·7 square feet; total 1448·2 square feet. The grate area is 28·7 square feet.

Regulator and Steam Pipes.—Plates 33 and 34. These are similar to those used on the S.B. engines; but the length of fire-box does not admit of the regulator being worked from the back of box. The rod is therefore carried through a stuffing-box attached to the back of the dome and projecting inside the cab front. The handle is fixed horizontally as before, but is longer for convenience.

Chimney.—Plate 33. The chimney is smallest at about 6 inches above the top of the smoke-box, being 16½ inches diameter at that point and increasing to 18½ inches diameter at top. It is made of Bessemer steel plate, with cast-iron top and bottom rings; and has a light outer barrel cased with Russian iron, the space between having ventilating holes at top and bottom. The chimney base is a separate casting, as in the former classes.

Grate. — The grate consists of ten rocking bars and dump arrangement. The bars are made to rock in two sections of five bars each, so as to lighten as much as possible the work of rocking them.

Ashpan.—This is made in three sections, to admit of being taken down easily for repairs. It has two sliding doors in the bottom, to permit of ashes being dropped if necessary; and is provided with front and back dampers.

Boiler Mountings.—These are similar to those used on the former classes of engines.

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Cylinders. — As shown in Plate 34, these are of the "half-saddle" type, and are bolted together in the centre, the top forming the seat for the smoke-box. They are secured to the frames by being placed between the upper and lower bars, and bolted by four vertical bolts driven through both frame-bars and cylinders, and by three horizontal bolts through the lower frame-bar. They are also keyed in position between lugs on the frame-bars. The steam passage S in the saddle divides, and enters the steam-chest at the bottom at both ends. The exhaust passages E are brought as near to the centre as possible, where they enter the smoke-box; and are semicircular, to suit a circular exhaust-pipe. The cylinders are 19 inches diameter by 22 inches stroke, so as to reduce the piston-speed. The steam ports are 18 × $1\frac{5}{8}$ inch, and the exhaust ports 18 × $3\frac{1}{4}$ inches. The valves are of the Allen type with $\frac{9}{16}$ inch supplementary port; the lap is $\frac{15}{16}$ inch, and the lead $\frac{3}{32}$ inch full. The travel in full gear is $5\frac{3}{4}$ inches, the throw of the eccentrics being $5\frac{1}{2}$ inches. A bracket B is fixed on the underside of the saddle, to connect with the equalising lever of the truck, and so carry the front end of the engine.

Frames.—Plate 33. These are forged from selected scrap iron, and are each made in three pieces. The main frame extends from the back end to the front of the first driving wheels, and has extension arms to which the upper and lower bars at the front end are keyed and bolted. These bars carry the cylinder between them, and project to the back of the buffer-beam, being there keyed and bolted together. Cast-iron brackets are inserted between them, to carry the cross-bars for the truck bearing-centre and sleeve. The lower bar also carries the cross-bar for the truck radial centre R, Figs. 24 and 25, Plate 35. The front end is constructed similarly to that of the former engines, except that the angle-irons connecting the buffer-beam and heavy horizontal cross-plate are boxed to fit against the frames, and are bolted to them. This is necessary for hauling heavy loads backwards when required. The back end of the frame is formed of two heavy cross-bars, checked for the frame, and checked into the frame above and below, the upper one being extended to carry the back casting of the cab, and the lower one brought up to form a truss; and they are bolted together a t

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the outer end by the footstep rod. The drag-box D is bolted between these bars, and the pin hole is placed in front of them. The wedge block is bolted on the top of the upper bar, which is considerably the stronger; and the whole arrangement is made to suit any of the standard tenders for freight engines. A heavy cross-stay A is bolted to the back of the trailing horns; and behind the main drivers the upper bars and lower bars are connected by two cross-stays T, which have a stiff plate bolted on them; this arrangement entirely prevents any twisting movement in the frame from the weight of the boiler above. The motion plate M is secured to the top of the frames by brackets, and is placed between the first and second drivers; it has a stay-plate bolted on and extended to fit against the underside of the boiler barrel, with an angle-iron under the barrel but not fixed to it, thus preventing any upward deflection of the frame. A cross-stay on the top of the frames between the second and third drivers serves to carry the spring for counterbalancing the weight of the motion. A heavy wrought-iron strut is placed between the upper and lower bars of the frame between the first and second drivers, where the spring equaliser is placed below. The horn stays, plates, and wedges are all duplicates of those in the S.A. class.

Motion.—The motion is constructed in a similar manner to those of the former classes, the rough steel castings being duplicates of them in nearly all cases. The piston-head is solid, with split cast-iron rings sprung in, and is secured to the rod as in the former classes. The cross-heads, as shown in Figs. 16 to 18, Plate 32, are of cas steel, and are of the Laird type, that is, their sides D extend upwards and are bolted on the sides of a cast-iron slide-block B, which works between two bars R, both secured above the piston-rod, so that the lower bar passes through the cross-head and forms the lateral guide, while the upper bar is wider and covers the whole slide-block, thus giving extra bearing surface, besides acting as a cover to protect the lower bar; the whole arrangement is thus raised out of the way of dirt from the ballast. The connecting-rods are similar to those of the S.B. class; but are longer, so as to connect on the third pair of drivers. The side-rods are forged from best selected scrap iron, and the first and fourth ends are duplicates of those in the S.A. class.

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Axles and Crank-Pins.—These are of similar material to those in the former classes; the rough axles and the axle-boxes complete are duplicates of those in the S.A. class.

Driving Wheels.—The driving wheels, shown in section in Fig. 19, Plate 32, are of cast iron, with hollow spokes and rim, and are all from one pattern, with changeable crank-pin hubs, the balance-weight being cast partially solid in the first and fourth pairs, while the second and third pairs are cast hollow and filled with lead. As a result these engines run remarkably steadily and quietly. The wheels are 51 inches diameter with 3-inch tires, and the two centre pairs have bald or plain tires 6 inches wide, the first and fourth being flanged and 5½ inches wide.

Truck.—Figs. 23 to 25, Plate 35. The frame D of the truck is a wrought-iron forging, with two vertical cross-bars welded in the form of a rectangle upon two horizontal bars, which latter carry the horns bolted to the underside. A swinging casting G in the centre of this frame is connected with it by four inclined links and pins, and supports a hollow cast-iron pillar, working in a guide-sleeve which is carried by cross-bars C secured to the frame of the engine between the cylinders and the buffer-beam. A strong bolt in the inside of the pillar is fitted to it with a ball joint at the top, and has an eye at the bottom, to carry one end of an equaliser L pivoted in a casting B placed under the cylinder-saddle, Plate 34, as previously described; the other end of the equaliser is connected with the driving springs, and thus the equaliser carries the front end of the engine. The radial frame E of the truck is V shaped, Fig. 25, the two ends being bolted at the front to the main frame D of the truck, and the centre is bored and bushed for a centre pin R, which is carried by a cross-bar on the lower frame-splice, as previously mentioned, and also by a stay from the cylinder-saddle. The axle and boxes are duplicates of those in the S.A. class, and the wheels are duplicates of those in the S.B. class. The springs S are double spiral, two to each box, placed under the corners of the truck frame, and connected fore and aft by a pair of equalisers Q, shaped like a horse-shoe hung upon the top of the box.

Driving Spring-Gear.—As shown in Plate 33, the spring-gear is arranged in such a way as virtually to support the engine on three

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points. The weight on the third and fourth drivers on each side is carried by three springs inserted in the interior spaces of the frame; one heavy spring is in an inverted position in the centre, with the buckle bearing against the underside of the top bar of the frame, and each end is connected by hangers to a pair of equalisers resting on each axle-box, alongside of the frame; the other end of each pair of equalisers is connected to the buckle of a smaller spring, the ends of which rest in cast-iron shoes fixed to the underside of the top bar of the frame.

The first and second pairs of driving wheels have springs over the top of the frame, which are connected by hangers to an equaliser placed below the frame. The front ends of the first pair of springs are connected by a lateral equaliser, the centre of which is connected by a hanger to the back end of the truck equaliser, as previously mentioned.

Cab.—The cab is similar to former ones, but larger, being made wide enough to permit the driver and fireman to stand alongside the fire-box.

Clothing and Furniture.—The boiler is covered with a layer of thick woven asbestos felting of fine quality, and then lagged with wood and covered with Russian iron in the usual way. The clothing is continued inside the cab to the back corner of the fire-box, as a protection for the driver and fireman.

The sand-box H on the top of the boiler, Plate 33, serves for forward running only. For backing, two hind boxes are placed under the running boards below the cab.

The feed-water is supplied by two lifting injectors, one No. 8 on the right-hand side, and one No. 9 on the left-hand.

The remainder of the attachments are similar to those on the other engines.

These engines are equipped with Westinghouse pump, reservoir, and driver brakes between the first and second pairs of drivers; also with the American steam-brake between the third and fourth pairs of drivers.

Tender.—The tank has a capacity of 3000 gallons of water and 10 tons of coal. It is mounted and carried in exactly the same way

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as in the former classes, Plate 30. The tender brakes are arranged to work either with the Westinghouse air-brake or with the American steam-brake or by hand. The weight of the tender when empty is 35,000 lbs., and when fully loaded 85,000 lbs.

S. G. Mogul Engines.—The term "Mogul" is applied to such engines as have a two-wheeled truck in front of the cylinders and three pairs of coupled drivers behind. The author is now engaged in working out the details of a class of Mogul engines with 19 × 24 inch cylinders, as shown in outline in Plate 36, designed for fast freight service in summer on the heavier sections of the road, and for heavy fast passenger service in severe winter weather. The lines of the S. D. class (page 207) have been followed to a great extent, in order to obtain the requisite boiler power; and duplication of parts of former classes is also closely adhered to, not a single new pattern being required.

The boiler is similar to that of the S. D. class, the same flange blocks being used; it is somewhat shorter in the barrel, but its centre is the same height above the rails, namely 7 ft. 3 ins., though the wheels are increased from 51 ins. to 62 ins. diameter. The bottom of the fire-box is made shallower at the back end, to clear the trailing axle-boxes; while the front end is kept to the full depth, to allow sufficient depth of fire below the bottom tubes. The frame is similar to that of the S. D. class, but with three pairs of horns; between the driving and trailing wheels it is forged down to suit the fire-box, thereby enabling the boiler centre to be kept to 7 ft. 3 ins. height, although driving wheels of 11 ins. greater diameter are used. The cylinders are made from the S. D. pattern, but lengthened in stroke to 24 ins., and made shallower in the boiler seat. Other duplicates of the S. D. class are the truck, buffer-beam, pilot, crosshead, crank-pins, spring saddles, details of spring gear, side-rod brasses, motion plate, back beams, drag box, cab, details of grate and shaker, chimney, exhaust and steam pipes, regulator and handle, steam-chest cover and hopper.

Duplicates of the S. B. class are the connecting-rod, piston and rod, valve buckle, eccentrics and straps, details of motion, rocker box, smoke-box front and door.

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Duplicates of the S.A. class are the wheel centres, tires, axles, boxes, horns and wedges, horn stays, and reversing handle.

Boiler mountings, brass fittings, fire-door, bell, and a number of minor details, are standard, and common to all classes. The tender duplicates with the S. D. class. The Westinghouse brake will form part of the equipment; and Delancey's balanced slide-valves will be used, as shown in Figs. 27 to 32, Plate 37.

The weight of this class will be about 100,000 lbs. or 44½ tons, of which about 86,000 lbs. or 38½ tons will be on the driving wheels. The boiler will be set to carry 170 lbs. pressure.

Cost of Production.—A batch of five engines of the S.A. class which the writer has recently completed cost, without extras, $5,205 each, or about £1,071; or 2·44 pence per lb. for the finished engine and tender. The cost of an English engine, built in the shops of the London Brighton and South Coast Railway, has recently been given by Mr. Stroudley at 5·57 pence per lb.* The cost here given by the writer, being less than half that of the English engine, may be regarded with some surprise; and a few leading details will therefore be added. This cost includes all the coal used in the forge, blacksmith's, boiler and other shops, as well as all small tools and supplies used in the construction of the engines, such as brooms, brushes, candles, chisels, files, hammers, handles for tools, hemp, oil, waste, sand paper, tallow, wrenches, &c.; and also a complete set of tools of all sorts, lamps, oil cans, jacks, dogs and wedges, fire-irons, &c., for the equipment of the engine in running order. But it does not include the salaries of foremen, draughtsmen, and clerks; repairs to machinery; maintenance of buildings; water or coal used in the stationary boilers required for running the shop engine. These are not included, for the reason that on some railways such expenses are charged in a lump sum, varying from 5 to 15 per cent., which is added to the cost of the finished engine. In the main shops of the Canadian Pacific Railway these expenses are about 5 per cent.; but in order to put these shops on such a basis as will compare with any

* Institution of Civil Engineers, Proceedings, March 1885, vol. lxxxi, page 149.

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other establishment, it is the practice to add 15 per cent. to the cost of both labour and material of the manufactured goods. Hence, by omitting this charge altogether in the cost above given, a comparison can be more easily made according to the varying practice of other railway shops and manufactories.

Detailed Costs.—With regard to the detailed cost of certain portions of finished work for these engines, the forged frames cost 2 pence per lb., including scrap (charged out at market value) and all coal; when planed, drilled, and slotted all ready for erecting, the frames cost $2\frac{2}{3}$ pence per lb. The finished boiler ready to go into the frames costs 4 pence per lb., the steel plates having to be imported from Scotland, and freight and duty paid. The total cost of cylinders, fitted with covers, studded, and ready for erecting, is $2\frac{3}{4}$ pence per lb.; and as the shops do not include a foundry, 2 pence per lb. has to be paid for the cylinder castings. The cast-iron driving-wheel centres cost $1\frac{1}{8}$ penny per lb., including cost of freight for over 400 miles. Connecting-rods and side-rods, fitted up with brasses, cotters, &c., all ready for use, cost $7\frac{1}{2}$ pence per lb.

The writer has lately built ten engines of the S.A. class and eight of the S.C. class, all of which are sent across the continent and are running between the Rocky Mountains and the terminus on the Pacific Ocean.

Appended is a specification of the tests prescribed for materials used in the construction of locomotives built outside the Montreal shops of the Canadian Pacific Railway.

Appendix.—Tests of Materials.

All materials used in the construction of the locomotive must be of the best quality of their respective kinds, carefully inspected, and subjected to the following tests. Notwithstanding these tests, should any defects be developed in working, the corresponding part will be rejected.

Boiler Iron.—All boiler iron to be best quality Lowmoor, Bowling, or Krupp. A careful examination to be made of every

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sheet, and none to be accepted that show mechanical defects. In every boiler one sheet to be ordered 3 inches longer than the size required, from which a strip is to be cut and tested. The piece so tested must have an ultimate tensile strength with the grain of not less than 50,000 lbs. per square inch, an ultimate tensile strength across the grain of not less than 45,000 lbs., and must show a ductility, measured by elongation or reduction of area, of not less than 20 per cent. Should any of the test pieces fail to fulfil the above requirements, the entire boiler may be rejected. Should any plates develop defects in working, they must be rejected. Each plate must be stamped with the maker's name.

Boiler and Fire-box Steel.—A careful examination to be made of every sheet, and none to be accepted that show mechanical defects. A test strip from each sheet, taken lengthwise of the sheet and without annealing, should have a tensile strength of 55,000 lbs. per square inch, and an elongation of 30 per cent. in an original length of 2 inches. Sheets are not to be accepted if the test shows a tensile strength less than 50,000 lbs. or greater than 65,000 lbs. per square inch, nor if the elongation falls below 25 per cent. Should any sheets develop defects in working, they must be rejected.

Iron and Steel Stay-Bolts and Boiler Braces.—Iron or steel for stay-bolts and braces must have an ultimate tensile strength of not more than 60,000 lbs. nor less than 48,000 lbs. per square inch, with an elongation of not less than 20 per cent., and a reduction of area of fractured section of not more than 35 per cent. It must also withstand the following test. A piece of the iron or steel from 18 inches to 24 inches in length is to have one end fastened in a vice; over the other end a piece of pipe is to be passed to within 6 inches of the vice. By means of the pipe the sample must be bent until the end is at right angles to the portion in the vice, and then bent back to its original position. This must be repeated not less than twelve times without showing fracture, the bending being each time in the opposite direction to that previous.

Boiler Tubes of Steel or Iron.—All boiler tubes must be carefully inspected and be free from pit-holes or other imperfections. They must be rolled accurately to the gauge required. They must be

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expanded in the boiler without crack or flaw. When tested, iron or steel tubes must show a tensile strength of not less than 55,000 lbs. per square inch, and a ductility of not less than 15 per cent.

Tubes of Brass or Copper; Brass and Copper Pipes.—Tubes of brass or copper to be of uniform circumferential thickness and solid drawn; to be perfectly round. A piece 30 inches long, annealed and filled with rosin, must withstand being doubled until the extremities touch each other without showing defects. A piece 30 inches long, not annealed, filled with rosin, and placed on supports 20 inches apart, must withstand bending to a deflection of 3 inches without showing defects.

Bar Iron.—All bar iron (flats, rounds, and squares) must be capable of sustaining an ultimate tensile stress of 50,000 lbs. per square inch, with an elastic limit of 25,000 lbs., and a minimum ductility, measured by elongation or reduction of area, of 20 per cent.

Discussion.

The PRESIDENT explained that it was the author's own desire that the present paper should be read and discussed in his absence, as he did not see any such likelihood of being able to come over from Canada as should afford sufficient reason for preferring that it should be delayed until he could visit this country.

Mr. THOMAS W. WORSDELL, Member of Council, said that, having had a considerable amount of experience, some fifteen or twenty years ago, with the American type of locomotives, there were one or two points in which the author seemed to him to have gone back considerably from the American practice, and in regard to which therefore it was unfortunate he was not present to explain his reasons.

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The principal point that attracted his attention was the method of attaching the cylinders. It would be observed how different from the English practice was the very wide spread of the outside cylinders. They were put as much as 6 feet 9 inches apart from centre to centre; and the ordinary practice at that time in American locomotives was to have an independent saddle fixed between the frames, with the cylinders independently bolted on each side of the saddle, which contained all the steam and exhaust passages. It was found that the joints would seldom keep tight; the steam passages connecting through the saddle from the steam-pipe to the cylinder, and the exhaust passage from the cylinder to the smoke-box, were continually leaking. The result had been that a better method of making a firm attachment had to be devised; and indeed the author appeared to have shown this in Plate 34, where each of the two cylinders seemed to be cast in one piece with half of the saddle, and the two halves were then bolted together in the middle; and the middle portion took only the exhaust, which was not of high pressure, and consequently this plan did not involve danger of leakage.

Another feature in which the Canadian engine differed so much in appearance and in form from English locomotives was what had been described in the paper as the wagon-top boiler. There was indeed nothing in the wagon-top boiler different from what had been used originally in England some thirty or forty years ago, excepting that, instead of there being an abrupt connection between the barrel and the fire-box, the wagon-top in the American practice was connected by a sloping or taper plate. No doubt the reason was that the practice of flanging was one in which there had not yet been any very great experience in America. Hitherto the general practice in that country had been to connect in the simplest possible way, either directly by a sloping or taper plate, or by means of an angle-iron joint. Up to a recent date flanging was done by hand in America, and a small piece at a time, in default of having fully formed flanging-blocks and a hydraulic press for doing the whole at one process.

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(Mr. Thomas W. Worsdell.)

Another notable feature referred to in the paper was the cast-iron wheels. About the year 1866 he remembered that on the Pennsylvania Railroad the engines had solid cast-iron wheels, without any part cored out; the consequence was they frequently had cracked spokes and cracked rims, and had to depend entirely on the tires. About 1866 the hollow spoke was introduced; and from that time forward he believed the hollow-spoke cast-iron driving wheel had become very general. Whether the Pennsylvania Railroad was the first to use it he did not remember; but it was introduced there about that time, and was considered to be a great improvement. Not many weeks ago, in looking through some of the old material and discarded wheels and axles from some sections of the North Eastern Railway, he had been much struck to find a hollow-spoke cast-iron wheel, which he was informed was at least thirty-five years old; it must therefore have already been long in use before the introduction of similar wheels on the Pennsylvania Railroad.

Very little was said in the paper about the use of mild steel for fire-boxes and boilers; but it was a fact that American engineers seemed to have been able to use mild steel for fire-boxes, whilst in English practice its use for this purpose had not yet been found generally satisfactory. It was quite true there were steel fire-boxes running in this country which had made pretty good mileage; but as a rule the copper fire-boxes had not been departed from, or where they had been departed from they had in many instances been reverted to. Having himself made a large number of steel fire-boxes in America, he had had no failures whatever with them; but the water had been exceptionally good, and he regarded this as the main reason why the steel had stood so well. As however the use of steel fire-boxes was universal in America, it would be interesting to know whether on lines where the water was very bad the thin mild steel in use for fire-boxes was found satisfactory under the high pressures that were carried.

The form of cross-head described in page 211 he distinctly remembered being introduced by Mr. Laird, with whom he had been associated about 1865 on the Pennsylvania Railroad. It would be

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seen that it was a form which had been used extensively in England.

The same remark that he made regarding the fire-box might apply to the tubes. It was almost the universal practice in America to use iron or steel boiler-tubes. Although this was also largely the practice already in this country, it was perhaps more general to use brass or copper tubes; but these were hardly ever used in the States.

With regard to the cost of production, there must of course be a material difference if all the tubes were of iron instead of brass, and the fire-box of steel instead of heavy copper, and other parts of the engine of cast-iron instead of costly brass, weight being of very little consequence on some of the American lines. But it was a question whether the cost of maintenance was not an item that should be well taken into consideration, besides the cost of production. It was sometimes urged that cheap material should be used, and when it was worn out it should be thrown away as it did not cost much. But it depended upon the amount of labour expended upon each part of the machine whether it was to be thrown away when too much wear had taken place; and he was inclined to believe that the very best material, however expensive it might be, if it was to have a large amount of manual or mechanical labour of any kind put upon it, was the cheapest in the end, when the maintenance of all the parts and the stability of the engine and its general strength were taken into consideration. For instance, while the English used largely steel and wrought-iron forgings, the Americans used largely heavy castings. Forgings had a great amount of labour on them, while castings had comparatively little. The objection to the labour required in forgings was now being got over by employing steel castings; and no doubt these would be the great factor in reducing the cost of English locomotives.

Mr. SAMUEL W. JOHNSON, Member of Council, said one point which had struck him in these Canadian engines, as compared with English practice, was the use of cast-iron wheels; another was the tires fastened by their own shrinkage without any other kind of

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(Mr. Samuel W. Johnson.)

fastening; and a third was that the engines had steel instead of copper fire-boxes. The following comparison with the engines under his charge on the Midland Railway would serve to show some of the main differences between the English and Canadian practice :—

Comparison of English and Canadian Locomotives.

MIDLAND RAILWAY.	CANADIAN PACIFIC RAILWAY.
Six-coupled Goods Engine and Tender.	S.A. Four-coupled Engine with Bogie and Tender.
Cylinders 18 ins. diam., 26 ins. stroke.	Cylinders 17 ins. diam., 24 ins. stroke.
Wheels 4 ft. 10 ins. diam., wrot-iron.	Wheels 5 ft. 2 ins. diam., cast-iron.
246 Tubes brass, 1⅝ inch diam.	185 Tubes iron, 2 ins. diam.
Fire-box copper.	Fire-box steel.
Heating Surface { Tubes 1150 square feet. Fire-box 110 square feet. Total 1260 square feet.	Heating Surface { Tubes 1132 square feet. Fire-box 112½ square feet. Total 1244½ square feet.
Tender 3250 gallons.	Tender 2800 gallons.
Weight of engine and tender empty 53½ tons.	Weight of engine and tender empty 47 tons.
*Cost { £1677 total. £31 7*s.* per ton. 3·36 pence per lb.	†Cost { £1071 total. £22 15*s.* 6*d.* per ton. 2·44 pence per lb.
*Including 10 per cent. added on all labour.	† Net cost, except items specified.
Credit not taken for scrap.	Credit taken for scrap.

Detailed Costs per lb.

Cylinders fitted complete 1·87 pence.	Cylinders fitted complete 2¾ pence.
Coupling rods 4·89 pence.	Coupling rods 7½ pence.
Connecting rods 6·14 pence.	Connecting rods 7½ pence.
Cast-iron wheel centres 0·63 penny.	Cast-iron wheel centres 1⅛ penny.

It would be seen that the cost of production of the Canadian engine was £1071, while that of the English engine was £1677: the difference was accounted for by the use in this country of brass tubes, copper fire-boxes, wrought-iron wheels, wrought-iron crank-axles, brass axle-boxes, and plate frames. The average cost of the Canadian engine was stated to be 2·44 pence per lb.; while in a number of engines which he had recently made, six-wheel coupled, but in other respects of pretty much the same type, the

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average cost was 3·36 pence per lb., the difference being principally due to their having copper fire-boxes and brass tubes, as against steel and iron. Among the detailed costs he found that the English coupling rods cost 4·89 pence per lb. as against 7½ pence mentioned in page 216; and the cost of cast-iron wheel centres, which he had made for some engines used for shunting, was 0·63 penny per lb. as against 1⅛ penny in the paper, the latter including the cost of freight over 400 miles.

Mr. ARTHUR PAGET, Vice-President, asked whether Mr. Johnson was giving the real actual cost as a manufacturing firm would take it, including interest on capital, rents, taxes, buildings, and superintendence; or whether he was omitting these, as seemed to be done to a certain extent by the author of the paper.

Mr. JOHNSON explained that the entire cost of the English engine, about £1677, came to about £31 7*s.* per ton, as against about £22 15*s.* 6*d.* per ton for the American engine; but the larger amount included an addition of 10 per cent. on all labour, which, after allowing for the above-named difference in the qualities of materials, would bring the result to about the same amount as that given by the author.

He should be glad to know how the steel tires were found to answer without fastenings: on his own engines he certainly should not like to try steel tires without any fastenings except their own shrinkage, as he should consider them unsuitable for fast travelling. The Mogul type of engine was not made in this country, and he did not think it was likely to come in.

Mr. ROBERT H. BURNETT considered the present paper was of interest as indicating the advance or otherwise in Canadian locomotive practice on the American type of engine, on which, as stated in page 188, the general design of the engines described was based. If looked at from this point of view alone, the Canadian engines appeared to be fully abreast of American practice, so far as he had had experience of it.

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(Mr. Robert H. Burnett.)

In discussing the relative merits of American and English locomotives, it was futile he thought to compare the former, whose chief merit was adaptability to rough roads, with engines designed for the strong, well made, and well maintained railways of this country; and it was not to be assumed that Canadian or American practice was in any way in advance of English practice, because the locomotives used in this country might not be suitable for the rough roads peculiar to Canada and other parts of America. It was equally unreasonable to draw comparisons between locomotives made in this country for some of our colonies twenty or twenty-five years ago, and still at work there, with American locomotives of comparatively recent construction: seeing that the former were made at a time when the lines were less curved than later extensions, and when the provisions now necessary for the modern sharper curves were not required. Comparisons to be of use should be made between engines contemporaneous in date of construction, and built for countries where the conditions in regard to curves and gradients and roadway were similar to those of Canadian or American railways. From this point of view there did not appear to him to be a single arrangement or detail that showed anything in advance of the best English practice to be met with in the Australian colonies, where he had himself had experience with both English and American locomotives.

The general designs of these Canadian engines were spoken of in page 188 as presenting three advantages:—firstly, in giving a flexible wheel-base to suit the road when disturbed by frost and thaw; secondly, in affording easy access to all parts of the mechanism; and thirdly, in enabling necessary repairs to be effected with the greatest facility. With respect to the first of these features it might be remarked that English engineers were not called upon to design locomotives for countries where the roads were so seriously disturbed by frost and thaw as they were in Canada. But short of any special provision there might be in the Canadian Pacific engines to meet that extreme condition, he failed to find among the whole of the details described in the paper anything which gave these engines any special superiority over locomotives of English design for service in our

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Australian colonies and elsewhere. In fact flexibility of wheel-base seemed to him hardly to constitute a special feature in these engines, after he had been accustomed to English-built engines working with ease and freedom round constantly reversing curves of 8 chains radius on inclines of 1 in 40 and even 1 in 30 on the main lines of the New South Wales Railways. This was a much more trying duty than that required of the locomotives on the Canadian Pacific Railway, on which it was mentioned (page 186) that the maximum gradient was only 1 in 100, and the sharpest curves not less than 955 feet or about 14 chains radius.

With regard to the second and third features named, the only provision which seemed deserving of notice as calculated to secure them, and not usual in English practice, was the placing of the steam-chests and slide-valves outside the frames, on the top of the cylinders, thereby necessitating the introduction of rocking-shafts, on account of the eccentrics and link-motion being kept inside the frames, as in English practice.

The old-fashioned bar-frame, now obsolete in this and most other countries, was adhered to for some strange reason which he was at a loss to understand, no explanation of this preference being offered in the paper. While he failed to see what was gained by the retention of the bar-frame, it seemed on the other hand very clear that with the 4 ft. 8½ ins. gauge the width between the frames, available for the fire-grate, was thereby narrowed by as much as one-sixth; or the fire-box had to be cut short to enable it to be spread over the frames, as in the case of the Consolidation engines shown in Plate 33, which necessitated either a shallow box, or an increase in the height of the boiler from the rail-level. In the Consolidation engine the height of the centre of the boiler was 7 ft. 3 ins. (page 208), with wheels only 4 ft. 3 ins. diameter.

With respect to the material of the fire-box plates and the tubes, it was well known to be a question almost entirely of the quality of the water used, and to some slight extent also of the quality of the fuel. If the water was good and free from lime, iron or steel would answer for the plates and tubes. But when the water was not good, copper plates and brass tubes gave better results, and were

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(Mr. Robert H. Burnett.)
more economical in the long run. This had been the experience on the New South Wales Railways, where in engines of American construction, having steel fire-boxes, he had found that within three years of their going to work the lower parts of the fire-box plates failed by buckling and cracking in lines from the stay-bolts, and had to be repaired by cutting out the lower portion to the height of about 2 ft. 6 ins., and patching with new plate. The same objection applied to the use of iron tubes, of which the replacement had to be commenced in American engines after two and a half years' use, in consequence of their becoming perforated by corrosion.

Cast-iron wheel-centres, as used in Canadian and American locomotives, answered well enough no doubt for diameters not exceeding say 4 feet, and for low speeds; and they enabled a saving to be effected in first cost, for which credit might be fairly claimed. But for the larger sizes of wheels in common use, wrought-iron centres were not only lighter, but being more elastic they caused the tires to suffer less. They were also more reliable than cast-iron centres. The New South Wales Railways had obtained from one of the ablest makers in the United States two locomotives for passenger traffic, which had driving wheels 5 ft. 3 ins. diameter with cast-iron centres. Within little more than two years of their going to work, two of these centres, one in each engine, split at the boss and had to be replaced. As the engines were four-coupled and the other wheels were only 2 ft. 6 ins. diameter, the failure of wheels over 4 ft. diameter was here at the high rate of one in four. This was possibly an exceptional case; but still these locomotives had been supplied as examples of the best American design and make. With wrought-iron wheels he had met with no such failures. There was also an important objection to cast-iron wheels, in the circumstance that the contact of their bosses with the cast-iron axle-boxes, with which American engines were usually fitted, resulted in great wear on lines with sharp and frequent curves. At all events that had been the experience in countries where the dryness of the climate caused much dust; although it was right to say that on the New South Wales Railways this objection had been experienced principally with the American locomotives of the Consolidation

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type, and in their case was in a measure due no doubt to the comparative rigidity of engines having as many as eight coupled wheels, and to the cross straining incidental thereto.

With respect to minor details in American engines some saving was effected in first cost, but at the expense he thought of durability. Each item taken alone might not be serious; but taken as a whole they formed an important feature in any comparison between American and English practice. The bogie, for example, in the American engine was much inferior in workmanship and much less substantial than that of an English engine. Again some saving in first cost was effected in American and Canadian practice in the matter of axles. While the axles of English locomotives were made with the wheel seats of larger diameter than the rest of the axle, in order to prevent the risk of breakage within the boss or at the point of junction with it, where an incipient crack could not be detected beforehand, American practice was to turn down the ends of the axles, where they entered the boss, to an equal and often to a smaller diameter than the rest of the axle. Again the axle-boxes and axle-forks in American engines were less durable than those of engines made in this country. What seemed indeed to be aimed at in American locomotive construction was to make an engine not so much with a view to endurance and economy in working, but one which, when it broke down, could be readily patched up in an out of the way district; while the object aimed at in this country was to make an engine not only economical in working, but which could be relied upon not to break down by the way, and which would do the duty required of it with the smallest cost for maintenance and repairs.

The American type of tender, mounted on bogies as described in page 204, formed a very flexible vehicle, suitable for going round exceptionally sharp curves, say of a radius no greater than that of a large turntable. But such a duty was not required of tenders, any more than of the engines themselves; while the form of construction adopted was very unsuitable for the application of powerful brakes. Tenders so built compared very unfavourably in this respect with the six-wheeled tenders of English design, which, while excellent

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(Mr. Robert H. Burnett.)

for brake power, ran with ease round curves of half the radius of those on the Canadian Pacific Railway, being without flanges on their middle wheels. The question of brake power was of course a more important one on lines with such steep gradients as those on the New South Wales Railways than on the Canadian Pacific, where, with the comparatively easy inclines, the defect in the construction of the American type of tender had probably not shown itself.

The standard passenger engines in use on the New South Wales Railways since 1877 corresponded very closely in their leading features with the S. A. Canadian engines described in the paper, although they had slightly greater tractive power, namely 117 lbs. per lb. of pressure in the cylinders, instead of 112 lbs. as in the Canadian engines. They had outside cylinders, 18 ins. diameter by 24 ins. stroke, and four coupled wheels of 5 ft. 6 ins. diameter, and a four-wheeled truck or bogie in front with lateral motion. Their weight in working order was 37½ tons, of which 25¼ tons were on the coupled wheels. They were provided with compensating beams between the springs. Prior to 1877 the standard passenger engines were almost identical with these, but the bogie had only two wheels in place of four.

Prior to 1881, the standard goods locomotives on the New South Wales Railways were six-wheel coupled inside-cylinder engines, the cylinders being 18 ins. diameter by 24 ins. stroke, and the wheels 4 ft. diameter. In 1881 he had modified them by putting a two-wheeled bogie in front, placing the cylinders outside, and increasing the stroke to 26 inches, the weight in working order being 41¾ tons, with 35½ tons on the six coupled wheels. They were provided with compensating beams between the springs. Engines of this type, while retaining the substantial character of the English engine, possessed in the fullest degree the flexibility claimed for the engines used in Canada and the United States, and were in all essential features equivalent to the Mogul engines described in page 214 of the paper, except that their tractive power was greater, being 176 lbs. for each lb. of pressure in the cylinders. These engines had so fully met the conditions of working and the requirements of the roadway that they had been frequently repeated since their first

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introduction. He therefore considered that English engineers were not behind Canadian or American engineers in adapting locomotives to the particular conditions under which they were required to work.

Mr. ROBERT S. BOYER could not understand how it was possible for the cylinders (page 216), for which twopence per lb. had to be paid in the rough castings, to cost no more when finished than $2\frac{3}{4}$ pence per lb.; because the loss of weight in the finished cylinders would have to be taken into consideration, and also the addition of more costly material in the form of studs and fittings.

It was mentioned in page 195 that the boiler was not generally subjected to the hydraulic test, because it might be injuriously strained by the excessive pressure. This however was not found to be the case in English practice, in which the necessity of the hydraulic test was generally recognised; and he could not at all agree in the desirability of foregoing it.

Mr. JOHNSON considered the figures given for the cost of the cylinders were quite right, because in his own Midland engines he found the cylinders fitted complete cost 1·87 pence per lb.

Mr. DAVID JOY thought it was a mistake to compare English and American locomotives as to which was best, because they were two quite different machines, designed for different requirements. This he had always maintained, especially during his visit to the States, where he had had every opportunity of seeing the American engine, and had repeatedly been asked to make such a comparison. The American engine he considered was a marked example of natural selection, or the survival of the fittest design for the special work required to be done: namely hauling the greatest possible loads over very difficult and crooked roads, and without regard to fuel economy. But it was not suitable for the requirements of English railways, as shown by a trial made some years ago. On the other hand the English locomotive was suited admirably for the extraordinary work it had to do: namely hauling fair medium trains at very high speeds continuously, on good roads, and with great

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(Mr. David Joy.)

economy both as to repairs and as to fuel consumption, which in England was a great point. This type of engine had been matured by the talent and experience of some of the ablest engineers in the world; but it was not fitted for the trains or the roads which the American locomotive worked successfully. It was a question therefore how far some of the features of the American engine might be adopted with advantage in the English engine: notably the elasticity of the whole structure, or of some of its parts. Thus the pony truck, carrying the leading end of the Mogul type of engine, might relieve some of the strains coming on the front end of some of the very large English engines, which were now carrying far too much weight on their leading wheels.

With regard to steel, it appeared to be used with great satisfaction for the fire-boxes; but he understood they had to undergo a periodical cutting out and renewal of the lowest part all the way round. When new the steel plate was only a quarter of an inch thick; and where cut it looked like a piece of silver.

The old cast-iron wheel mentioned by Mr. Worsdell he believed must have come from one of the old engines built by Mr. John Gray, who he believed had been the first to introduce expansion in locomotive engines, and who had built numbers of his express engines with 6 ft. cast-iron wheels having hollow spokes.

Mr. JAMES HOLDEN said that for the construction of fire-boxes three different varieties of steel plates had been tried on the Great Western Railway during the time he was on that line, two made by some of the best English manufacturers, and one specially imported from America; but the experience with all of these had been very unsatisfactory: they cracked across the rivet-holes and down the corners, and were taken out after doing a comparatively small mileage. On the Great Eastern Railway also a steel fire-box had been tried, which after doing some 80,000 miles had to be taken out, having previously been cropped round the bottom. On this railway he had a number of engines with 5 ft. 2 ins. cast-iron wheels, which were working very satisfactorily; but he did not fasten the tires on in the American fashion, but used Mansell

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fastenings instead. These engines were used for running fast goods trains, not passenger trains. Some years ago the Great Eastern Railway built a number of engines of the Mogul type, which had been working till very recently; they took a heavy load, but were found to compare unfavourably with engines of English type doing the same service, being more expensive both in fuel consumption and in repairs.

Mr. DAVID GREIG, Vice-President, considered the English locomotive could hardly be made better than at present for English lines; but he did not know how it could run in countries where the track went up and down three inches, and varied also in the space between the rails. In India indeed, where the railways were very nearly perfection, English locomotives did very well; but for railways in countries like New South Wales, South Australia, and New Zealand, they were altogether unsuited. For a bad road, and for the circumstances under which the locomotives described in the paper worked on the Canadian Pacific Railway, the American locomotives were much better adapted than any English engine that had yet been made. English manufacturers were losing their position through not following the lead of those who were their pioneers in matters of this kind. The subject of the present paper was dealt with by the author in the most practical way, and it was advisable that every locomotive maker should study it carefully. He remembered standing in Sydney station and seeing an engine of English build, second to none in the world, come in with some of the rivets sheared off the frames by the strains to which they were subjected in consequence of their rigidity. This would not occur with American engines, because they had sufficient elasticity to overcome the difficulties of the road. He had himself passed over the Canadian Pacific Railway as far as about 400 or 500 miles beyond Winnipeg, but no farther; and on a track that was being laid at the rate of 3¾ miles a day he had seen locomotives coming up before it was levelled. Such a sight he had never seen before. English locomotives could not do a thing of that kind. He was particularly impressed with the simplicity of the American engine,

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(Mr. David Greig.)
with its cheapness, and with the remarkable ease with which its parts could be replaced.

With regard to cast-iron wheels, he had seen them cast in the Pennsylvania shops, and once bought ten tons of old discarded wheels, which he brought over to England and took to the foundry and asked the men to cast them into cylinders in any way they liked; but they told him they could not break them. The cast-iron wheel however was not altogether of so much importance for English locomotive makers, because they had a still better material for wheels, namely steel; and they were not likely now to revert to the cast-iron wheel, for the simple reason that the cast-iron they would make it of was not so good as the American.

With regard to the boilers of American locomotives, they were hardly what would be called boilers in England. They were not well put together, and in his opinion were bad from beginning to end; and the sooner they were altered, the sooner would they be able to compete with the English make. At the present time he was making six boilers a week with fire-boxes of Siemens-Martin steel; but they were of short length, and the contraction and expansion did not tear them to pieces as was the case with the long boxes made in America. The sooner the accordion principle of contraction and expansion was adopted, on the corrugated system introduced by Mr. Fox, the sooner would the proper construction of fire-box be attained.

Mr. DRUITT HALPIN said the only American engine he had ever seen was the one shown in the Paris Exhibition of 1878, which for design, workmanship, and material, left a very great deal indeed to be desired. Among the peculiarities of the American type of engine, one of the first to attract attention was the system of trellis-work called the frame, which was of course a very old construction, being nothing else than the old discarded Bury frame. In the very early stages of English locomotive making that arrangement had been discarded; and it had never been reverted to in this country. What was thought of it in America seemed evident from Plate 31, from which he inferred that even the strain from the brake-blocks when

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on one side only of the wheels was more than it was thought desirable to throw upon the bar-frame; and the levers and double blocks shown in Plate 31 were therefore required for taking the strain off the frame, though no difficulty of that kind was experienced in this country with the plate frame. Another great objection to the bar-frame was that it robbed the fire-box of width, and thereby led to the abnormally long fire-boxes that were such a great evil, particularly when made of steel, to which the expansion and contraction did so much harm.

The wagon-top boiler had been stated by Mr. Worsdell to be of English origin; and it was well known that originally the English fire-box was cranked up above the top of the boiler barrel. One of the best designs which had been perpetuated in English locomotives he considered was the Crampton boiler, which had simply a flush top from one end to the other. The wagon-top boiler with its rise at the back end was supposed to give the advantage of getting the regulator high up and thereby avoiding priming. But this was accomplished at the expense confessedly of nearly filling the whole barrel with water, so that the area of water surface was greatly decreased; and it seemed questionable to himself whether such a decrease of the water area would not increase the trouble it was intended to avoid. From the mention in page 196 of a drooping flange or collar on the regulator pipe, it seemed evident there must be some good reason for putting the flange there. But on the Continent he had seen a much more elegant way of preventing priming; wherever a dome was to be placed on a boiler, the hole in the boiler was cut somewhat smaller than the dome, and the boiler-plate was flanged roughly downwards or inwards round the hole, not with blocks but with hammers. That plan gave a great strengthening all round the hole, and also stopped the priming most effectually. In the dome shown in Plate 27 it appeared to him that turning the flange out, whereby the metal was necessarily thinned at the flange, and then riveting it on the boiler, made but a very poor job, notwithstanding that some sort of compensation was attempted by inserting an extra thickness of plate as a strengthening ring.

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(Mr. Druitt Halpin.)

The fire-hole was described in page 191 as elliptic in form, 16 inches long by 14 inches high. When made so nearly round, it was not clear to him why it should not be made truly circular, so as to get a plain simple construction.

The boiler work was stated on page 194 to be all punched, which he thought in the light of present experience was low-class practice. It would also be observed that in the S.A. light engines the longitudinal seams of the boiler barrel of 52½ inches diameter were double-riveted zigzag with lap joints. But in the S.B. heavy engines, with a boiler only 2 inches larger in diameter and only 10 lbs. higher pressure, the better practice was adopted of riveting the longitudinal seams with double-welted butt-joints. Yet further on (page 208), in the boiler of the S.D. Consolidation engines, with the same larger diameter of 54 inches and the same higher pressure of 160 lbs., the double-riveted lap-joints were reverted to, which certainly appeared somewhat inconsistent.

The substitution of cast-iron for wrought-iron appeared to be largely carried out in these engines; but the smoke-box door (page 195) seemed to him not a happy place for the use of cast-iron. When it was so used however, he should have thought the number might have been cast on the door, instead of making it a separate casting and bolting it on.

Boiler testing seemed in page 195 to be looked upon as a doubtful expedient. But in the papers already discussed at this and other Institutions the subject of riveting had been so thoroughly investigated as to the strength of the joints, that any engineer could now calculate what were the safe proportions, and could keep well within the elastic limit of the material, so as not to run any risk.

From page 196 he was very glad to see the steam-pipe was made as large as 5½ inches diameter inside, and in the heavy engines 7½ inches diameter (page 206). This he thought was a move in the right direction, and one that might be followed in this country with great advantage. In general he believed the steam-pipe diameters were so small, and the velocity so high, that a great amount of power was lost in the cylinders. In page 199 the boiler mountings were spoken of as being screwed into the fire-box shell. Of course the

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work could be made cheap, if done like that. Another thing that was not considered good practice in England was the retention of the ancient try-cocks, which had here been abandoned for a long time past in favour of two water-gauge glasses.

In accordance with the almost universal practice in American engines, the valve-chests were placed on the top of the cylinders, and the valves were worked through a rocking shaft. The only purpose, as far as he could see, of introducing such a complication was in order to get at the valves. But the valves were working all the year round, and were only wanted to be got at about once a year to see that all was right. It certainly seemed questionable therefore whether it was worth while introducing all those extra joints simply to save getting once a year into a rather awkward position to do a job that did not last long. At the present time indeed all those jobs were done with automatic machines bolted on and driven from a shaft.

By placing the dome on the wagon-top, it was mentioned in page 190 that the heavier portions of the boiler were concentrated over the driving wheels, for increasing the adhesive weight. That was a very good object; but still it did not seem to be sufficiently realised thereby, because it appeared from page 201 that a heavy cast-iron foot-plate was added at the back end of the frame.

About the "United States" metallic packing-rings, of which it was mentioned in page 201 that a set lasted about twelve months, he was anxious to know more; and he trusted the author would give a more detailed statement on this subject. The mileage run could be the only true criterion of efficiency; for if time only were mentioned, the engine might have been standing in the shop for a considerable portion of the period.

For the eccentric straps it was stated in page 202 that mild cast-steel was used. But if there was any part of a locomotive for which cast-iron had shown itself to be thoroughly adapted for use in this country, he believed it was the eccentric straps and sheaves running together.

The crank-pins were stated in page 202 to have broken off in frost when the engine was left standing long; and he remembered hearing

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(Mr. Druitt Halpin.)

some years ago * a similar statement about one of the Lowmoor tires having burst on each of three engines left standing in a shed in Nova Scotia. He wished therefore the author would give some additional information on this important point.

With regard to the wheels (page 202), these were certainly a very weighty and formidable item in an engine; and here again he thought the paper seemed somewhat inconsistent. The driving wheels appeared to have the peculiar distinction of hanging together by the boss and nothing else; because it was stated that at the end of the counterweight on each side the rim was cut through, and then a tire was put on which was not fastened: so that the whole wheel hung together by the boss alone. Into that boss the axle was forced with a pressure of 80 tons, to which there could be no objection if it were a wrought-iron wheel. Beyond that pressure there was yet a further unknown splitting force by driving a key in tightly. This plan appeared to him to be inconsistent with the mode of dealing with the small truck-wheels (page 203); in which there was no danger, unless their higher number of revolutions were regarded as dangerous. These truck-wheels were stated to be coiled discs of wrought-iron with Mansell tires, thus going quite to the opposite extreme of construction, after making the express driving-wheels of cast-iron and held together by the boss only.

The cost of 2·44 pence per lb. for the finished engine and tender came to £22 15*s.* 6*d.* per ton. Adding the 15 per cent. mentioned in page 215, it amounted to only £26 per ton, which he thought could only be accounted for by the extent to which cast-iron was used in the construction of the engines. But on the question of castings he might mention that he had recently been informed, by an engineer who had had large experience in America, that as a rule the American cylinders were so soft that he wondered the American engineers did not send over to England and get them cast here.

Mr. JOSEPH TOMLINSON, Vice-President, was unable to concur in regarding the corrugated fire-boxes of Mr. Fox (page 232) as belonging

* Proceedings of the Institution of Civil Engineers 1880, vol. lx, page 196.

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to the engine of the future. Considerably over thirty-five years ago he had himself worked engines on the South Western Railway with corrugated fire-boxes; but these were given up because there was so much difficulty in getting the stays in exactly where they were wanted. Altogether they gave a great deal of trouble.

In reference to any comparison of English and Canadian railways, he hardly thought the two were really comparable. In the first place, English locomotives had a good road to run upon all the year round; while in Canada in the winter they had a road that was hardly better than paving stones. Frosts would come on suddenly; and the water being in the soil, it was not an uncommon occurrence for the rail level to vary by lifting or by depression, as much as 5 or 6 inches in the night; so that unless the engines were elastic, the chances were that they would come to grief. Many years ago, when the Grand Trunk Railway was opened, all the stock was made at the Canada Works at Birkenhead, and the engines were of the London and North Western old type, with outside cylinders, having 3 ft. 6 ins. wheels in front, and four coupled driving wheels. Those engines went on very well during the summer; but in the first winter, owing to the inequality of the road, they were off the road frequently; and it was not until they were altered by putting a bogie front that they were enabled to keep the road. If the rail was lifted 5 or 6 inches, and the engine had a rigid frame with only 1½ inch clearance between the top of the axle-boxes and the horn, and no compensating beam to allow for the irregularity of the path, the consequence must be that the engine would get off the road. The engines described in the paper were all made upon the most lissom principle imaginable; but he had never been able to arrive at figures which would give any comparable results as far as cost was concerned. It seemed clear to himself, and indeed he thought that the Americans would admit it themselves, that an American engine could not do as much for a pound of coal as an English engine. There might be circumstances connected with the hauling of long trains on single tracks, which might make it better to haul such very long trains and to pay a little extra for coal, and so save wages; but he was always troubled to know what was the cost of maintenance. Neither the boiler nor the engine described in

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(Mr. Joseph Tomlinson.)

the paper appeared to him suitable for work in England. There were engines now running on the Metropolitan Railway, with copper fire-boxes, and brass tubes, and wrought-iron boilers, which had run over 650,000 miles, and were still in good working order and carrying the original steam pressure of 130 lbs. per square inch that they had when they started new in 1863–4. They had run on an average 30,000 miles a year from 1864 to the present time; and he did not believe there was any American engine that would at all compare with them.

Mr. DANIEL ADAMSON, Vice-President, remembered with great distinctness that the forged bar-frame illustrated in the paper and adopted by the Americans was the representative frame of Bury, Curtis and Kennedy, who built the engines for the London and North Western Railway up to about 1848, Mr. Bury being the locomotive superintendent. The bar-frame being rigid laterally was certainly not so well adapted for any lateral action as the plate-frame, nor was it so cheap in first cost. It occupied more time in construction, and it interfered seriously with the width of the fire-box. Altogether he considered it was a thing of the past, and that the Americans would do a great deal better if they adopted the English plate-frame, instead of continuing to use the forged bar-frame. He also remembered twelve engines being built by his old master, Timothy Hackworth, with cast-iron hollow-spoke wheels, about 1843, for Mr. John Gray, the locomotive superintendent on one of the lines south of London; they did good work, and had something like a horse-leg reversing gear or radial link, which was adapted to supersede and did supersede the old gab motion for reversing. He was not surprised at the Americans using more cast-iron for wheels, and in fact for many other purposes, than was used in England, because they had a high-class charcoal-iron that answered the purpose better than ordinary English iron. One effect of such a discussion as the present he hoped would be to lead to the introduction of new compounds, whereby as good or better results could be got at much less cost.

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The one-sided slide cross-heads described in page 211 were just like some that he remembered as a draughtsman designing about 1845–6, for a set of engines which were working on the Stockton and Darlington Railway at the time of his leaving that line in 1849.

The boiler manufacture described in the paper (page 194) appeared to him decidedly objectionable, as a double-riveted lap-joint was altogether unsuitable for the longitudinal seams of locomotive boilers working at the present high pressures. As long as five and twenty years ago, in connection with an explosion on the London and North Western Railway of a boiler with a single lap-jointed seam, he had satisfied himself that the guttering of the joint arose from the departure from a true circle, though only to the extent of the lap of a $\frac{3}{8}$-inch plate. With regard to the wagon-top, it was certainly a prudent course (page 195) not to test it by hydraulic pressure according to the method pursued at his own works, namely by putting the pressure up quickly two or three times in two or three minutes; because he was sure at the third time such a boiler as that described in the paper would fail: the disturbance of the structure would be so great that it would not be able to endure the unequal strains in its different parts. Had it been a stationary boiler, working steadily under uniform pressure for hours, it might indeed endure such a change of form as was occasioned by the wagon-top and the lap joints; but for a locomotive boiler, with the pressure rising and falling considerably within two or three minutes, it was inadmissible to have anything but a true circle, either rolled out of a solid ring, or having a butt joint with cover riveted on one or both sides. As the circle contained the largest area, a lap-jointed boiler was always trying to adjust itself to a true circle; and the only safe plan was therefore to have a perfectly true circle in the original construction of the boiler.

The steadiness of the Canadian locomotives was of course explained by their being supported on three points only: just as a three-legged stool would stand on any ground without rocking, but with four legs it was difficult to make it stand steady. With the locomotive supported on three points, when the wheels passed over any irregular ground those three points underwent less disturbance

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(Mr. Daniel Adamson.)

individually, and the engine therefore remained comparatively steady upon them. It might be some advantage occasionally in this country to have such engines for working branch lines with inferior roads and irregular traffic; but he thought the time had gone by when railways in general had such irregular roads as to need such an adaptation; and he hoped the time was not far distant when there would be a still smaller record than at present of breakages of rails, tires, and axles. With a better selection of material, not only would the security be increased, but there might be a corresponding increase in speed. He was strongly impressed with the idea that it was to the interest of railways to get higher speed; and if they got it, whether with the American engine or with their own, so as to do more work in a given time, they would prove more remunerative than at present. In regard to the general details of the Canadian engines, no doubt the engineers who were connected with a country having such a variable temperature, such heavy gradients, and such irregular and bad roads as to be almost like paving stones for running over, must best know what was required. The engines described in the paper were evidently roughly made, and therefore did not possess any of the refinements of the fine race-horse engines taking express trains in England; but so long as the Canadian engines met the requirements of the railways in that country, by all means let them be adhered to; and if there was anything in their construction that English engineers could take advantage of, they would always be ready to do so.

Mr. JEREMIAH HEAD, Past-President, observed that in the balancing of the gear, referred to in page 202, the counterbalance was calculated to balance the total revolving weights and one half of the reciprocating weights. The data were not given for ascertaining exactly what was the speed of revolution of the wheels in the present case; but it was well known to be of very great importance in quick running engines that they should be balanced as perfectly as possible. With regard to revolving weights, there could be no question as to the expediency of balancing them completely with revolving counter-weights; but it was impossible to balance reciprocating weights perfectly in any other way than by other reciprocating weights. In

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that direction the best plan that had come under his notice was Mr. Crampton's recent scheme for a double compound engine, in which one set of weights was flying in one direction and another set in the opposite direction, and both were close together. Another way of neutralising the reciprocating weights and rendering them innocuous was to arrange a cushion of steam in the cylinder in such a manner as to bring them up gradually. In the paper it was stated that one half of the reciprocating weights was counterbalanced by a revolving weight. No doubt when the engine was on either of the two horizontal centres, the strain on the axle-box guides in those positions was thereby minimised. But when the cranks were in a vertical position, the excess of the revolving counterbalance weight over and above the other revolving weights—the excess which was intended partly to neutralise the flying weights—was then unbalanced. When on the top centre it would tend to lift the wheel off the rail, and when it was at the bottom it would give more or less of a blow on the rail. It seemed questionable to him whether such a mode of counterbalancing, which would, while the engine was running, alternately lift the wheels partially off the rails and then give a blow on the rails, was not a bad plan. Possibly in going round curves at a high speed it might lead to accident. As Mr. Worsdell had had so much experience with American locomotives, he should be glad to have some information from him on this subject.

Mr. R. PRICE-WILLIAMS, Member of Council, said that, having recently visited Canada and the United States, he recognised the type of engine described in the paper as the one suited to the rough roads and the special conditions obtaining there. Through the kindness of the principal locomotive engineers in the United States, New Zealand, Victoria, and New South Wales, he had been fortunate enough to have the opportunity of examining the several kinds of engines in those countries. In the case of the Baldwin engine he had had special opportunities of judging of its performance in connection with the question of cost. Through the kindness of Mr. Rotherham, the chief locomotive engineer for the government of New Zealand, he had been furnished with complete details in regard to the relative

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(Mr. R. Price-Williams.)
performances of the Baldwin and the English types of engines, which were generally used there. Having had the opportunity of riding on the respective engines for a great number of miles, he was able to say that in regard to economical results the rougher type of engine had a great advantage over the more highly-finished engines, which were more suited for the beautiful lines in England than for the rougher and lighter ones in the countries he had named. Having directed his investigations especially to the economical aspect of the question, he agreed with Mr. Greig that English locomotive engineers would do well to have more regard to the special requirements of the engines for those countries, and to forget as much as possible the requirements here. The circumstances were entirely different there. Amongst the engines in New Zealand and New South Wales he had seen some splendid specimens of English engines, such as those made by Messrs. Beyer and Peacock, which were specially designed for meeting the requirements of the roads there. Judging from the particulars given in the paper respecting the heavy passenger engines (page 205), which were specially designed for working very heavy and fast trains, up to ten coaches weighing 60,000 or 80,000 lbs. each, at a speed of 45 miles an hour, he had come to the conclusion that that special type of engine in no way approached the performances of a standard Midland or London and North Western engine, which, with the same diameter of cylinder and a little longer stroke, would pull a much greater load at the same speed of 45 miles an hour. But the Canadian engines were no doubt admirably adapted for their special purposes; and although they might not be suitable for adoption in this country, yet valuable hints might be obtained from some of the special features in their construction.

Sir LOWTHIAN BELL, Bart., Past-President, supposed it was clear that no peculiarity of the road could in any way affect the material of which the fire-box was made; and he confessed that, having had the opportunity of making enquiries in the United States with regard to the use of steel fire-boxes, he had been astonished to find how universally they were approved of there and how completely they

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were condemned in this country. If the conditions were the same in both cases, the conclusions could not both be right. If locomotives of the same construction were running under similar conditions as to road and water used, copper could scarcely be right in England and wrong in America. There were of course two questions to be considered in selecting one material in preference to the other. The first was the question of original cost and maintenance, and the second was the consumption of fuel. Mr. Worsdell had dwelt upon what he was sure no locomotive engineer overlooked, namely the necessity of embracing in the cost the question of maintenance. It was idle to speak of one locomotive fire-box being cheaper than another, if, after it was made, either in wear and tear or in consumption of fuel it was a good deal more expensive. If a great deal of tinkering and mending was constantly needed, it was clear that a fire-box which in the beginning was apparently cheaper might in the long run turn out to be much dearer. How was it that locomotive engineers in this country had not been able to lay down with more precision than they appeared to have done the relations between those two items—the first cost and the cost of repairs—and to compare copper with iron in these two respects? As an outsider and as one interested in the economical working of locomotives as well as in their original cost, it seemed to him a most extraordinary thing that engineers so sagacious and acute as those in America should persevere in a system which appeared to be condemned on every side in this country. America was a country exporting copper largely and importing iron largely: so that one would have thought that under those circumstances copper would be the material preferred there. Here precisely the reverse obtained: England imported a large quantity of copper and exported an enormous quantity of iron. One advantage claimed for the steel fire-box was the thinness of the plates, permitting the transmission of heat much more quickly than copper, in spite of the superior conductivity of copper. But on the other hand it was asserted that with the steel fire-boxes the consumption of fuel was much larger. Was this actually so? Were there any figures to show that the running per train-mile cost more in fuel in England

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(Sir Lowthian Bell, Bart.)

than it did in America? Something had also been said about water: it had been spoken of by Mr. Worsdell (page 220) as having been exceptionally good in his own experience of the steel fire-boxes on the Pennsylvania Railroad. At all events there must be a close correspondence in the quality of the water falling upon the American and English soils. It might be that geologically the structure of the ground in America was such that the water became less contaminated there; but surely upon some occasions it might be expected that bad water would be found there, while even if that were not the case, good water in England was not an uncommon occurrence. In spite of all these considerations however, the fact remained that the American railways, which had ten times the extent of those in England, used almost uniformly steel fire-boxes instead of copper.

Mr. DAVID JOY mentioned, in regard to the consumption of fuel in America, that on one of the American locomotives, when running at the rate of about 27 miles in 32 minutes, he had heard an excessive noise at the chimney; and on asking the master mechanic what was the consumption of coal, he was told it was 55 lbs. per mile. An engine on an English railway drawing the same train of five Pullman cars at the same speed would do it with 25 lbs. per mile; this was being done every day.

Mr. ARTHUR PAGET, Vice-President, said the author was right in surmising that the costs of production of his engines, as given in page 215, appearing to be less than half those of English engines, might be regarded with some surprise. They certainly were so regarded by himself. The further statement that the cost did not include certain expenses which were then enumerated, and that these expenses amounted to about 5 per cent., seemed to present a vagueness contrasting strangely with such accuracy as was implied in giving the cost to two places of decimals as 2·44 pence per lb. instead of 2½ pence per lb. Before the costs of production were published in the Proceedings, he hoped the writer of so admirable a paper would take the opportunity of revising some of his statistics. The accuracy of

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the statements made by locomotive superintendents he considered might be relied upon in almost all respects but the important one of the costs of production; and on this one point he thought their statements seemed, perhaps not unnaturally, sometimes unreliable. Commercial engineers, having to sell what they produced, had two important checks on their reckonings of the prices of their productions. In the first place, if they reckoned the prices of production too high, they could not sell; and in the next place, if they reckoned them too low, they found they were losing money. But locomotive and dockyard superintendents, and other engineers occupying similar official positions, had neither of these valuable checks; and it therefore seemed to him to be very necessary that their statements as to the costs of production should at all times be carefully examined, and even sometimes treated with some degree of doubt.

Mr. JAMES REID was unable to understand how an engine and tender of the dimensions given in the paper could be produced at so low a cost as only £1071. Having been a locomotive builder for a great many years, during which he had turned out nearly four thousand engines, he had never been able to bring down the cost to anything like that amount. The cost of forged frames was said to be 2 pence per lb., which he considered was entirely out of the question, as was also the addition of only $\frac{2}{3}$ penny per lb. for the cost of planing, drilling, and slotting the frames ready for erecting. Again the cost of the cylinder castings was said to be 2 pence per lb.; and when finished, fitted with covers, studded, and ready for erecting, the cost was only $2\frac{3}{4}$ pence per lb. The cost of the cast-iron wheels was given as $1\frac{1}{8}$ penny per lb.; but in this country the wheels cost more than 1 penny per lb. of mixed metal for casting, and in addition one farthing per lb. had to be paid for the carriage of anything over 400 miles, which was very different from the statement in the paper. He agreed with Mr. Paget in desiring that locomotive superintendents should be as careful as possible in their statements of cost of production. Such an allowance as only 5 per cent. for costs or charges in the shops he considered was wholly inadequate; the

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(Mr. James Reid.)
average cost was nearly 10 per cent. upon the wages paid, and sometimes more. In some departments these costs varied from 10 up to even 25 per cent. upon the wages paid, which would still scarcely cover the general charges over the whole establishment. As an instance of locomotive practice he might mention that, when he left Manchester nearly twenty-four years ago, the firm with which he had there been connected was turned into a limited company and published their profits; and the superintendents of railways were so much struck with the great profit made out of locomotive building that several similar establishments were started on the faith of the statements made. All were managed by experienced railway men, but all had now ceased to exist as locomotive builders. This surely verified the opinion that railway accounting was particularly fallacious and misleading; and he hoped therefore the statements made in the paper as to cost of production would be thoroughly revised by the author before being published. With regard to the flexible engines made in America, he thought if a great many of the parts introduced into them were to be introduced into the practice of this country some good might thereby be obtained; but unfortunately locomotive superintendents differed so greatly in their particular requirements. Some preferred engines with flush boilers and without steam domes; others, flush boilers with steam domes. Some made their engines without balance weights on the wheels, others put them on; so that there was no approach to uniformity in their practice. If they would leave the building of new engines entirely to the manufacturers, and would confine themselves to repairing and maintaining the rolling stock, it would be more beneficial to the different railways than the practice now being so extensively introduced of building their own engines. Between engines which he had himself built, of exactly the same power and the same class of material, there had been a difference of 10 per cent. in the cost, because one engineer required so many special details, while another was perhaps inclined to have a simpler engine to begin with, which was cheaper not only in first cost but also in maintenance. In so complex a machine as a locomotive, maintenance became a serious item, which superintendents sometimes overlooked.

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The PRESIDENT pointed out that the Institution was in no way responsible for the statements made by the authors of the papers published in the Proceedings; and he was sure the Members were always glad to welcome the genuine results of practical experience, contributed for their information and discussion, however wide might seem to be the divergence from opinions generally entertained.

Mr. T. HURRY RICHES, Member of Council, referring to the question of staying the roofs of fire-boxes, had found in the South Wales district that the old plan of the beam roof-stays was not as useful as that of the radiating stays shown at the trailing end of the box in Plate 25. In the two front rows he himself inserted stays having provision for allowing the top of the tube-plate to expand upwards. Where the water was largely impregnated with carbonates and sulphates of lime and magnesia, particularly carbonates, there was a great deal of difficulty in keeping the water-spaces clear of incrustation. When the beam roof-stays were placed transversely, they were objectionable because they almost entirely prevented washing the crown of the box; but if they were laid longitudinally, or if radiating stays were used similar to those at the trailing end of the box in Plate 25, it was easier to get the mud off the box in washing out. Wherever it was possible however, he thought it was better to do away with the beam roof-stays altogether; in 120 or 130 engines he had entirely done away with them, and he had found the results very beneficial.

Iron tubes appeared from the paper to be generally adopted in the Canadian locomotives (page 194); but having himself tried iron tubes he had failed to get even two years' life out of them, in some districts where the water was bad. In the Taff Vale district he had found iron tubes were not in any way successful. A great deal depended on the water used; where brass tubes only could be used in one boiler, iron and steel could be used in another; and no hard and fast rule could be accepted.

The old system of lagging with wood he observed was adhered to (page 204). Whether it was still followed in this country to any large extent he did not know; but he had himself given it up for ten

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(Mr. T. Hurry Riches.)
years, finding that the radiation from cement lagging was very much less, and the heat retained consequently much greater, besides which the dirt and dust from the burning of wood lagging was done away with. Non-conducting cement, such as the Eagle or Leroy's, not only gave a much better result in economy of heat, but also avoided the objection of getting the iron sheeting damaged and spoiling the appearance of the engine, as so often happened with wood lagging. He had never found any injury occur to plates from the use of this cement.

With regard to balancing, some time ago he had had some engines balanced with rather heavy blocks, which were concentrated immediately opposite the cranks for inside-cylinder engines, so as to give the necessary angular balance. But for the last eight or nine years he had adopted the principle of diffusing or spreading the weight over a longer arc of the rim; and notwithstanding there was some slight increase in the balance-weight, the spreading had so modified the blow from which the wheels used to suffer when the weight was concentrated too closely at one point, and by which flat places had been caused on the tires, that since this alteration it had been rare to find any flat places on the tires.

On the question of cost, he thought some of the remarks made had been rather hard upon locomotive superintendents. As a rule however it would no doubt be admitted that engine builders were rather keener in their costs than locomotive superintendents, and more particular in their gauging. In buying plates, for instance, the engine builders gauged the thickness from the edge of the plate, but at the same time required that the plates supplied to them should not exceed a certain limit of weight per square foot. In that way they got some little advantage, which the locomotive superintendents were content to put into engines built by themselves in the shape of increased material. When locomotive superintendents specified for a half-inch plate, they took care to get a plate that was not less than half an inch thick throughout, not only in the centre but at the edges also; whereas if the plate were callipered in the centre only, it might there be half an inch thick, but at the edge it might be somewhat thinner. Other small economies

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in coring the materials and skinning little bits out of the patterns suited the engine builders very well in making large numbers of engines, and enabled them to realise a very considerable profit upon small items, which only added to the first cost of the patterns, and which they thereby got the benefit of, but which railway engineers preferred to take in the shape of increased material in the engine, and consequently additional life.

Mr. THOMAS R. CRAMPTON said that nearly forty years ago he had introduced on the Continent the principle of balancing the reciprocating weights by means of revolving weights on the wheels; and up to the present time 28 million miles had been run by locomotives so balanced and with very large wearing surfaces. The heating surface which he had originally adopted of 1200 square feet had formerly been largely exceeded; but had been confirmed by modern practice in this country, as well as in the engines described in the present paper.

Mr. THOMAS W. WORSDELL, Member of Council, explained with regard to the steel fire-boxes, that when he went to the Pennsylvania Railroad in 1865 copper fire-boxes were the universal practice, but they were in a most deplorable condition. When they were renewed he ascertained the cause of their condition: they had worn out almost immediately from the excessive friction of the very inferior fuel that was used on the railway at that time. There were many kinds of coal, but most of them were bad; the few that were good were mostly bituminous. A very sharp blast was necessitated by the comparatively small wheels and large cylinders, which required the steam to be made very rapidly in the small boilers used, and in consequence of their small heating surface the boilers had to be forced; these causes, together with the obstructive wire netting placed in the chimneys for preventing the cinders from setting fire to the crops, all combined to render a sharp blast necessary, and thereby to affect in the most detrimental manner the wear of the copper fire-boxes; and he had no doubt that this was what had led to the change from copper to iron. For three years he had put in a

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(Mr. Thomas W. Worsdell.)
large number of iron fire-boxes; but there was a good deal of unsatisfactory work connected with them. Sometimes when the box was comparatively new he had had to take out a considerable portion on account of the blistering of the plate. Then the manufacture of steel came to the front. The first steel used on that railway, and possibly on any railway, was imported from England; but the steel seemed to harden, and he had no doubt the process of manufacture was not perfect enough at that time; it was introduced rather too early. But the Americans soon began to make a crucible steel, which was a really mild steel. He had put in as many as 250 steel fire-boxes on the Pennsylvania Railroad, and not one failure had occurred in any of them during the six years he was there; the steel boxes were found to last for four or five years. At the same time he must say the water was exceptionally good; there was no place on the railway where the water was impure or bad. A deposit from carbonate of lime was almost unknown; it was more like the water obtained here from peat lands, which was always admitted to be good water and free from carbonates. The water he therefore believed must have had a good deal to do with the success of the steel fire-boxes, though he was not prepared to say what the experience had been on American lines where the water had been bad. On the Great Eastern Railway he knew steel fire-boxes had not proved a success, nor had they on the London and North Western, because directly there was a slight deposit the plate began to yield to the fire.

The balancing of the reciprocating parts in a locomotive was a very difficult question, because it was necessary to take into account the element of friction, though he was afraid this was not always done. No doubt the amount of balancing adopted in practice had been arrived at by trial. When he had had to balance the new engines on the Pennsylvania Railroad, he had had the wheels placed upon straight edges, with all the rods and other connections attached to them, and had them run for the purpose of seeing how much would be required for balancing the reciprocating parts as nearly as possible, and with regard to each individual wheel. When balanced in conformity with the information so obtained, the engines apparently ran very well; but it was noticed that they

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ran very differently down hill without steam from the way in which they ran fast on a level with steam. So that there were many circumstances to be taken into account. Mention had been made in page 212 of some of the wheels being cast hollow and filled with lead in the part required for balancing; but in this respect he thought the author had gone back some years in the American practice. For he remembered the American engineers thinking they had done a good thing when they introduced hollow-spoke wheels and had the hollow balance-chambers filled with lead; but after a while they had been troubled with a great knocking, and could not make it out. The driver did not know whether it was the axle-box or the road, or what; but as soon as the wheels came in for repairs it was found that the lead had got flattened, and the consequence was that there was considerable play in the balance-chamber, and the lead was knocked against the walls so violently that there seemed a risk lest it would break the chamber. They therefore went back to the old plan of either casting the weights in solid, or fitting loose weights in; and his own preference was for fitting in loose balance-weights. Mr. Crampton considered there was no necessity for a revolving weight, so far as regarded the balancing of the reciprocating weights; but it should be borne in mind that he got over the difficulty by duplicating the engine; he had in fact two engines in place of one. Locomotive engineers however could not afford to have one engine balancing another engine; such a plan would involve additional complication of an undesirable kind, and for his own part he much preferred simplicity. Locomotives could do very well with two cylinders; they did not want three, certainly not four; and if an engine could run with one cylinder only, he should advocate that.

Some of the English locomotives, as mentioned by Mr. Reid, were doing without steam domes, while some had domes on one part and some on another. His own opinion was that a dome was not wanted, if the boiler could raise the steam fast enough and had plenty of dry room to contain it. But if there was a dome, it should not be placed where the Americans put it, which was in the spot where the most violent ebullition took place; but in a quiet portion

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(Mr. Thomas W. Worsdell.)
of the boiler, where the level of the water was likely to be nearly the same under all circumstances. Another objection to the dome being over the fire-box was that it cramped very much the space above the roof-bars of the fire-box for getting in any proper mechanism for the regulator.

In reference to the waste of fuel in the American engines, or their large consumption of fuel per mile, it was true that the most efficient engine was that which evaporated the largest quantity of water with a given quantity of coal or coke or wood; but it was very convenient, knowing the miles an engine made, to take the relative consumption of fuel per mile, irrespective of the quantity of water evaporated. The American practice had hitherto been very heavy in regard to the consumption of fuel; but there were two reasons which might be given for this. The first was that their engines were constructed, at any rate at the present day, for drawing heavier loads under worse conditions than the English engines. The wheels were generally smaller; where English engines had from 6½ ft. to 8 ft. wheels, the American had not more than from 5½ to 6 ft. wheels; and where the English cylinders were 17 or 18 inches diameter, the American were 22 inches. The latter therefore required a much larger quantity of steam. At the outset of the paper the author had taken pains to make it clear that their object was to get the trains moved away, regardless of working the engines economically. If that was so, it was of course out of the question to criticise the working of the engines on the score of economy of fuel. The second reason had regard to the quality of the fuel. From his own experience with regard to the bituminous coal on the Pennsylvania Railroad, he was of opinion that there was much better coal in England. With the anthracite coal he had not had much experience; that necessitated a totally different class of engine—so far at least as concerned the fire-grate—and also a different kind of handling.

In reference to cost of production, Mr. Reid had insisted on the great advantage it would be if railways would not make their own engines, but have them made for them; and he had instanced the many differences in style that were to be met with in the engines of

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the different railways. But even if the engines were built for the railways by other makers, they would still have to be built according to the designs of the respective locomotive superintendents of the several railways; and it did not follow that their designs would agree any more than they did at present; there would still be just as much variety of design. It used to be so in America, even before they had the present skilled master-mechanics, who corresponded with the locomotive superintendents in this country. Scarcely any railway then built its own engines, but they were all ordered from a type. The master-mechanic was formerly not a man suitable to be consulted. The makers simply asked what was the freight to be hauled, what were the gradients, and so on; and then offered an engine of their own pattern, from which they would not deviate. There were various types, and the railways had to choose whether they would have the Baldwin, the Patterson, the Norris, or others. That was now done away with, and the makers had to build the engines according to the requirements of the road, which could only be known by the master-mechanics, who had now acquired a position such as could only be filled by engineers of capability and skill. The question of having engines designed and built for railways by private firms had also another side. Those engines when used by the railways had to come into their own shops for repairs; and then came the question whether the material and the design generally were such as to be suitable for duplication. In his own experience in America he remembered that they had about twenty sets of brass fittings for engine repairs, and had to throw them all away, because they were all made after the fashion of plumber's work, light, and beautifully cored out, elegantly finished and nicely fitted, but not sufficient in strength. Even the maker of them had himself said he believed there was a large trade in them, and that the other railways would follow suit if he had a proper locomotive fitting as a pattern; and he wanted to borrow those that the Pennsylvania Railroad had fitted up. They lent a set, and that firm and others he believed had since followed out the plan of making strong and durable locomotive fittings. This would serve as an illustration that railway engineers did know sometimes what they were about, and were able occasionally to do good work and to maintain it.

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(Mr. Thomas W. Worsdell.)

With regard to the transverse beam stays on the fire-box roof, it would be observed from Plate 27 that the ends of these stays had a firm strong bearing directly over the vertical plates of the fire-box sides, and the roof-plate being of steel was flanged with pretty sharp corners for joining the sides; and as those stays were themselves very strong and stiff, they needed no other support than their ends resting upon the corners by a small block alone, which did not prevent getting at the crown underneath the ends of the stays. But with a softer metal such as copper, having the corners more rounded, it would be very difficult to put the transverse stays in that way, with so small a bearing at their ends. The advantage that the Americans gained was that they could get a very long roof to the fire-box by having those short stays placed transversely. With a long fire-box there would be some difficulty in getting the roof girders strong enough if placed longitudinally.

With respect to the use of cement or plastic lagging, he had himself had a great deal of trouble with it. He had covered more than a hundred engines with a plastic lagging, put on like plaster and smoothed down; it made a very nice job at the time, and looked beautiful when finished, and no doubt it was a good non conducting material. But he had found a very serious drawback to it for steel boilers; if there was a little leakage from one of the seams of the boiler, the steam saturated the composition; and as it was hidden by the sheet-iron covering, it was impossible to see what had occurred. But when the engine was taken in for repairs, and the composition was stripped off and the boiler examined, it was found that a serious corrosion had taken place at the point where the saturated cement had been bearing upon the steel plate. From that time forward he had abandoned the use of the cement lagging, and had gone back to the old wooden lagging, properly supported here and there with longitudinal T irons, so as to keep the sheet-iron covering in position, and prevent any bulging or slipping or getting out of shape, such as had been mentioned by Mr. Riches.

The cost of the cylinders (page 216) he did not consider was at all out of the way. A good deal of comment had been made upon the price of the cylinder castings being only twopence per lb.; but

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this was equivalent to about eighteen shillings per cwt., in addition to which there was three farthings per lb. for finishing, bringing the cost up to about twenty-five shillings per cwt. The cylinders, if each cast in one piece with half the saddle, weighed about 30 cwts. each, so that their total cost would amount to nearly £40 each.

Mr. DANIEL ADAMSON, Vice-President, occupying the chair, said that the present paper had not only proved to be exceedingly useful and interesting in itself, but had also led to a valuable discussion. In asking the Members to pass a vote of thanks to Mr. Brown for his paper and illustrations, he thought they ought not to forget that Mr. Worsdell was also entitled to their acknowledgments for his aid in befriending the author in his unavoidable absence, and giving his own views of American practice as well as English.

Mr. BROWN sent the following reply to the observations made in the discussion.

Having been unable to be present in order to explain such parts of the paper as were not perfectly clear, he feels much indebted to Mr. Worsdell for the explanations which he kindly furnished from his own experience. At the same time, during the interval which has elapsed since Mr. Worsdell was engaged in American railway work, changes have naturally taken place. For instance (page 219) it is now quite usual in Consolidation engines for the centres of cylinders to be 7 feet apart, while in the ordinary American engines with 17-inch cylinders they are only 6 feet 2 inches apart. In his engines of the S.A. class, the author has now adopted the half-saddle style of cylinders, similar to that shown in Plate 34 for the S.D. class. His reason for previously using an independent saddle was that he does not possess a foundry, and previous experience in Canada on the Grand Trunk Railway had taught him the difficulty of obtaining good cylinders cast with the half-saddle; but as soon as he found the makers capable of producing these, he discarded the

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(Mr. Brown.)
independent saddle, and now uses the cylinder cast with half-saddle for all classes of engines. But even in the cylinder with independent saddle, it is seen from Plate 28 that the steam and exhaust passages are cast solid with the cylinder and entirely separate from the saddle, and that they do not connect through the saddle from the steam-pipe to the cylinder. The author has never experienced difficulty in keeping the joints tight; but he prefers the cylinders cast with half-saddle for economy and simplicity.

The wagon-top boiler (page 219) differs from the old English plan not so much in form as in strength and cheapness of construction, while it presents many advantages, as pointed out in the paper. With regard to flanging, the author's practice is to use fully formed flanging-blocks, and as far as possible to flange at one heat, the plates being heated in a furnace capable of holding the largest sheet to be flanged for any of the locomotives; and the contract price for the complete flanging of a set of plates for an S.A. boiler is £9, which result could hardly be obtained if the flanging were done a small piece at a time, as described by Mr. Worsdell.

With regard to the use of mild steel for fire-boxes (page 220), and the question whether on lines where the water was bad the use of thin mild steel was satisfactory, the author unhesitatingly states that it is satisfactory; and on some lines in the Western States using water containing an average of thirty grains of lime to the American gallon of 231 cubic inches ($=0\cdot8333$ imperial gallon) he is informed that steel stands better than any other material. Some nine years ago, when on the Grand Trunk Railway, he tried some copper half-side sheets to repair inside fire-boxes, and found they did not last so long as steel, the sharp blast cutting them away rapidly. On the same railway in 1879 a copper fire-box was put in for trial, and the result was unsatisfactory for the same reason; as the material cost about six times as much as steel, the author considered further trials would be only a waste of money. The question why copper was unsatisfactory seems to be answered in Mr. Worsdell's later remarks (page 249), where he gives his own experience of copper on the Pennsylvania Railroad as having been unsatisfactory, and assigns as reasons a sharp blast, inferior fuel, and the netting of the

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spark arresters; and attention to these is drawn by the author in the preamble of the paper, page 187. If steel fire-boxes are not found a success in England, it would be well to look to the systems of firing practised, and to the quality and thickness of the steel used.

With regard to the size of tubes in use, referred to in pages 190 and 194 of the paper, the author would add that tubes smaller than 2 inches outside diameter are very liable to give trouble by becoming filled with deposit from the coal, notwithstanding the sharp blast. As to the quality of the tubes, no trouble is ever experienced with good lap-welded wrought-iron tubes of German or American make.

The author's view quite coincides with Mr. Worsdell's (page 250), that the balancing of locomotives is a very difficult question, being complicated by the reciprocating motion of some of the parts, and still further by the different conditions of running with or without steam. As no theory has ever been formulated to cover all conditions, the practical result has to be accepted as the true value of any attempt. As practised by the author the balancing is computed by theory; and as a success in practice it leaves little to be desired. The amounts of the revolving and of the reciprocating weights are calculated separately. The revolving parts are taken to extend as far as the centre of the connecting-rod, and to include the following:—two unbalanced parts of crank hubs, two crank pins, one side rod, and one large half of connecting-rod. The reciprocating weights are taken to include—small half of connecting-rod, cross-head and pin, piston and rod; and one half of their sum is taken as concentrated at the journal on the crank pin. As these disturbing weights do not all work in the plane of the weight which is to balance them, it is evident that they must be counterbalanced across the engine by an additional weight in the opposite wheel, exactly as in engines with inside cylinders; and the balance weight required must be equivalent to the resultant of the disturbing weight and its counterbalance. The same must be allowed for the opposite side of the engine. Thus there would be two weights in each wheel, one large and one small, concentrated at 90° apart. If these are compounded they will produce the true balance weight, which will therefore not be quite opposite to its own crank. The whole amount of balance

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(Mr. Brown.)

weight is made decidedly over, rather than under, the amount thus calculated, and is equally divided between the driving and trailing wheels; this is far from being a theoretically correct method, but was adopted in order to cast the wheels off the same pattern, and no apparent defect has been found in practice from doing so, as the steadiness of the engines is remarkable. The balance weights are made crescent shaped, and cover rather more than one-fourth of the circumference of the wheel. In some cases they are cast solid, and in others are filled with lead. No trouble has been experienced with the lead. Probably in the case cited by Mr. Worsdell (page 251) the lead did not fill the cavity, but was put in to produce a certain weight; whereas in the author's practice the lead is calculated and made to fill the cavity, and is caulked in tight.

With respect to steam domes and their position (page 251), it will be admitted that, whether it is advisable or not to put them over the point of most violent ebullition, it is certainly advisable to put them where no priming is found to occur; and whereas on other roads in Canada great trouble has been experienced from priming with level-top boilers and domes on the barrel, the engines on the Canadian Pacific Railway are remarkably free from it.

Regarding the alleged waste of fuel in the American engine, it is not necessarily the most efficient engine that evaporates the largest quantity of water, though this remark may apply to a boiler. Neither is it any measure of efficiency to compare the weight of fuel consumed per mile, regardless of quality, cost, state of track, or weight of train. The only true basis of comparison is the cost of hauling one ton one mile under given conditions; and in Mr. Dorsey's paper read before the American Society of Civil Engineers (see Transactions January 1886) figures are given which show, so far as they can be compiled, that the American engine is far the more economical machine, when considered in regard to motive power, but not from an ornamental point of view. It is not meant to be inferred from the outset of the present paper (page 186) that, because the preference is given to keeping trains in motion, therefore the question of economy of fuel is disregarded. It is far from being so; but to economy of fuel is necessarily given the second place.

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The asbestos cloth used under the lagging of the engines (pages 200 and 213) is a very different thing from asbestos plaster or cement. It is made of soft fibrous asbestos cord, woven with fine wire to form a cloth about half an inch thick, which can be removed for inspection when the lagging is taken off, and can be replaced at pleasure, exactly like a blanket; no amount of shaking will cause it to crumble or fall while on the boiler, nor is it in any way detrimental whenever leakage takes place. The author has tried asbestos plaster, and has discarded it for the same reasons as those given by Mr. Worsdell (page 254).

The remark as to weight being of little consequence on some of the American lines (page 221) strikes the author as being rather odd, because in the first place the rails on American roads are oftener 56 to 67 lbs. per yard than heavier, and in the second place all excess of weight adds to the cost of the engine, and so far as the author has had experience weight has been one of the great objections. And in reference to costly brass being used in England, as against cast-iron in America, the author is unable to call to mind any instances except slide-valves, and in a few cases driving axle-boxes, both of which tell materially against the English engine in cost of maintenance. Again as to forgings, if the forged frames of the American engine are set off against the forged wheels of the English, there seems but little difference either way.

In reference to the comparison of English and Canadian locomotives, presented in Mr. Johnson's remarks (page 222), the author would explain that the scrap of the materials in his own case is but a small amount per engine, and not sufficient to influence the result materially. Including 10 per cent. added on all labour, and taking no credit for scrap, the comparison of cost in page 222 will stand as follows:—

MIDLAND RAILWAY.	CANADIAN PACIFIC RAILWAY.
* Cost { £1677 total. £31 7*s.* per ton. 3·36 pence per lb.	† Cost { £1156 total. £24 12*s.* per ton. 2·64 pence per lb.
* Including 10 per cent. added on all labour.	† Including 10 per cent. added on all labour.
Credit not taken for scrap.	Credit not taken for scrap.

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(Mr. Brown.)

As to the detailed costs per lb., the author would be much interested in learning the cost both of casting and of fitting up the cylinders on the Midland Railway, in an iron-producing country and with all the advantages of free trade. The same remark applies to coupling rods, in regard to which the author is under the impression that those made on the Midland Railway have bushed ends, whereby the cost of manufacture is materially diminished; while those made by himself have half brasses and cotters, as better suited for the road bed. Similarly the steel connecting-rods of the Canadian engines are imported as forgings, and freight and duty are paid on them; while the cast-iron wheels cost at least one-eighth of a penny per lb. for freight, and their price then must be considered in connection with their being produced by contract in a protected country and principally from imported materials. It must be remembered that the English engine is built in an unprotected country, whereas the author has to contend against protection, and to pay duty, freight, insurance &c., on all imported goods, of which the Canadian engine is largely composed. The Midland engine, delivered in Canada, with duty paid of 25 per cent. and freight say 5 per cent., making a total of 30 per cent., would cost £2180 or £40 15*s.* per ton or 4·36 pence per lb., against the author's cost of 2·64 pence per lb. This £2180 cost for the English engine is within a few pounds of a quotation which the author received a few months ago from a British firm for engines of the S.A. class delivered in Montreal. Since building the engines of the S.A. class, of which the cost is here quoted, the author has built engines of all four classes, S.A., S.B., S.C., and S.D.; and he has just completed a batch of five S.A. engines at the cost of £1097 each, including 10 per cent. added on labour, and with credit not taken for scrap; this total cost is equivalent to £23 7*s.* per ton, or 2·50 pence per lb.

As to how steel tires answer without fastenings for driving wheels (page 223), the author is glad to be able to say that the system answers excellently. Of course loose tires are not unknown, but a broken tire is a far greater rarity, as it should be, considering the cost of the consequences; still the breakage of a tire does not often cause derailment. Travelling at 60 miles per hour or 290

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revolutions per minute for 5 ft. 9 ins. wheels is anything but uncommon, though as explained in the paper (page 187) the frequent stoppages of ordinary traffic do not admit of high journey speeds. Loose tires occur most frequently during the winter, owing to the hammering on the road bed, which is as hard as rock; they are slacked off with a fire, and extremely thin liners of sheet iron are inserted, which effectually secure them when cooled.

In Mr. Burnett's remarks as to the maximum curvature to be provided for (page 225), it seems to have been overlooked that the limit of 6° is expressly stated in the paper (page 186) *not* to apply to mountain sections, where curves occur of 10° or 573 feet radius, corresponding very nearly with the 8 chains or 528 feet radius cited; but they occur on steeper grades than 1 in 40, and are passed round with equal readiness, and are worked every day when required, without any rivets or bolts being sheared off, as happens to the English type of locomotive described by Mr. Greig (page 231). Is the author to infer that curves of 8 chains radius and grades of 1 in 40 to 1 in 30 are common in New South Wales practice through easy country? And what were the type and the wheel-base of engines which performed this service before it was found advisable (page 228) to imitate American practice by conversion in 1881 to the Mogul type? Again, what did the conversion cost? and what percentage was that of the cost of an equally efficient new American or Canadian Mogul engine of equal power? It is interesting to notice that Mr. Burnett found it to his advantage six years ago to follow American practice under such circumstances. If the English system of wheel-base were perfect for all conditions, why has the American four-wheeled truck gained such headway for fast express engines even on the perfect English track? where the lines are old, and are not the later extensions referred to in page 224. Is it to be understood that the Australian practice has some features in advance of that of England, other than those copied from the American?

As to the old-fashioned bar-frame being now obsolete (page 225), there are about 28,000 bar-frame engines in the United States and Canada alone, or nearly twice the number of the plate-frame locomotives reported to be running in the United Kingdom; and in

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addition locomotives with bar-frames are exported to South America, Australia &c., where the demand for them is growing. While the bar-frame is considered by Mr. Burnett to be a mistake, in consequence of its narrowing the fire-box and thereby diminishing the fire-grate area, the author is just as much puzzled by the retention of the crank-axle in England, which by shortening the fire-box diminishes the fire-grate area to a similar extent.

With regard to the opinion that the elasticity of the wrought-iron driving wheels causes the tires to suffer less (page 226), the author believes the opposite to be the fact. The light rims of the English wheels do not support the tires between the spokes, and the spokes also deflect, so that the elasticity commended appears to be the very cause of the trouble experienced with English engines, and of the expense incurred for obtaining a suitable fastening for the tire. Cast steel is better, in that it has more stiffness; and it would probably be still better, if the forms which were suitable for forgings were discarded, and the stiffer forms which castings admit of were adopted. But from an economical point of view, including maintenance, the cast-iron wheel is incomparably better for Canadian requirements.

While some saving in first cost of axles is admitted by Mr. Burnett (page 227), due to their form in American engines, the equally great saving in maintenance is omitted. The author would also call attention to the fact that, when the axles are of steel, as is usual at present, the absence of any change in size adds largely to the life of the axle, and failure inside the wheel is of extreme rarity: which cannot be said of English engines, even though the corners are filletted to a large radius. This is probably accounted for by the leverage, equal to the length of the fillet, at which the weight on the wheel acts in tending to break the axle, since the box cannot be made to bear on the fillet or it would run hot at once; whereas in the American axle the leverage at which the weight acts is equal only to the slackness of the box sideways, and this is but a fraction of the former leverage. A further important disadvantage of the English form of journal with rounded corners is that the actual bearing surface is diminished by the amount of the two curves;

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that is, an American axle with a journal 8 inches long has as much efficient bearing surface as an English axle with a journal 10 inches long, and the consequence is that with journals of equal length the American engine does 25 per cent. more service before the boxes need any attention. The inside fillet of course could not be dispensed with for crank-axles; but the outside one might in all cases be discarded, thus adding 12 per cent. to the bearing surface, and therefore diminishing the repairs.

The durability of axle-boxes and axle-forks (page 227) has to be considered in relation to the kind of track. Though wedges are used in all Canadian engines, they cannot always be kept in the closest position, some allowance having to be made for permitting the engine to rock, and to rise and fall, without the boxes getting fast in the horns; and this slackness, though small, necessarily diminishes the life to some extent. If the American engines cannot be relied upon not to break down by the way, how is it that they have ever succeeded in working the boundless prairie? where a repair shop is not at hand every few miles, nor even a stick of wood to block the crosshead and get along "with one leg." Even under the adverse circumstances, the author is of opinion that the American engine cannot be approached by the English for cheapness in maintenance and repairs. The materials mentioned throughout the paper as being of English manufacture had freight and duty paid on all of them, which tells against the price of the engines built by the author; and thus it appears that anything but the whole locomotive can be obtained in England at a low price.

Regarding the wheel-base and brakes of tenders (page 227), the double-truck tender does not need the wheel flanges cut away for enabling it to pass round any curve found advisable; nor are the wheel flanges cut by the rails, which close inspection would show them to be in the six-wheeled tender with its long fixed wheel-base. As to the brakes, does Mr. Burnett apply any brake more powerful than the Westinghouse automatic air-brake, which it is usual to apply to the wheels of the double-truck tender? and if so, does he calculate on skidding the wheels when the tender is empty?

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The standard passenger engines of New South Wales (page 228) approach so nearly in their main features to the American, that the author considers scarcely any merit can be claimed for them apart from the latter. They even copy the defect of being "over cylindered" to some extent, unless the boiler pressure is very low; this defect is gradually being corrected in modern American practice. The Moguls also (page 215) could not really utilise more than 130 lbs. boiler pressure. It seems hardly fair as a comparison to advance a hybrid copy of an American engine as a type of English engines.

In considering the English engine unsuitable for American roads the author cordially agrees with Mr. Joy (page 230); but it is an open question how far the peculiarities of American practice might be adopted to improve the English engine, even for service on its own road. The author is aware that a trial of an engine built in America was made in England some years ago (page 229); but he is not aware whether the engine was of genuine American type, nor has he seen any published results of the trial, or any reasons given why the engine was considered unsuitable.

As to an American engine using 55 lbs. of coal per mile (page 244), the author is led to think it must either have been a poor specimen or on a difficult piece of road, or that the English engine would use considerably more than 25 lbs. of that particular coal per mile. If 35 lbs. were named instead of 55 lbs. per mile, it would probably better represent good American practice.

Mr. Holden's experience of steel fire-boxes (page 230) must have been unfortunate. The author would ask what was gained by using Mansell clip-rings for tires on cast-iron wheels. If the tires were shrunk on, after having been bored with an allowance of 1–100th of an inch per foot of their diameter less than the cast-iron centre, satisfactory results would probably be obtained. The behaviour of the Mogul engines on the Great Eastern Railway (page 231) probably does not militate against the type, but against the design of the particular engines referred to.

The remarks made by Mr. Greig from his own experience in regard to boilers (page 232) do not seem to be applicable to the boiler

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requirements for winter service. As to the "accordion principle," reference may be made to the design of engine by Mr. George Strong,* running on the Lehigh Valley Railroad.

The remarks of Mr. Halpin on the trellis-work called the frame (page 232), and his inferences as to the brake arrangement, seem to be due to his having seen only the one American engine exhibited in Paris in 1878. The usual arrangement of the Westinghouse driver brake is generally classed as one of the wedge type of brakes.

Four kinds of fire-boxes are used in America. First, the deep box, limited in length by the axles &c. and in width by the frames, which has about the same area as the corresponding English box for the same driving-wheel base; with this kind there is no trouble from the length of the box. The next kind, where some increase of grate is necessary, is used in cases where the trailing axle is brought forward under the fire-box, which is cut sufficiently shallow to clear the top of the axle-boxes, and is extended backward to any desired length up to 10 feet or more. These boxes have given trouble when extra long, but are being superseded by the third kind, which are raised above the level of the frames and made equal to the full width over the frames, whereby the length may be much diminished if the class of coal will permit the diminution of the grate area; these give but little trouble from their length. The fourth class is the Wootten fire-box, which is raised and extended laterally over the wheels to about 8 feet width. There are no fire-boxes in England which would permit of comparison with the two last kinds.

As to whether the wagon-top is any benefit against priming (page 233), one winter's experience in Canada would do much to dispel all doubts, and cause the advantage to be appreciated of having the dome on the wagon-top. When striking a snow bank at 45 or 50 miles per hour, with the regulator wide open, the consequent rush of water forward gives an excellent chance in a level-top boiler of filling the cylinders, bursting off the covers, and disabling the engine at the worst time; and as it is then incapable of getting out, the line is blocked. Where there is any liability to

* See "Engineering," 29 April 1887, page 407.

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prime, the water will creep up the steam pipe to the throttle-valve by capillary attraction; and the drooping flange has been found a safeguard against this. At the same time the author also cuts the hole in the boiler much smaller than the dome. As to the dome connection, the author observes that flanging to the boiler is extensively practised on large railways both in England and on the continent, and even in Mr. Webb's compound engines with 175 lbs. pressure per square inch. Furthermore, as pointed out in the paper (page 192), the dome in the author's engines is braced to the crown-bars; consequently it does not rely upon its connection to the boiler for vertical strength, which is a weak point in English practice.

As the author does not block up half the fire-hole with deflector-plate machinery &c., he fails to see the use of making it larger than will suit a shovelful of coal, while at the same time nothing would thereby be gained in cost.

As to the difference in the kind of joint for the longitudinal seams of the boiler barrel in the S. A. and S. D. classes and in the S. B. class (page 234), the author scarcely thought it necessary to point out that the former classes were designed for freight service almost entirely, while the latter class are for passenger service, and would be expected to carry their full boiler-pressure for a longer period without any decrease.

For a smoke-box front (page 234) the author fails to see wherein wrought-iron has any advantage over cast-iron: certainly not in repairs or renewals, as the extra cost in labour for repairing a wrought-iron front would pay for the cast-iron front and put it on; and he should not care to repaint the number on the door every time it got blistered off by an extra collection of cinders in the box, to say nothing of the convenience of changing fronts in winter emergencies.

The lately published papers on the subject of riveting should in the author's opinion draw quite as much attention to the question of getting reasonably tight boilers as to extraordinary ultimate strength of joints.

On some Western roads the water is so bad that two sets of try-cocks are used (page 235), and no glass gauge; they are thereby

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ensured against neglect by the driver, and they cannot be stopped with sediment if their use is thus enforced.

If slide-valves needed only to be examined about once a year (page 235), they must have been working under very exceptional circumstances. Their examination will hardly be considered a trifling matter, when having to be done at 20° below zero Fahr. Automatic valve-facing machines are also in general use in America.

The representation made (page 236) as to driving-wheel centres hanging together by the boss only is quite true so far as it goes. The split in the wheel is filled with hard babbitt, and the wheel is then bored, turned, and pressed on the axle in that condition. Very occasionally a defective wheel will burst; but that only ensures the survival of the fittest. The tire is then heated and shrunk on, having an allowance of about 1-100th inch per foot of its diameter, so that when cold it would take from 150 to 200 tons to pull it off again. The key is then fitted to the keyway to be tight sideways, and is driven in. There is no inconsistency in fastening the truck-wheel tires with retaining rings, inasmuch as wrought-iron centres by their flexibility both destroy the tire and allow it to get loose. The truck-wheels however are made solid discs of wrought-iron, because a broken truck-wheel is a tolerably sure precursor of a badly wrecked train; whereas such cases of broken driving-wheels as have come within the author's experience have rarely caused more than a slight derailment. In the very few cases in which a driving-wheel cracks, it is found out and changed in time.

From his experience of Canadian foundries the author certainly prefers the English cylinders for quality (page 236); but the difference is not sufficient to pay freight and duty.

Respecting the Birkenhead engines on the Grand Trunk Railway (page 237), Mr. Tomlinson's remarks are perfectly correct. But there is a difficulty in making a comparison between an American and an English engine in their performance per pound of coal. If however the American engine cannot do as much for a pound of coal, it can probably do considerably more for a dollar. The Metropolitan engines have not made an extraordinary mileage—2,500 miles per month—as compared with the Canadian Pacific Railway

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engines, some of which have latterly made over 6,000 miles per month even in winter service, and not in any isolated month; whereas the Metropolitan engines have literally no hard conditions to contend against. Could their boilers, while still carrying the original pressure, stand also without defect the test given by Mr. Adamson (page 239)? and how many have had heavy boiler repairs, or what have they cost for maintenance?

The inference implied by Mr. Adamson (page 238), that the plate-frame is not rigid laterally as is the bar-frame, seems rather strange to the author. Considering that in English practice the front ends are usually plated and riveted together and bolted to the cylinders, making the frames as permanently rigid as a girder for at least 3 to 4 feet length, and that the foot-plate gives the same rigidity at the back, it is impossible for the frames to bend, unless one or other of them were to stretch or contract, which cannot be: or unless the driving horns were set bodily aside by a double swan-necked bend in each frame, which could not be without loosening the motion plate and cross plate in front of the fire-box. The lateral flexibility of the plate-frame appears to be a myth; else why is the bogie found to be such an advantage, or why is the radial axle-box required? Instead of the bar-frame requiring more time for construction, the author has found it an economy both in time, in first cost, and in subsequent maintenance. While on the Grand Trunk Railway from 1877 to 1883, the author repaired many engines with plate-frames, and found the cost of repairs and maintenance much higher than for engines with bar-frames; and on new work the plate-frame was a great additional source of expenditure. This is from Canadian experience, and it must be remembered that the plates for plate-frames have to be imported from Great Britain, and duty, freight, &c., paid on them; whereas the bar-frame is made from the railway company's best selected scrap. On locomotives of British type and manufacture the author is aware that the plate-frame would be the cheaper; whereas on those of the Canadian type the opposite is the case. He has had charge of many engines made in Canada with combination frames, the back portion being of imported plates and the front ends of forged bars, connected by a splice in front of the

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driving horns; they gave satisfactory results, but were more expensive to build and maintain. An instance of what a well designed and well built bar-frame will stand is afforded by an engine which he built in the latter part of 1883. During the following two years and a half this engine had an exceptional run of bad luck, having been off the track twice and badly "ditched," once owing to cattle on the track, and again from a broken rail; next it was in a butting collision, and again it was run into an open turntable pit; not a bolt, key, or joint, in the frame was started in any one of these casualties, and all the repair required for the frame consisted in straightening one front end which was bent by the butting collision. The author much doubts whether an engine with a plate-frame could have borne such rough treatment with such trifling damage and at such a low cost for repairs. In a butting collision it is invariably the cheap front end which suffers damage, the back and more costly part escaping injury; the front ends are easily taken down, cheaply repaired or if necessary replaced, and quickly put up again, so that the locomotive is only a very short time out of service.

Due consideration does not seem to be given (page 239) to the different circumstances under which locomotive and stationary boilers are used. As the latter are designed to be clothed in a mass of brickwork, almost entirely hidden from ordinary inspection and subject to examination at stated times only, while during the interval considerable damage may occur unknown and endanger numbers of lives, the greatest attention has consequently to be paid to giving them extraordinary strength as compared with the strain placed upon them. On the other hand locomotive boilers are subject to inspection every day to a great extent, and many of their defects are instantly apparent to a casual observer, while few escape detection by the engineer. Moreover they are subjected to external strains in every direction; so that, if any tendency to failure occurs, it is made to develop itself in the shape of leakage, and is at once detected. It necessarily follows that, in order to have an equal margin of economy and safety in each case, the locomotive boiler has to run with a lower theoretical factor of safety than the stationary boiler; but that this factor is only theoretical is proved by the relative number of

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explosions of each class. Again, the corrosion of stationary boilers is very apt to go on both inside and outside, while in the locomotive it is almost all inside, if not entirely so; consequently the plates of stationary boilers have to be correspondingly stronger. Hence it is evident that in the construction of the stationary boiler the factor of safety has to be the principal object; while for the locomotive boiler at least equal attention has to be paid to getting tight joints for the pressure to be carried. If a comparison may be instituted with the boiler built by Mr. Webb for compound locomotives and six-wheel coupled goods engines, as shown before the American Railway Master Mechanics' Association in June 1883, the boiler designed by the author for the S. D. Consolidation engines, though the most unfavourable for such a comparison, has nevertheless a somewhat greater margin of safety if constructed in a similar manner. The author is well aware that a single-riveted lap-joint causes rapid corrosion, owing to deflection of the plate consequent upon its departure from a true circle; and also that probably not more than one-third as much corrosion is liable to occur when a double-riveted seam is used, because the deflection which the joint then undergoes under pressure is much less than in the former case. Further, the practice is still largely followed in England of making single-riveted circular joints, and yet in such cases instances have occurred in which corrosion has taken place along the side of the joint round the lower part of the boiler until the plate has actually been cut through, and this has not been detected until the boiler was scaled. Thus it seems that too much attention can be paid to the form of one particular joint, while others are neglected. As to its being a fatal error to depart from a true circle in the construction of a boiler, it seems rather odd that the same theory does not hold good with regard to the longitudinal section, which is more or less rectangular; here however the staying of the ends counteracts the otherwise inevitable destruction. In an exactly similar way the parts of a wagon-top fire-box, or indeed of any locomotive fire-box not being a circle, have to be stayed against all possible deflection; and the sides of the wagon-top are not only stayed to the inside fire-box, but are stayed together over the top of the inside box, so that no

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deflection can take place, and consequently no destruction can ensue. As a fact, no objection has ever been found in practice against testing the boilers constructed for these engines up to 220 lbs. per square inch for any number of times, the test pressure having been repeated for various purposes. As regards testing boilers with water, there is one very important difference between the author's practice in that respect and the general practice in England: namely that, instead of using cold water and a pump, he uses hot water forced in by an injector, and consequently the boiler is subjected to the strains of expansion, and is in a condition closely approaching the actual condition of work.

While much pleased to be assured that his engines have none of the refinements of the fine race-horse engines running in England (page 240), the author would add that they partake of none of the race-horse's costly attention and care; but he has the fullest confidence that if one were put on any of the heavy passenger trains in England it would give such an account of itself as would cause favourable comment. It would be well if one of the English railways would determine to do as the Pennsylvania Railroad is reported to be doing with Mr. Webb's compound engine: namely to get a well designed and well built modern American engine, and to try it carefully, both as to performance and as to maintenance.

In regard to the comparative hauling power of the S.B. heavy passenger engines and a standard Midland or London and North Western engine (page 242), the train referred to in page 205 of the paper is about 312 tons without locomotive and tender, and has to be hauled on a Canadian road. But if the total weight of a train of twenty-three vehicles as given by Mr. Stroudley* at 335 tons, inclusive of engine and tender, may be quoted as a fair example, then a train of twenty-three coaches, without engine and tender, on either of those two English railways cannot weigh more than about 270 tons; whereas the little longer stroke referred to by Mr. Price-Williams, presumably 24 instead of 22 inches, should give one-eleventh greater load than the Canadian train of 312 tons, making 340 tons, equal probably to about twenty-nine English coaches.

* Institution of Civil Engineers, Proceedings March 1885, vol. lxxxi, page 101.

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(Mr. Brown.)

As to mileage and repairs, referred to by Sir Lowthian Bell (page 243), the author would quote fifteen engines built by himself for the Canadian Pacific Railway from the end of 1883 to April 1884, of the S.A. and S.C. classes. Nine of these are in freight service, and have averaged up to May 1887 over 2,700 miles per month, including time for repairs; the other six are in passenger service, and have averaged during the same period 3,360 miles per month, including time for repairs. Also five passenger engines of the S.B. class, built from May to September 1884, have averaged 2,560 miles per month since new. Up to the present time none of these twenty engines have had the slightest repairs to their steel fire-boxes, nor are there any signs of any such repairs being required. The water is commonly called good, in the sections over which they principally work, but is not of extra quality.

A different system of accounts does not necessarily imply a vagueness such as is mentioned by Mr. Paget (page 244). Having had occasion to revise his figures, the author has not found any change for a number of separate orders for engines. Further, as the author does not himself keep the accounts nor even the time of the men, which come under a separate department, he can scarcely have a more potent check on the suggested irregularities. Again, as an estimate is made and tendered in all cases before an order is given, he sees no difference between his position in such respects and that of a private builder or commercial engineer.

The same remarks apply to the comments of Mr. Reid (page 245); and as the author's costs for cylinders and wheels are fully borne out by Mr. Johnson's experience on the Midland Railway (page 222), the rest may be taken as being quite as correct. It appears strange that British builders, living in an unprotected country, and some of them having many of the requisite materials almost at their shop doors, seem unwilling to compete with Canadian and American builders, living in highly protected countries, and where in many cases the necessary materials have to be brought long distances. It is plain that the saving is a great part of it in labour; and not altogether in the materials, as it is mostly assumed to be. The design of the Canadian engines permits of obtaining these results in

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economy of labour; and advantage is taken of every opportunity to cheapen the cost of production without detriment to the finished engine.

Similar expansion arrangements to those mentioned by Mr. Riches (page 247) are usually made by the author whenever direct crown-stays are used; but they nearly always give some trouble by leakage. In order to prevent a solid deposit and to permit of cleaning more easily, the crown-stays used by the author are spaced higher than is usual in either English or American practice.

The spreading of balance weights over a longer arc of the wheel rim (page 248) is considered by the author to be an important point.

In regard to balancing the reciprocating parts by using four cylinders as advocated by Mr. Crampton (page 251), the author concurs with Mr. Worsdell in considering that it would be an expense, not an economy. A four-cylinder locomotive by Mr. Shaw was tried in the United States three or four years ago, with the same object in view of balancing one set of parts by the other; but it was discarded.

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MEMOIRS.

WALTER SCOTT DAVY was born at Sheffield on 13th February 1832, his father being one of the founders of the firm of Messrs. Davy Brothers, Park Iron Works, Sheffield. In these works, first as apprentice and subsequently as partner, he acquired a practical knowledge of mechanical engineering; and in later years dealt with the adaptation of machinery to modern requirements, more particularly to the manufacture of Bessemer steel on a large scale. In 1872, on the conversion of the firm into a company, he became one of the managing directors and also chairman, and took an active part in the erection of some of the largest steel-making plants in various parts of the country. In 1882 he resigned that position, as well as his connection with the Sheffield Forge and Rolling Mills and the Eckington Collieries, in order to take for three years the management of the Barrow Hæmatite Steel Works. On the completion of this engagement, his health having suffered from the anxieties and responsibilities attending it, he returned to Sheffield, and resided there in comparative retirement until his death, which occurred on 18th February 1887, at the age of fifty-five. He became a Member of this Institution in 1874.

WILLIAM DENNY, F.R.S.E., was born at Dumbarton on 25th May 1847, and went to school first in his native town, then for four years in Jersey, and afterwards to the Edinburgh High School. In 1864 at the age of seventeen he entered his father's shipyard at Dumbarton as an apprentice, and went through a complete practical course of training in each of the several departments. The extraordinary tact, generosity, and prudence which he always showed in his subsequent relations to his workpeople were the results of his intimate association with them during his apprenticeship. In 1868

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at the age of twenty-one he was admitted by his father as a partner in the shipbuilding firm. The problem of piecework was one of the earliest which engaged his attention in the administration of the business; and in 1871 the iron departments of the yard were placed upon this footing with satisfactory results. Having already in 1869 written a paper embodying his views on the dimensions of sea-going ships, he gave in 1870 a series of public lectures on the subject of iron shipbuilding. In the same year also he first carried out trials of one of his steamers upon the measured mile at progressively increasing speeds, obtaining thereby data for a curve of speed and power; and the results so obtained led to his writing successive valuable papers on steamship propulsion. In 1875 he supplied the results of the trials of steamers, constructed by his own firm and other builders, for the production of the late Mr. William Froude's paper in 1876 to the Institution of Naval Architects on the ratio of indicated to effective horse-power. In 1876 his experience in the use of mild steel began with the building of a river steamer of Bessemer steel, which was followed in 1878 by another of Siemens steel; and in 1879 the first ocean-going merchant-steamer was built of mild steel. The works at Dumbarton were gradually so extended as to enable vessels to be completed there in all details; and there was added an experimental tank, similar to that devised by Mr. Froude for the Admiralty, for the purpose of constantly carrying out many interesting experiments on the hulls of vessels. Simultaneously with the extension of the shipyard, another matter in which he engaged, of wider interest as affecting the other shipbuilders and the general welfare of Dumbarton, was the improvement and deepening of the river Leven. His numerous professional and scientific papers, in addition to the few already mentioned, show the very wide scope of his investigations and the very large amount of work which he performed. Almost his last public work was done on the load-line committee, which completed its labours in August 1885. Already in 1882 the strain of work had begun to tell upon him, necessitating a holiday absence; and in the summer of 1886, having again to travel for the sake of health, he went to South America, partly also on business. While there, his

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death took place at Buenos Aires on 17th March 1887 in the fortieth year of his age. He became a Member of this Institution in 1882, and was a Member of Council from 1885. He was also President of the Institution of Engineers and Shipbuilders in Scotland, besides being a member of numerous kindred societies, to which his many original and valuable papers were so liberally contributed in such rapid succession.

SAMUEL GODFREY was born at Ebbw Vale on 15th June 1832. To his grandfather was due the invention of the cataract, for timing the strokes of the Cornish pumping engine; and his father was engaged for many years at the Neath Abbey Works in making sugar-mill and other machinery required in the West Indies and other colonies. He was educated partly at Merthyr Tydfil, in the school of Mr. Taliesin Williams, father of the late Mr. Edward Williams of Middlesbrough; and afterwards at a Bristol school. He then went into the offices of Mr. Crawshay Bailey at the Aberaman Iron Works, where his father was at that time engineer; and was afterwards employed at Nantyglo. He was next engaged at the Neath Abbey Works, and although very young was there entrusted with the occasional supervision of machinery erections, chiefly furnace and mill work, in various parts of the country. Thence he was taken at the age of twenty-four by the late Mr. John Vaughan to act as chief engineer for Messrs. Bolckow and Vaughan on their growing concerns at Middlesbrough and Witton Park, and on their collieries; and in that capacity contributed to the progress of the iron manufacture by his persistent advocacy of higher blast-furnaces, as well as by the introduction of useful machines of his own contrivance for fish-plate making and for cutting and drilling and straightening iron and steel rails. He also devised improvements in furnace grate-bars, in rotary puddling, and more recently in boring machinery for salt-mining in Middlesbrough and elsewhere. When the late Mr. Edward Williams became the general manager of the firm of Messrs. Bolckow Vaughan and Co. in 1865, he retained his position as chief engineer, and initiated the steel business of the company by adapting to their new requirements the Gorton Works

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near Manchester. Afterwards he laid out and constructed the firm's Eston Steel Works near Middlesbrough, for which he also planned the steel-making plant. The anxieties attendant upon this, the greatest work of his life, broke down his health; and in 1880 he made a voyage to New Zealand, from which he derived some benefit. On his return however, finding the work too heavy, he retired after a service of twenty-six years. Subsequently he was engaged in the conversion of Welsh ironworks for the manufacture of steel, in arbitration, and in other business in which his experience was called into profitable requisition, until the harsh weather of the present year, acting upon his not robust constitution, led to his death on 18th April 1887 at the age of fifty-four. He became a Member of this Institution in 1862.

WILLIAM MCONIE, JUN., was born in Glasgow on 29th May 1851, being the son of Mr. William McOnie, ex-Lord Provost of that city, and senior partner in the firm of Messrs. W. and A. McOnie of the Scotland Street Engine Works. He received his education in a school at Sunderland; and was apprenticed as an engineer to Messrs. Randolph, Elder and Co. of Glasgow. Subsequently he entered his father's works, and acquired a practical knowledge of sugar-making machinery, in the production of which the works had long been largely engaged. He ultimately became a partner in the firm; and on the retirement of his uncle and his father in March 1886, the business was carried on by himself under the firm of Messrs. W. and W. McOnie. He died on 9th March 1887 in the thirty-sixth year of his age. He became a Member of this Institution in 1884.

WILLIAM STABLEFORD was born on 31st December 1815 at Birstal, a village about three miles from Leicester. At an early age he showed his mechanical inventiveness by so altering the little machine for weaving webbing, at which he was employed, as to double the amount of work it produced. A few years later he began to work for his father, who was a builder of railway wagons; and in 1846 he was appointed foreman in the works of Mr. Hamer at Leicester,

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on whose decease he became manager at the railway wagon works of Messrs. Johnson and Kinder at Bromsgrove. He subsequently took the management of Mr. Johnson's railway carriage and wagon works at Oldbury; and on the conversion of the business into a company in 1862 he was appointed general manager. This position he held for nine years, and in 1871 was appointed managing director, in which capacity he continued until compelled to retire in 1879 through failing health. In 1865 he invented a brake for railway wagons, which was extensively used both at home and abroad. When railways were being first opened in New Zealand, he designed the first rolling stock suitable for the narrow gauge, having combined centre-buffers and automatic couplings, for which he invented a safety shackle for preventing the draw-hook from getting out of position when in work. In 1879 he purchased a small repairing shop for railway wagons at Coalville near Leicester, which he developed into an extensive establishment, and executed there some large contracts for both English and foreign railways. For a number of years he had taken an active interest in the local affairs of Oldbury, until compelled by ill-health to retire about a year ago. He died on 4th March 1887, at the age of seventy-one, after an illness extending over three years; and during the last eighteen months he was quite blind. He became a Member of this Institution in 1862.

GEORGE JOPE YEO was born at South Zeal, near Okehampton, Devonshire, on 24th September 1844, and received his early education at St. John's College, Hurstpierpoint. In 1861 he was apprenticed to Mr. Sylvester Lees, locomotive superintendent of the East Lancashire Railway, Bury. On the expiration of the five years of his apprenticeship he served for two years with Messrs. Bland of Bury, being engaged chiefly in making and erecting beam and horizontal engines. Thence he went to the Worcester Engine Works, under Mr. Edward Wilson and Mr. Alexander Allan, for whom he had charge for about two years of erecting iron roofs and other work on the Metropolitan Railway. He then became assistant engineer of the Cheltenham Gas Works, under Mr. William Esson.

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In 1871 he went out to China as assistant engineer of the Shanghai Gas Works, where, owing to the disorganised condition of the works at that time and the increasing extent of the foreign settlement, there was a good deal of constructive work to be done. In July 1873 he was appointed chief engineer and secretary, having the entire management of the works; and he effected not only a great improvement in the quality of the gas but also a considerable reduction in its price. In 1884 he returned to England to recruit his health, which had been gradually failing; and recovered sufficiently to resume his duties at Shanghai at Christmas 1885, until his death took place there on 23rd June 1886, in the forty-second year of his age. He became a Member of this Institution in 1885.

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Institution of Mechanical Engineers.

PROCEEDINGS.

August 1887.

The Summer Meeting of the Institution was held in Edinburgh, commencing on Tuesday, 2nd August 1887, at Half-past Nine o'clock a.m.; Edward H. Carbutt, Esq., President, in the chair.

The President and Council and Members were received in the Library Hall of the University, by the Most Honourable the Marquess of Tweeddale, Chairman, and other members of the Local Committee; by the Magistrates of the City of Edinburgh; by the Principal and other Authorities of the University; and by other Dignitaries.

The Marquess of Tweeddale said he was present on behalf of the Reception Committee formed in Edinburgh, to offer a hearty welcome to the President and Members of the Institution of Mechanical Engineers. The Committee considered that a great honour had been conferred on the city by its selection as the place for the Summer Meeting of the Institution; and they regarded it as a privilege to themselves to be instrumental in any way in rendering the visit of the Members agreeable and profitable to them. Edinburgh presented many objects of great interest, industrial and otherwise; and within easy access there were many undertakings which he was sure would have a considerable interest for the Members of the Institution. One of the most important of those undertakings, the Forth Bridge, would be visited this day; and as two papers respecting it were to be read and discussed before the visit, it was not necessary that he should occupy the time of the Members in referring further to it. He would only express a warm hope that their sojourn in Edinburgh would be a pleasant one; and he would promise

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(The Marquess of Tweeddale.)
that nothing which could be done would be left undone on the part of the Reception Committee to make their visit thoroughly successful.

Sir WILLIAM MUIR, K.C.S.I., Principal of the University, desired on the part of the University to express their gratification at the honour conferred on the University by the visit of the Members of the Institution of Mechanical Engineers. The University rejoiced at the advent of the Institution, and trusted that the sojourn of the Members, and the many objects visited, would prove all that had been expected in advancing the interests of the Institution and the material welfare of the country.

The PRESIDENT said that on behalf of the Institution he begged to thank the Marquess of Tweeddale, Sir William Muir, the Lord Provost and Magistrates, and the members of the Reception Committee, for the hearty welcome accorded to the Members of the Institution on the occasion of their visit to the northern Athens, the queen of all capitals, and one of the most beautiful places in the United Kingdom. The Members were delighted to come to Edinburgh to view the many attractions of the city, and to receive the hearty welcome and hospitality offered to them. But they had come especially to obtain information; and he hoped that the papers which would be read would afford information not only to the Members themselves, but to many of the inhabitants of Edinburgh. In considering mechanical questions he hoped that the Edinburgh professors with their academic learning would join in the discussions, and throw any light they could upon the papers read, either in pointing out the defects or illustrating the merits of the special mechanical subjects dealt with. He begged again to return the hearty thanks of the Members to the Reception Committee for all the trouble they had taken to receive them.

The PRESIDENT then took the chair in the Lecture Theatre.

The Minutes of the previous Meeting were read, approved, and signed by the President.

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The President mentioned that their esteemed Past-President, Mr. Thomas Hawksley, was unable to attend the present Meeting, in consequence of the celebration of the eightieth anniversary of his birthday. A message of congratulation to him upon so notable an occasion had accordingly been sent this morning from the President and Council, on behalf of the Institution; and the following telegraphic reply had been received from him:—"I return my best thanks for your obliging congratulations."

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following thirty-one candidates were found to be duly elected:—

MEMBERS.

Thomas Napier Armit,	Dundee.
Robert Alexander Baillie,	London.
Adam Carlisle Bamlett,	Thirsk.
Charles McGuire Bate, Capt. R.E.,	Woolwich.
James Brown,	Newcastle-on-Tyne.
Frederick John Browne,	London.
James Chatwin,	Birmingham.
William Basil Dixon,	Hull.
William Tregarthen Douglass,	London.
Ernest Gaertner,	Vienna.
Manassah Gledhill,	Manchester.
Charles Gershom Gourlay,	Dundee.
William Hindson,	Gateshead.
Thomas Jones,	Manchester.
Joseph Lindsay,	Dundee.
James Grieve Lorrain,	London.
Sidney Herbert Nelson,	London.
John Lucius O'Flyn,	Cardiff.
William Spence,	Dublin.
David Alan Stevenson,	Edinburgh.
Andrew Stewart,	Glasgow.

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William Webster,	Samarang, Java.
Henry Wood,	Bolton.

ASSOCIATES.

Henry Peech,	Sheffield.
William Henry Peech,	Sheffield.
Walter Scott,	Newcastle-on-Tyne.
Edward Sanderson Tozer,	Sheffield.

GRADUATES.

Joseph Harrison Ashby,	Warrington.
Wrey Albert Edward Hanby,	Bengal.
William Hogg,	Crewe.
Edward Henry Tabor,	London.

The following Papers were then read and discussed :—

On the Structure and Progress of the Forth Bridge; by Mr. E. Malcolm Wood, of London.

Notes on the Machinery employed at the Forth Bridge Works; by Mr. William Arrol, of Glasgow.

On Electro-Magnetic Machine-Tools; by Mr. Frederick John Rowan, of Glasgow.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Lecture Theatre of the University, Edinburgh, on Wednesday, 3rd August 1887, at Half-past Nine o'clock a.m.; Edward H. Carbutt, Esq., President, in the chair.

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The following Papers were read and discussed:—

Description of the Electric Light on the Isle of May; by Mr. DAVID A. STEVENSON, of Edinburgh.

Description of the New Tay Viaduct; by Mr. FLETCHER F. S. KELSEY, Resident Engineer.

On the Dredging of the Lower Estuary of the Clyde; by Mr. CHARLES A. STEVENSON, of Edinburgh.

The two remaining Papers announced for reading and discussion were adjourned to subsequent meetings.

The PRESIDENT proposed the following Votes of Thanks, which were passed by acclamation:—

To the Chancellor, the Principal, and the Senatus Academicus of the University of Edinburgh, for their kind invitation to hold the present Meeting in the University, and for the important facilities they have so obligingly afforded for this purpose.

To the Edinburgh and Dundee Reception Committees, and the Executive Committee; to the Chairmen, the Most Honourable the Marquess of Tweeddale, and Provost Hugh Ballingall; and to the Honorary Local Secretaries, Mr. St. John V. Day and Professor Ewing; for the highly acceptable arrangements made by their exertions for the Meeting and Excursions, and for their hospitable reception of the Members in Edinburgh and Dundee.

To the Right Honourable the Lord Provost, the Magistrates, and the Council of the City of Edinburgh, for their obliging invitation to the Conversazione in the Science and Art Museum.

To the Engineers of the Forth and Tay Bridges, the Commissioners of Northern Lighthouses, the Engineers of the Edinburgh Water Works and Dundee and Leith Harbours, and the Proprietors of the numerous Engineering Works and other Establishments open to the visit of the Members, for their welcome invitations and the facilities they have offered in connection therewith.

To the Chairmen and Directors of the North British and Caledonian Railways, for their kindness in arranging Special trains for the convenience of the Members in the various Excursions.

Mr. ST. JOHN V. DAY, in acknowledging the second vote of thanks, said the work he had undertaken had been exceedingly

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(Mr. St. John V. Day.)
agreeable; and nothing could have given him greater pleasure than to do anything that was acceptable to the President, Council, and Members of the Institution of Mechanical Engineers; he deemed himself fortunate to have been asked to perform the duties of Honorary Secretary. The neighbourhood of Edinburgh was not in the fortunate position of representing a very large proportion of the engineering interests of the kingdom; but just at present it was a centre around which an unusual amount of interest from an engineering point of view had gathered, in the two great works of the Forth Bridge and the Tay Viaduct, the former greater in its height, and the latter in its length, than any other bridges in the world. In addition to these gigantic bridges, visits had been arranged to some of the very interesting works in Dundee, which was the centre of one of the greatest industries of Scotland, namely the jute manufacture; the mills were the finest of their kind in any part of the world, and the trade had spread abroad to Calcutta and other parts of India. He would only add that his work in connection with the present meeting had been exceedingly grateful to him; and it would be long cherished in his memory that he had been asked to undertake the post of Honorary Secretary.

The Meeting then terminated. The attendance was 276 Members and 65 Visitors.

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ON THE STRUCTURE AND PROGRESS OF THE FORTH BRIDGE.

By Mr. E. MALCOLM WOOD, of London.

As a visit to the works of the Forth Bridge is included in the programme of the present meeting of this Institution, the author trusts that a short sketch of the preliminary proceedings, with a description of the structure and progress, from a Member engaged on the work from its outset, will prove of interest in explaining the reasons and means adopted for connecting the railways on opposite shores of the Firth of Forth, at the site of the historic ferry and still existing Hawes Inn, whose time-table for the departures of the ferry boat is so quaintly alluded to in "The Antiquary."

Previous Proposal.—For many years, suggestions for establishing direct communication between the Fifeshire lines and the southern railways running into Edinburgh, with the object of more direct access to Perth and the north, had been frequently considered by the companies interested in that route; but until an act of parliament was obtained in 1873 for crossing the Forth at the site of the present works by means of a suspension bridge, designed by the late Sir Thomas Bouch, no proposal gave prospect of successful issue. Although the type of bridge then proposed was not one generally considered applicable for the passage of railway trains, yet no positive objection seems to have been taken to it, inasmuch as a contract was entered into for its construction, workshops were erected at the site, and foundations were started. But after the

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severe gale at the close of the year 1879, so destructive to a viaduct in an equally exposed position, it was deemed prudent to suspend operations; and the directors of the North Eastern, Midland, and Great Northern Railway companies, which each have an interest in obtaining direct access to the eastern and northern districts of Scotland, requested their respective consulting engineers, Mr. T. E. Harrison, Mr. W. H. Barlow, and Mr. (now Sir John) Fowler, to confer together and report upon the possibility of some other plan for making through communication between the existing lines at the point already selected. Tunnelling was out of the question on account of the depth of the water; the proposals therefore took the form of bridges.

Present plan.—On 4th May 1881 the engineers submitted their joint report, unanimously agreeing that the Steel Bridge on the cantilever and central-girder system, designed by Sir John Fowler and Mr. Benjamin Baker, was not only the least expensive, but the best suited for the situation. The soundness of this decision has since received confirmation in the fact that seven long-span bridges have been or are now under construction in different parts of the world, and many more are proposed on the principle adopted for the Forth Bridge. For the substitution of this design in place of the suspension bridge contemplated in 1873, the Forth Bridge Railway Co. appointed Sir John Fowler and Mr. Baker their engineers, and obtained an act of parliament in July 1882. The financial obligations for the construction of the bridge having been undertaken by the railway companies interested in the through route —namely the North Eastern, Midland, Great Northern, and North British,—tenders were invited for the work, and from the applications received two offers were selected; and with the combined firm of Messrs. Tancred Arrol & Co. a contract was made in December 1882 for the entire execution of the work.

General dimensions.—As seen from Plate 38, the total length of the bridge will be 8296 feet, or 376 feet over 1½ mile. There are two main spans of 1700 feet each, two side spans of 675 feet each, with

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the ends counterbalanced and anchored to the masonry, and three intervening piers; these together make up about a mile of the total length, and the remainder is composed of fifteen approach spans of 168 feet each, and of masonry arches and abutments. For a length of 500 feet in the centre of each of the two 1700 feet spans there is a clear headway for navigation of 150 feet above high water; the rails being placed at a level 6 feet higher. From the base of the deepest pier to the top of the cantilevers the total height is 450 feet or only 10 feet less than the great pyramid of Egypt.

The cross sections of the main spans are of trapezoidal form, as shown in Figs. 7 and 8, Plate 41, 330 feet in height from centre to centre of the members over the piers, and 33 and 120 feet in width across top and bottom respectively, and tapering towards the ends of the cantilevers, thus giving a form, as shown in the plan, Fig. 2, Plate 38, which is eminently suitable for withstanding lateral pressure. The girders carrying the railway are supported at intervals inside the cantilevers &c. by trestles or cross frames; and a continuous lattice work parapet 4½ feet above the rails extends the whole length of the bridge.

Load, and Wind Pressure.—In addition to its own weight the bridge is being constructed to support, without exceeding in any member the unit stresses permitted by the Board of Trade, a load equivalent to trains of unlimited length equal to 1 ton per foot run on each line of railway, or passing trains consisting each of two engines and tenders at the head of sixty coal trucks weighing 15 tons each; and also to withstand a lateral wind pressure of 56 lbs. per square foot of exposed surface of train and structure. The magnitude of the lateral pressure may be judged from the fact that over the mile length of main spans the estimated surface exposed to a point blank wind at right angles to the bridge amounts to a little more than 7½ acres; the pressure of 56 lbs. per square foot on this surface would therefore be equivalent to a total of more than 8000 tons. In addition to lateral winds, the direction from any point of the compass has been provided for, even including the imaginary condition of each group of main piers becoming the centre of a whirlwind.

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Effects of temperature will be provided for in the rails, and at the junctions of the central girders with the cantilevers; and the bearings on both the main piers and under the weighted ends of the cantilevers have provision made for allowing movements due to changes of temperature and to the elasticity of the cantilevers under lateral pressure. The lateral play allowed is limited, so that the whole of the piers may act in concert to resist combined actions of all forces tending to disturb the normal state of rest of the 50,000 tons of permanent load. As a further provision 48 steel bolts of 2½ inches diameter, secured 24 feet down in the masonry by anchor plates, hold down each bed-plate with an initial tension of 2000 tons; the nuts and saddle-plates are so arranged as to allow freedom of lateral movement to the skew backs; but any lifting would at once be prevented by the anchorage coming into action, which however could only happen under the assumed circumstance of a wind pressure more than double that already mentioned, acting over the whole estimated surfaces. The maximum pressure on the base of the piers will be a little over 6 tons per square foot.

Forms of parts.—The enormous forces to be resisted have been met by adopting the most suitable forms of parts for withstanding the stresses. Tubular members are used for compression, and open-braced box-forms for tension, as seen in Figs. 9, 10, 11, and 12, Plate 42. These parts vary in size as required. Though the tubular form has scarcely been used in this country for bridge members since its employment by the late Mr. Brunel, no difficulty has arisen in connection with its use; even the junctions are dealt with as readily as the generality of the work.

Masonry.—The masonry for the main piers, above the whinstone concrete filling of the caissons, consists of a casing of grey Aberdeen granite, enclosing and bonded into a hearting of Arbroath stone set in cement, and strengthened by three massive wrought-iron belts built into the stonework. The deepest pier weighs about 20,000 tons. The remainder of the masonry of the piers and abutments is of a similar class, whinstone being largely used in the interiors.

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Steel.—For the principal members of the superstructure subject exclusively to compression, the steel used has a tensile strength of from 34 to 37 tons per square inch, with at least 17 per cent. of elongation in a length of 8 inches; for the other parts 20 per cent. of elongation, with 30 to 33 tons tensile strength. The rivet steel has 25 per cent. elongation, and 26 to 28 tons tensile strength per square inch. The whole of the steel is manufactured by the Siemens process. No sheared edges or punched holes are permitted.

Work started.—No time was lost by the contractors in starting the work. The land was at once entered on, and connected by a siding with the North British Railway; the old workshops were put in order, and the extensive range of offices, stores, workshops, and yards was commenced, which now cover fifty acres. Meanwhile the centre line of the bridge was fixed, and the position of the piers determined. The foundations of those on land were begun simultaneously with the building of temporary jetties for gaining access to the piers that had to be sunk below water-level. These jetties, which are still used for conveying the material, are in themselves no small work; the southern or Queensferry jetty extends 2200 feet from the shore, and is connected with the workshops by an incline worked by a rope driven by a stationary engine. In order that the operations might be carried on continuously day and night when needful, electric light installations, supplemented by lucigens, were laid over the works and piers; and telephonic communication was established between the offices and all the centres of operations. The workshops and yards were rapidly completed, and furnished with tools, of which many are of a special and novel description. Ever since the commencement the work has progressed without interruption, and has gradually assumed the gigantic proportions of the present time. Over 3000 hands have been employed continuously for the last year; and during the present summer months the number has been increased to 4000. The majority find lodgings in the neighbourhood of the bridge; and the remainder make use of a special train service to and from Edinburgh

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and a steamer to and from Leith, put on for their use night and morning.

Materials.—The materials for the permanent work have been obtained throughout from producers of repute:—Aberdeen granite from Messrs. Fyfe; Portland cement from Messrs. Hilton and Anderson and Bazley White; Siemens steel from the Steel Company of Scotland and the Landore Steel Works. All the steel has been subjected to rigid examination, and has passed the ordeal of specified tests before leaving the makers' works; a few specimens showing its high quality are exhibited. The materials delivered up to the present time have included—

Granite	550,000 cubic feet.
Portland cement	21,000 tons.
Steel	43,200 tons.

The amount thus far erected has been—

Masonry in piers and abutments . . .	129,500 cubic yards.
Steel in approaches and main spans . .	19,000 tons.
Steel for main spans, prepared ready for erection, about 20,000 tons.	

By the time the first consignment of steel arrived, the shops were ready for the preparatory operations, and the whole establishment was rapidly organised to deal in the most complete manner with the work to be executed. Hydraulic power is freely used, from the extremely neat form of shop crane to the 1,600-ton press for curving the tube-plates. With the exception of the main-pier caissons, made by Messrs. Arrol Brothers of Glasgow, and the superstructure of the approach spans by Messrs. P. and W. Maclellan of Glasgow, the whole of the work has been turned out of the shops at the bridge, their present capacity being an output of 1300 tons of finished work per month.

Shop practice.—The procedure in the shops may be described as follows. The flat plates and bars are first straightened. The plates to be curved are heated to a uniform red heat in a gas furnace, and while red-hot are moulded in dies under hydraulic pressure to the required

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form, stacked and coated with ashes, and allowed to cool slowly and equally any subsequent warping is taken out by placing them again in the press when cold, and giving them a final squeeze into the correct shape. The butts of the bars are cold sawn, and the edges and butts of the flat plates are planed in the usual manner. The ends of the curved plates are planed in a novel form of machine, in which the tool travels in a circular path readily adjusted to the radius of the curved plate. On completion of the planing, the plates are taken to the tube yard, and are built up round the longitudinal ribs and internal stiffening frames, which have previously been fitted together in moulds to the exact diameter required: so that the plating of the framing at once gives the tube its proper form. The plates are in 16 feet lengths, and break joint alternately over the stiffeners at 8 feet intervals. Means are adopted to keep the tubes in line while the rivet holes are pierced by a travelling annular drilling frame, which is mounted on wheels and carries a boiler and engine driving ten drills by cotton ropes. A pair of drills are attached to each bed; and as the beds can traverse the circumference of the tubes, while the drills can traverse the length of the beds, the whole outside of the tube is commanded, and the holes are completed with accuracy to ensure their precise coincidence when the parts are rebuilt at the site. As fast as each section of 8 feet length is finished, the machines are propelled along the rails to take up a new position; they thus travel gradually in successive stages over the whole length laid down. The tee and trough-shaped parts are built together in the shops, and the holes are drilled by adjustable vertical and horizontal drills, fitted to a travelling carriage; the power is transmitted to the machines by ropes from the shop shafting. Numerous radial machines are also in use for the secondary parts. For dealing with special parts, many ingenious and somewhat novel workshop appliances have from time to time been brought into use, beyond those here mentioned. All the parts of the junctions are carefully fitted together in the yard in the exact positions they will relatively occupy in the bridge. After each member has been prepared, the pieces are painted, marked, and stored until required for erection.

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Founding Piers.—With the founding of the piers below water commenced the more difficult part of the undertaking; but without any sensible delay the whole of the piers have been successfully sunk and completed. The foundations for piers in shallow water were put in either by tidal work or by open cofferdams, and the excavation was carried down to boulder clay or rock. Though these were of individual interest themselves, from their size and the difficulties met with, they are dwarfed by the magnitude of the operations connected with the deep-water piers, of which those in the south group are embedded in the boulder clay in one case at 90 feet below mean water-level, while at Inchgarvie they rest on a level bench cut out of the sloping whinstone rock at a depth of 72 feet.

Caissons.—The caissons for all the deep piers are 70 feet in diameter at base, Plates 39 and 40; the cutting edges and shoe are of steel, and the upper parts of wrought-iron. They were first built on ways on the south shore, and were launched with sufficient ballast on board in the form of concrete to ensure their stability while towed out to their berths at the end of the jetties, where guide piles and dolphins were used to place them in correct position. Temporary wrought-iron cofferdams were built upon the top of the caissons, timber working-decks constructed, cranes and concrete-mixers fixed, air-pressure connections made good, and sinking operations commenced with a pressure in the excavating chamber sufficient to drive out the water; the air-compressing machinery was placed on the jetty alongside. The Inchgarvie caissons had to be equipped with all these fittings while moored to the south jetty, so as to be ready for work on arrival over their rocky bed.

The working chamber W was illuminated by electric lights; and communication was effected with it through three shafts S, as shown in Plates 39 and 40, with air locks L on the level of the upper deck. The two shafts for the skips bringing up the excavated material were constructed with horizontal sliding shutters, worked by hydraulic rams, in place of the usual swing doors. The winding drum for bringing up the skip from the working chamber was in the lock itself, but driven by an engine outside. On arrival of the skip in the lock, the

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lower slide was shut to, the blow-off cock opened for releasing the pressure, the top slide drawn back, and the hook of the discharging crane was coupled to the skip by hand. This direct and rapid method of transit for the excavated materials greatly facilitated the sinking; the whole operation from arrival of the skip in the lock to its removal lasted only about three-quarters of a minute in ordinary working, the sequence of the movements being automatically controlled by interlocking gear. The air locks in the third shaft for the men were constructed with a view of rapidly changing shifts, and had double chambers, each capable of holding seven men.

The silt overlying the harder deposit was expeditiously expelled from the working chamber by means of ejection pipes passing into the water outside, the air-pressure being sufficient to blow out charges of silt and water mixed in a box which communicated by a valve with the ejection pipes. On reaching the boulder clay, portable steel diggers, actuated by hydraulic cylinders placed between the roof and the implements, were brought into use to break up this hard material.

At Inchgarvie a modification of this system was required for sinking the deep piers into the hard whinstone rock, which had a natural slope of 1 in 4½, as shown in Plate 39. Bags of sand and concrete were deposited in two piles at B on the deeper side of the site to be occupied by the caisson, which had been launched with massive timber blocks in the chamber, to rest upon this artificial bed; these blocks and the edge of the caisson touching the rock on the shallower side were the first bearings it took when lowered at the site. The whole of these primary operations required extreme care to provide for differences of weight on the base, due to the depth of water at different states of the tide. Then by means of rock drills driven by air pressure, and ordinary quarrying operations inside the air-chamber, the rock was excavated until the caisson was sunk to a level bench cut out of the sloping rock. In these caissons the full pressure of air due to the head of water was maintained during the sinking, and it was found advisable to change the gangs every four hours; the maximum pressure reached at high tide was 33 lbs. per square inch above the atmosphere. The last of these caissons was got down to its final depth in October 1885.

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In sinking the southern group of caissons, Plate 40, the air-pressure hardly ever exceeded 22 lbs. per square inch, the silt and clay acting as a lute; and the working shifts were of six hours duration, about twenty-seven men being down at a time.

Recovery of canted Caisson.—With the exception of the north-west pier in the southern group, the whole of the piers were completed with regularity. But the caisson for that particular pier, weighing with concrete some 3000 tons, while ready at the site for placing in its final position, by some means became waterlogged on New Year's day 1885, and on the tide falling slid forwards on the mud about 15 feet, and canted over through 25 degrees. After an ineffectual attempt to right it by pumping, regular siege was laid to it; but not until the autumn following, after nine months of incessant work, was a timber jacket or cofferdam completed, which enabled the pumps at last to obtain command over the leaks. The caisson then floated again, and after repair was sunk in position in the ordinary manner, arriving at its final depth in 1886. After the excavation had been completed, the chambers were rammed with concrete and grouted up, the concrete and anchorage and masonry were completed, and the temporary cofferdam was ready for removal.

Men employed.—No difficulty arose in obtaining a sufficient number of men inured to work under air-pressure, as M. Coisseau, of the firm of MM. Couvreux and Hersent of Paris, brought his staff of trained excavators from the Antwerp harbour improvement works, and contracted for the work to be executed under air-pressure.

Raising Viaduct Girders.—After the masonry of the approach viaduct piers had been carried up to a convenient height, a temporary stage was built, upon which the girders were erected and riveted up. Steel cross-beams with pairs of hydraulic jacks were placed under the ends of the girders over the piers; and a stage surrounding the piers was suspended from the main girders. From this platform the men in charge of the rams conducted the operations of lifting and blocking up the girders; and the masons afterwards completed the

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stonework in the vacant spaces. By this plan the girders were raised to their final height in July of the present year. The whole of the ten spans on the south side were lifted simultaneously as soon as they were all riveted up. The materials for the piers were first raised in trucks, by a steam hoist on the jetty, to a tramway laid on beams between the bottom members of the girders, and afterwards lowered into position by winches over each pier, these winches being driven by running ropes from engines on the girders at alternate piers. These approach spans now require only the parapet and a few other details for completing them in all respects, ready for the permanent way.

Erecting steel work over main piers.—On the completion of the masonry, the operation of erecting the steel work was commenced on the northern piers early in 1885 by riveting up the bed plates, and lowering them into position over the heads of the foundation bolts. Their surfaces were afterwards smoothed by emery wheels, and coated with crude petroleum, to prepare them for receiving the bearing plates of the cantilever bases or skewbacks. These, as already mentioned, have freedom for a limited amount of sliding, and the gauges at present attached show that the sliding movements follow the changes of temperature as anticipated.

The skewbacks, forming the junction of five tubular and five rectangular members over the piers, were then erected, and were connected with the horizontal members at the same level, which had been built together on a stage. After the connections had been riveted up, a commencement was made upon the upper parts over the piers; these parts have since been erected without any form of fixed scaffolding, and the operation is still in progress over the Inchgarvie piers.

The lifting gear for raising the erecting platforms, shown in Plates 43 and 44, consists of a pair of plate frames FF, one below the other, fixed inside each 12 feet pier-column C, by pins passing through the wings of the frames and the ribs of the column. The lower frame supports the hydraulic lifting press L of 12 to 14 inches stroke; and upon the upper rests the through box-girder

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cross-beam B, at right angles to the length of the bridge, passing through voids in the columns, where plates are temporarily left out for this purpose. These cross-beams support lattice-girders GG in pairs, one on each side of the column C, which extend a little more than the full length of the side of the quadrangle formed by the piers. Upon the top of all comes the main deck D, furnished with gantries, cranes, oil-heated rivet-furnaces, &c., complete in all respects for carrying on the chief operations of erection. On the bottom level of the girders G is a lower deck H, with the ends housed in to form temporary shelters for the men. The box and other girders are built up of parts which will eventually be used in the permanent structure. Communication between the level of the jetty and the platforms is made by hoists, drawn up between wire-rope guides by the winding engine on the level of the jetty, which lifts the material by wire ropes to the platform; safety clutches are attached to each cage, for seizing the guide ropes in case the hauling gear were to give way. During lifting operations, access to the platforms is gained by ladders laid up the cross-bracing between the main columns over the piers.

The process of raising the platforms is as follows. Water-pressure at about 30 cwts. per square inch is conveyed from pumps on the jetty to the lifting presses by wrought-iron piping taken up the inside of the columns, and is turned into the cylinder L, Plate 43, lifting the load off the series of pins in the top frame. The pins are then withdrawn, and the ram lifts the box-girder B, carrying with it the loose frame, until opposite another series of holes in the ribs of the columns, into which the pins are then inserted; the pressure is released, and the box-girder again rests upon the upper frame. In the return stroke the ram, hanging by its shoulders from the upper frame, by means of its piston form now hauls up the lower frame, from which the pins have been withdrawn; and when this has been repinned, it is ready to support the press for another upward stroke. By this means the platforms have been gradually raised, generally through lifts of 16 feet at a time in steps of 6 inches or 12 inches according to convenience, until arrival at the summit. On their way up they

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have been utilised for building the tubular cross-braces and other work; and at the present time those at the southern and northern piers form the stage for erecting the top members between the heads of the main columns. The platforms at Inchgarvie are now only 25 feet below the height to which they will have ultimately to be raised.

In building the pieces together, they are connected by service bolts, until the hydraulic riveters are brought into action. For the open work the riveters are of the gap type; but for the closed tubular work, a special adaptation was devised by Mr. Arrol, by which the rivets are closed in any part of the built tubes. When these machines arrive at the top of the columns, after having completed the riveting on the way up, they are taken apart ready for application elsewhere.

Erecting Cantilevers.—The building out of the first projecting bays of the cantilevers is being conducted on the system just described, with such modification as to suit the altered circumstances. The bottom members are first erected, and have been built by means of overhanging frames in panels, resting upon the completed portions of the tube, and so constructed that, as fast as the work is riveted up by the annular riveting machines, and the forward portions of the cage-like framing are brought into bearing, the back frames can be unshipped and taken forwards to the working face. Upon the top of this framework a moveable hydraulic crane is placed for lifting the pieces into position, which are brought alongside from the pier by carriers suspended from a single rail of angle bar. As soon as the limit is reached at which these members can support the projecting work, inclined supporting stays are introduced, which connect the bottom member at this part with a temporary horizontal tie stretching between the main columns at about the level of the cross-bracing; thence the inclined stays slope down again, and are attached to the bottom member on the other side of the pier. After this has been done, platform girders with decks are built at a convenient level to rest on cross-beams carried by rising frames, which are introduced between the corners of the first upright member of the bridge: this member having been pierced beforehand with a

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series of pin-holes, in readiness for a lifting action similar to that used in the main columns. The ends of the platforms nearest the piers are raised by suspension bars, by the action of hydraulic rams attached to the main columns at a higher level. From these platforms, as in the previous cases, the erection of all parts commanded by them is carried on as they rise.

The erection of the secondary parts proceeds simultaneously with that of the main members, the railway girders being built by corbelling out from the supports, and the other parts by light stages when the parts themselves cannot serve as a means of support to extend the work. As will readily be understood, the erection of these sections calls for greater nerve and judgment on the part of the men employed than does that of the portions previously described.

In conclusion, the author desires to express his indebtedness to Sir John Fowler and Mr. Benjamin Baker, through whose kindness he has been enabled to place before the Institution the foregoing particulars respecting an undertaking, which, as shown by the magnitude of the works now being carried on, constitutes one of the greatest engineering feats ever attempted.

Discussion.

Mr. WOOD exhibited a series of photographs showing the present state of progress of the bridge in different portions of its structure; and also specimens of the steel employed, showing the tests to which it was subjected before being used in the bridge.

The PRESIDENT was sure the Members had been delighted to listen to the paper just read, describing what he supposed was the most remarkable engineering structure in the world. Until they

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had seen it they would perhaps be hardly able to appreciate its magnitude; but those who had taken part in the excursion down the Thames at last year's summer meeting, and had seen the large scaffolding erected by Messrs. Westwood Baillie and Co. for building the cantilever bridge designed by Mr. A. M. Rendel for spanning the river Indus at Sukkur, might form some idea of the size of the Forth bridge by bearing in mind that the Sukkur bridge was less than half its span. The Forth bridge was nearly four times the span of the Britannia bridge over the Menai strait, of which engineers were so justly proud when it was built by Mr. Robert Stephenson, Past-President of this Institution. The way in which the work described was being carried out would be highly appreciated by all. There was no unnecessary scaffolding, because the work carried its own scaffolding with it. The plan of employing a hydraulic cylinder to push up the erecting platforms, and then, when they were firmly fixed in position, letting the cylinder pull up its own support and start afresh, was indeed an admirable one. While great credit was due to Sir John Fowler and Mr. Baker for their admirable design, they must have been indebted to the engineers on their staff for many of the details in erecting the bridge; and he was sure the Members, when they visited the bridge, would be charmed not only with the general structure itself, but with the many interesting details which it presented. The present position of the work was clearly shown in the capital set of photographs which the author had kindly brought for the inspection of the Members. He would ask the Marquess of Tweeddale, as the prime mover in this great undertaking, to say a few words on the subject.

The Marquess of Tweeddale said that, though not an engineer, and having only for a short time been connected with the work as chairman of the Forth Bridge Railway Co., he desired to express the obligation he was under to the author for enabling him to become better acquainted with the bridge than he had been before, or than it was likely he would have been without having the advantage of listening to the present paper. Although he had visited the bridge on many occasions, and had had the benefit of the observations on the

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(The Marquess of Tweeddale.)
spot, he was free to admit that hitherto many points had seemed obscure which had now been made clear. All engineers he thought might well be proud of the structure, as really a triumph of mechanical engineering. However clever and able the design, the real difficulties must be met with in the details required for carrying out the design in the manner intended. These details he was glad to find would form the subject of a paper now to be read by Mr. William Arrol, to whose extraordinary ingenuity and resource the success of the Forth bridge might in a great measure be ascribed.

Mr. Daniel Adamson, Vice-President, had been greatly interested by the paper, inasmuch as it dealt with exact matters of fact; at the same time he should have been glad if it had entered somewhat more fully into the minute details of the work. From a metallurgical point of view he should like to know the actual composition of the steel employed, as he understood some trouble had been experienced in handling the heavier plates, which he presumed were those of the strongest material. The larger portion of the steel, he imagined, would contain only about three-quarters of one per cent. of alloy. From his own experience in working about 60 tons per week of steel of that class under all sorts of conditions and for a great variety of purposes, he had come to the conclusion that there was very little trouble in working such mild metal, and very little risk in its application; but so much could not be said in the case of a stronger material. The objections to anything higher than three-quarters of one per cent. of alloy were based upon the character and condition of the alloying elements. He was very glad of the opportunity of broaching the matter in this city of learning, because all the professors connected with the University would understand how necessary it was for mechanical engineers to receive from them all the information they could give, whether by calculation, by chemical investigation, or otherwise. If so much depended on a small quantity of alloy, as was no doubt the case, it followed that in working a material of large area, if there were any risk of not having it uniform throughout, the want of uniformity certainly did not arise from accident, but must be connected with some

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fundamental law. When a metal like steel, having a specific gravity of 7·85, was strengthened and hardened by alloying it with carbon, the latter he presumed could never be got more dense than a diamond, of which the specific gravity was about 3·0, or considerably less than half that of the metal. Then there were the other disturbing elements of phosphorus and sulphur, which were so much lighter; and if the metal contained a little too much of either of these, its quality could not be governed and kept uniform while the ingot was cooling. It was therefore easy to understand that an irregularity would be established, and an ingot would be softer at one end, and harder and stronger, less reliable and more brittle, at the other. The specific gravity of the phosphorus was only 1·77, and of the sulphur only 2·0. Just as the cream rose to the top of the milk, being specifically lighter, so both the sulphur and the phosphorus had a tendency to rise; and further, as the specific heat of both these substances was also much less than that of steel, dissociation kept going on while cooling was progressing. Therefore, in dealing with a metal that was not very low in injurious alloys, it was exceedingly difficult to get uniformity throughout the mass.

It appeared from the paper (page 291) that none of the steel used had a higher tensile strength than from 34 to 37 tons per square inch. For steel to be used for structural purposes, from 36 to 37 tons was the strength first decided upon by Sir Henry Bessemer and himself for steel boilers in 1862, before there had been much experience in the working of such metal; but as was well known the strength required had now come down to 28 or 30 tons. At that time he had not apprehended that the reliability and the excellence of the low-alloyed steel would be augmented in a large measure by its containing a still smaller percentage of the very light elements, sulphur and phosphorus. The material that he now thought should be used was one that should not contain more than one-tenth of one per cent. of sulphur, phosphorus, and silicon together. If the steel contained only one-tenth of one per cent. of these ingredients, this small proportion could be disseminated evenly or alloyed fairly throughout the whole mass of the metal; and together with 0·20 per cent. more carbon and 0·35 per cent. of manganese would

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(Mr. Daniel Adamson.)
produce a stronger metal that would carry about 50 tons per square inch, which might then be safely used in structures of the sort described in the paper. Having had the honour of being selected as sole arbitrator in regard to the metal to be used for the suspension bridge across the Forth that had been projected by Sir Thomas Bouch in 1873, his recommendations had then been that the suspension links should be of steel having a tensile strength of from 45 to 50 tons per square inch, and that they might at any rate be loaded generally up to fully 8 tons per square inch, and exceptionally up to 10 tons as the extreme.

What struck him as an alarming feature in the design of the present bridge was that in this great structure there were two members acting in opposition when under any variation of temperature. It would be a satisfaction to himself to know how the arch member of the bridge below the roadway was to be relieved of excessive load, when under increase of temperature it became elongated and was made to set up its back, while at the same time the suspension links on the upper side would be lengthening and letting go and taking less load. In a measure there was of course some compensation between these two movements; but the whole design must be of a very refined character, and very well thought out, if all the changes exactly counteracted one another. It could not be said that it was going too far to consider the effect of temperature upon such a mighty structure. In his early days he remembered how the old bridge over the river Wear at Sunderland —designed by the notorious Tom Paine, and erected in 1796 by a country squire, Mr. Rowland Burdon, largely at his own expense— used to go sideways, under the influence of an early eastern sun, to the extent of as much as 2 feet. That showed how great an effect might be produced, even in the case of a narrow bridge, by the sun acting upon one side, while the other side remained cold. The arched ribs of that bridge were put together in cast-iron segments, which were joined by something like the ordinary fish-plates on both sides of a rail (Proceedings 1858, page 261). Their renowned Past-President, Robert Stephenson, remodelled the structure in 1858, lining it inside with box girders, and thereby

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giving it the needed stability. But in the case of the Forth bridge it appeared to him that, as the structure was more of an open trellis kind, both sides of the bridge might get hot at once. There thus seemed to him to be a difficulty as to the extent to which each member would take its proper load under such variations of temperature as occurred between summer and winter, or day and night.

It was stated in the paper (page 289) that the force of the wind might give rise to a total lateral pressure of 8,000 tons. Suppose that pressure to be reversed by the wind blowing from the opposite side, then there was a difference of 16,000 tons in lateral load. It was seen from the plan of the bridge in Figs. 2 and 4, Plate 38, that the same structural conditions were applied laterally to resist the wind pressure as were applied vertically to support the load by the arch and the suspension rod. One side of the bridge would be acting as a girder to resist the lateral force by compression, and the other side would be acting as a suspension rod to resist by tension. There was therefore in this case also somewhat of an apparent antagonism, which it seemed to him might not be so clearly met as in the vertical members of the structure. The method adopted, wisely in his opinion, of erecting steel piers of 330 feet height, would naturally act as a means of compensating, by the vertical disturbing influence both on the lower member and on the top member of the bridge. On a hot day, if 800 feet of suspension rod became elongated by the heat, it was evident that the vertical column of 330 feet height, being proportionately elongated, would lift the suspension rod, tighten it, and place upon it a larger load than would otherwise be due to its position while under the disturbing influence of the higher temperature. This was a matter of vital importance; and he thought that unless the conditions were fairly balanced, and all the disturbing influences were very well provided against, there would be such an antagonism of strains in the bridge that it would not be likely to be as durable and substantial as could be desired. If the author would kindly describe how all these points had been got over, it would prevent the risk of any misapprehension upon a matter of great importance.

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Mr. JEREMIAH HEAD, Past-President, having acted as resident engineer under Mr. Phipps and the late Mr. Robert Stephenson during the reconstruction of the Sunderland bridge, said it was quite true that when the old bridge was taken down the girders were found to be 2 feet out of line; but that was not owing to the expansion, but to some of the cross-bracings having given way. When the new bridge was finished, it consisted of arched box girders from end to end, which took the weight altogether. It had been his duty to test what was the amount of the rise and fall from the changes of temperature between the full heat of a summer's day and the coolness of the night following; and as far as he remembered the bridge rose and fell with that variation of temperature about an inch and a half. He should be glad if the author would kindly state what percentage had been allowed for expansion in the Forth bridge between the two extremes of temperature to which it was likely to be subjected. This matter and everything of the kind he was aware had been most carefully gone into by the engineers; and it would be interesting for the guidance of some of the Members to know what percentage of expansion had been allowed for in a structure of this magnitude.

With regard to wind pressure he observed that 56 lbs. per square foot had been allowed as the maximum; and he should be glad to know whether in the observations which had led to this conclusion any such pressure had been found to occur in reality; and, if not, what was the maximum pressure per square foot that had been actually observed.

Mr. EDWARD B. MARTEN, Member of Council, said that, as the bridge now erecting so far exceeded in size any previous work of the kind, he wished to ask whether there was any fear lest one side of the columns of 330 feet height might expand more than the other, and whether the roadway might thereby be likely to warp or twist, in consequence of the hot sun acting on one side only of the column, instead of on the whole column.

He also wished to know whether the caisson was filled up at first to the extent shown in Plates 39 and 40, or only gradually; and when it was finally filled, was the working chamber at bottom also filled

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up quite tight on the boulder clay, or whatever it stood upon? If so, was there any further sinking of the pier under the weight of the superstructure gradually built upon it? or was it sufficiently firm in the clay to stand fast without yielding at all, even when the whole weight of the finished bridge would come upon it?

Mr. W. G. STRYPE said this was the first time that he had heard the question raised of the influence of expansion with regard to the unprecedented length of the important members in the main portions of the structure in the Forth bridge; it was certainly a most interesting point, and he should be glad to hear what had already been the effects observed with reference to it. He had lately had experience in building a concrete breakwater; it was important to make provision for the difference in length that took place by expansion and contraction in the parts above and below water. The desired object had been accomplished in that case by dividing the structure transversely into separate lengths or articulations. The variation in length of the structure was different according to the height of the work. In the portion always under water it was assumed that no variation in length would take place, but that the earth and the work itself would expand and contract equally; but as the structure rose out of the sea and reached higher into the air, some portions ascending 40 feet above the bottom surface, expansion and contraction set in with greater effect. The difficulty had been successfully overcome by dividing the work transversely into vertical articulations, increasing in number as the work ascended. Starting from the level of low water they were at a distance of 40 feet apart, higher up 20 feet, and finally 10 feet apart. Of course in the leading members in the Forth bridge it was not practicable that anything in the nature of articulations could be introduced; and he imagined that expansion and contraction must be met entirely by the elasticity of the steel itself.

Mr. CHARLES COCHRANE, Vice-President, considered that any misgivings with reference to the expansion of the bridge would be dissipated by looking at the examples preceding it, which might

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(Mr. Charles Cochrane.)
establish confidence that the material itself would provide for its own expansion. Referring especially to the case of Westminster bridge, in which there were wrought-iron pieces intermediate between cast-iron cantilevers, and the latter were actually backed against wedged pieces fitted tightly in, he did not think any fear was entertained lest the bridge might be going to fall. Although the arch was a very low one, the expansion adjusted itself entirely within the material, as imagined by Mr. Strype. The Brooklyn bridge also presented another most remarkable example of expansion being provided for: the lengthening of the chains taking effect in a downward movement, whilst the tendency to upward movement in the curved or arched roadway by reason of its longitudinal expansion was compensated for by sliding-pieces fitted one within the other. In the case of the Forth bridge it would be seen that the two cantilevers were entirely free to expand in every direction; consequently the roadway could adjust itself completely, so that no danger could happen. Coming to the two ends of the cantilevers, all that was there to be provided for was the expansion of the intermediate girder, which presented no difficulty, inasmuch as it rested on and was fixed at the extremity of one cantilever, and could move freely on the extremity of the opposite cantilever. There was therefore no danger of binding or anything of that kind in the Forth bridge.

Mr. GEORGE CAWLEY pointed out that the principle on which the Forth bridge was being constructed had been adopted by Japanese bridge-builders for centuries. That of course did not in any way diminish the interest connected with the present immense bridge, which was, or no doubt would be when completed, one of the great engineering wonders of the world. For spanning a stream of considerable breadth, a Japanese bridge-builder would lay two balks of timber, embedding one in one bank and the other in the other, with their ends projecting over the stream so as to form two cantilevers, and would then add a centre balk stretching across from one to the other. By supposing each overhanging beam or cantilever arranged with triangular bracing, the principle of the Forth bridge would be very closely represented. A good example of a bridge of

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this kind was one constructed across the mountain stream which flowed through Nikko; although built about two hundred years ago, it was known as the "temporary bridge," to distinguish it from the more elaborate structure crossing the stream near it, which had its approaches closed against all but imperial and aristocratic travellers.

The Marquess of Tweeddale wished to confirm Mr. Cawley's statement by referring to a bridge of a similar character across the Sutlej, over which he had often passed. The only difference that he could see was that, whereas the beams of the Japanese bridge were presumably embedded in the earth of the river banks, those of the Sutlej bridge were embedded in the masonry of the vertical abutments. The beams employed were each 100 feet long; to the extent of 50 feet the two side beams were embedded in the masonry, the other 50 feet of their length projecting; and on their outer ends rested the centre beams, the span of the bridge being about 200 feet. Whether rightly or wrongly, he had always understood that bridges of that design, which were well known in the Himalayas—and, as he now learned for the first time, in Japan also,—contained the germ of the idea of the Forth bridge.

Mr. Henry Davey understood the cantilever system of bridge building was carried out by the Japanese in a more elaborate manner than would be gathered from Mr. Cawley's description. Starting with only a slight overhang of the first beam, a second was laid on the top of it and projecting further; and so on with a series of beams, each projecting beyond the one below, until the tops of the two cantilevers so built up approached each other near enough to be joined by a centre beam resting on their overhanging extremities. By that plan a much greater amount of overhang was obtained than could be got with only a single beam for each cantilever.

Mr. Wood, in reply, said that there was nothing of the arch principle in the steel portions of the Forth bridge, as seemed to be inferred in some of the remarks. The overhanging parts were

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(Mr. Wood.)
girders on the cantilever system pure and simple, which, like arms, could expand and contract. When the centre part was added, one end of it would be pinned to one cantilever, while the other end would be left free to move on rockers on the other cantilever in the ordinary way, so that there would be complete freedom in every direction. Between the points where the extremities of each of the two main spans were fixed, about one inch per 100 feet would be allowed for the longitudinal motion at the junction of the centre girder and the cantilever. In the case of railway bridges that had been erected in this country, and where careful records had been kept, the variation during the year had been found to be only about half an inch per 100 feet; so that an extra allowance had here been made beyond what had been observed under ordinary conditions.

During the last five years the maximum pressure registered by the large wind-gauge of 300 square feet, placed on the island of Inchgarvie, had been 35¼ lbs. per square foot. The smaller gauges in the same locality had given a higher pressure at the same time, probably due to the wind acting in small whirls of higher intensity than the average over large surfaces.

In reference to warping, there would probably be a slight change of form under difference of temperature between the two sides of the cantilever; but it would only be similar to that occurring in the case of the open framework of a roof or any other steel structure, which would simply give a little one way or the other by its elasticity. It would not dislocate the railway, and was of little consequence in practice, as evidenced by the behaviour of the 1511 feet tubes of the Britannia bridge, and those of the Saltash and Chepstow bridges which approximated to the form of those in the Forth bridge. The effect of variation in temperature was often imagined to be a great deal more than it actually was, from cases having arisen where proper provision had not been made. The huge 12-ft. columns of 330 feet height on each pier were united by cross bracing, which prevented any distortion; and all other tubular members were treated in a similar manner, the effects of temperature, wind, and gravity having been most carefully considered in all their bearings, whether affecting the structure in detail or as a whole.

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With regard to the caissons, after filling them with sufficient concrete as ballast to steady them while floating them out, more concrete was gradually added as it was wanted for sinking them, so as to drive them down through the clay. Plates 39 and 40 showed the quantity of concrete in them at the time they arrived at the depth shown. When they had been got down to the required depth, the bottom chambers were all cleared out and were rammed with concrete and grouted up under pressure. No subsidence took place after that, the boulder clay being so hard that Mr. Arrol had had to devise a hydraulic digger for breaking it up. When the concrete inside the caisson had been filled up to the water-level, the pier was carried up with a granite face, encasing stone bedded in cement. The whole pier was then perfectly solid; and as the pressure per square foot on the base was not excessive even under maximum loadings, the pier was as firm as if on rock, and could not go down further.

Mr. ADAMSON wished to repeat that the fundamental principle of the cantilever was that its lower member was in compression while its higher was in tension; and when the temperature was increased it would augment the load on the compressed member, while the upper member becoming elongated would relieve itself from the load. This action he believed as a matter of fact would have a disorganising and disturbing influence on the structure.

The PRESIDENT, in moving a vote of thanks to Mr. Wood for his paper, said he was sure the Edinburgh meeting would be remembered by this description, and by the visit to the bridge itself. The Members were greatly indebted to the author for the trouble he had taken in preparing the paper and the extensive series of diagrams by which it was so well illustrated, and for presenting to the Institution the photographs now exhibited. He recalled with pride the fact that Sir John Fowler, who had designed the bridge, was one of the original Members of the Institution.

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NOTES ON THE MACHINERY EMPLOYED AT THE FORTH BRIDGE WORKS.

By Mr. WILLIAM ARROL, of Glasgow.

The greater part of the Machinery at the Forth Bridge Works is original in design and novel in construction, chiefly because of the unusual nature of the work to be carried out. It may be roughly classified under the following heads:—hydraulic bending and setting, planing, drilling, erecting, and riveting. In designing the machinery and tools to accomplish these different kinds of work, there had ever to be kept in view rapidity of production, with a very high quality of work in the finished structure. An idea of the quantity of machinery provided to deal with the material passing through the shops may be partly formed from the fact that it is capable of finishing 1,500 tons in a single month.

Hydraulic Bending and Setting Machinery.—To bend and twist the large steel plates required in the construction of the tubes and their connections, a great variety of hydraulic presses had to be provided. The largest of these, shown in Plate 45, is capable of exerting a pressure of 1,600 tons between the dies. It consists of four 24-inch cylinders C, resting on two longitudinal girders G bedded on concrete. From each cylinder rise two iron columns L, which carry a fixed table F overhead. On the top of the rams another table T is placed, which can be raised or lowered at will. Between these two tables are placed the blocks B which stamp the plates to the desired shape. In most cases this shape is the arc of a circle, but in others the form is very varying, while in some instances the plates are flanged as well as bent or twisted. In nearly every case, after a plate has been set while heated, it requires

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to be finally adjusted when cooled. To dispense with the heating of the plates gives unsatisfactory work, and is in many cases impossible. In no instance is this plan of bending adopted to any extent without annealing the plates both before and after the work has been put upon them. Much of the final adjusting of the plates is done by presses consisting of a simple ram fixed to the upper of two girders, which are bound together at the ends, the lower girder serving as the seat for the block on which the plate is placed. Numerous other forms of presses are employed for lighter work.

Planing Machinery.—A special class of machinery is employed to plane the edges of the plates. In the case of most of the plates this requires to be done very carefully, because in the structure of the bridge a certain percentage of the stress in compression is taken up by the plates butting, instead of wholly by the rivets as in the tension joints. This statement applies to all plates in the tubes.

The side edges of the curved plates are first of all planed on what may be looked upon as an ordinary planing machine, Plate 46. It is provided however with special double side-cheeks C, between which are two fixed swivelling tool-boxes T, one on each side of the machine. These tool-boxes can when desired be transferred to a special cross-slide, as it is sometimes more convenient to work with one box in the cross-slide than with both between the side-cheeks. Both tools act together and cut continuously, that is during the backward as well as the forward travel of the table. The plate to be planed is fixed upon curved blocks B, which in turn are securely bolted to the table.

For planing the end edges of the curved plates a special machine had to be designed and built, Plate 47, in which the plate is secured to a fixed table B, Figs. 6 and 7, while the tool T is made to travel backwards and forwards in a swinging pendulum P that receives its motion through a connecting-rod from a travelling saddle S. The tool cuts both ways in this instance also, and is fed to its work by hand.

The planing machines employed to finish the side and end edges of the rectangular plates for girder-work, Plates 48 and 49, are of

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the usual pattern for plate-edge planing, but with the addition of an end slide E provided with a separate tool, for planing one end edge of the plate P at the same time that one of its side edges is being similarly treated. This machine finishes a plate at two settings, with the certainty that the ends are at right angles to the sides.

In some machines two saddles are upon the main slide, and in others two tools are in one saddle; both devices have their advantages. The facing of the tees, angles, and other sections, is done as a rule by cold steel saws, in order to secure good butting.

Drilling Machinery.—As will be inferred from the varying character of the work, the drilling is performed by various classes of machines. The principle kept in view is that, wherever possible, girders, tubes, &c., should be drilled only while their various parts are temporarily built and held together by bolts in the position they will finally occupy in the finished structure; in this way the highest class of work is obtained.

For drilling the tubes, the machines, each complete in itself, are made large enough to embrace the entire circumference of the tube. As shown in Plates 50 and 51, they consist of a wrought-iron under-frame or carriage C, on which are placed the engine and boiler. On it are also fixed two large cast-iron annular rings or headstocks R, embracing the tube T, round which ten drilling slides S and heads H travel circumferentially. The slides are moved around the rings and consequently around the tube by a worm at each end, gearing into a worm-wheel that forms part of the rings R. The motion of the drill-heads H on the slides S is longitudinal, or parallel to the tube. These two motions easily permit of the ten drills working at any part of the circumference of the tube comprised between the two annular rings R, which embrace a length of 8 feet. When this length is finished the whole machine is travelled forwards, and is again ready to drill a new length of 8 feet. The tube rests on timber blocks, which are removed from the front and placed behind as the machine travels forwards. In the case of the lighter tubes, the rate of drilling is as high as 12 lineal feet of tube per shift of ten hours; this represents about 800 holes drilled.

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The booms of all girders are drilled separately on blocks, thus leaving the bracings to be drilled to template, which is done by radial drills at another time. The machines employed to drill the booms are of a wholly different kind from those used for the tubes. They are moved along rails, running on each side of the blocks upon which the booms are built, and parallel with them. As shown in Plates 52 and 53, they consist of a double carriage C with upright columns L, connected together by means of a crossbeam B and sundry other framing for carrying the shafts, pulleys, etc. To the columns and crossbeam are secured slides, to which nine fixed drill-heads H are bolted on the front of the machine; while to the back are attached four radiating arms A, each carrying a single drill. In this way there are both fixed and swinging drills on the two sides of the machine, capable of drilling holes in either a horizontal or a vertical plane. The fixed drills serve for all holes in the regular pitch, while the movable drills take what may be called odd holes, such as those where the struts and ties are to be secured to the booms. All the fixed drills are self-feeding, but the movable ones are fed by hand. The number of drills simultaneously at work varies greatly; at times as many as the full number of thirteen have been employed together on a single boom.

Other machines having radials with only single drills, as shown in Fig. 11, Plate 49, are used for a special class of drilling, and are found to work to great advantage. With the exception of a few special tools, all the remaining drilling is done by radials capable of making a complete circle round the column on which they are supported. Tables are placed on each side of these machines, and the work is fixed on one of the tables; and as the drills are placed at a convenient distance from one another, all the drilling required is easily accomplished without a second shifting of the work.

Erecting and Riveting Machinery.—To erect and rivet such large quantities of material at the immense height at which much of it requires to be done demands a large quantity of special plant for riveting and other purposes. The ordinary class of riveting is accomplished by means of small portable riveters, shown in Figs. 14

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and 15, Plate 51, consisting of two arms held apart by links and stays; one arm acts as the holder-up H, while the other carries the hydraulic cylinder C for supplying the power, the cylinder and arm together forming one casting. For some of the more difficult work, where neither could this form of riveter be employed nor could the work be done by hand, small direct-acting hydraulic cylinders were used; the die for forming the rivet-head was here fixed into the piston. Two 4-inch cylinders were usually employed, held to their work either by hard wood packing placed against the permanent structure, or by temporary girders brought into proper position. In these machines the pressure employed was 3 tons per square inch. A large amount of excellent work was performed by these machines in positions where it was practically impossible to do it otherwise.

The riveting of the vertical columns of the piers is done by riveting machines attached to the undersides of the lifting platforms. They are lifted with the platform, and do their work while the platform is at rest. As shown in Plates 54 and 55, they consist of two longitudinal girders or uprights G, one on the outside and the other on the inside of the column C. Along the face of each girder a riveting cylinder R is raised or lowered by hydraulic power. The inside girder has a trunnion at top and bottom, fitting into a step in two temporary diaphragms F for supporting the thrust of the rams in riveting. It is turned round on the trunnions at will by means of worm gearing, so as to rivet up an entire length of 16 feet of the tube circumferentially as well as longitudinally. The outside girder and riveting cylinder when at work always face the inside. The outside girder is attached at top and bottom to two wrought-iron rings W, which encircle the column, and not only furnish the necessary support but also permit of the outer riveting cylinder being moved round the column by hydraulic power as required. Over 800 rivets have been closed in a day by one of these machines.

In the erection of the large piers of the bridge, hydraulic power is utilised to a great extent. The principle adopted is to build the piers from off a platform raised by hydraulic pressure as the work of erection proceeds, utilising the piers themselves in process of building as the support of the rising platform.

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Discussion.

Mr. W. FORD SMITH said the whole of the machinery described in the paper certainly appeared to him to be very ingenious and well adapted to the work it had to do, although he had not yet had the pleasure of seeing it in operation.

Mr. JAMES PLATT was sure that all engineers who had followed the progress of the work at the Forth bridge must have been struck with the admirable manner in which the author had met all the difficulties in his way. He had shown how by machinery work could be accomplished which had been hitherto thought impossible except by hand. The Members were greatly obliged to him for describing to them the many appliances he had used on this vast structure; and they were looking forwards to a great treat in witnessing the performance of his machines.

Mr. JOSEPH BARROW had recently had the pleasure of seeing the machinery described in the paper; and had been greatly impressed with its remarkable adaptability for the work it had to do. One point which had especially struck him was no doubt interesting to all engineers, namely the amount of power needed for drilling a large number of holes. Generally speaking, the maximum rate of drilling holes in wrought-iron or steel was an inch hole through an inch depth in one minute; but when, as in the present case, from ten to thirteen drills were in operation simultaneously, it was exceedingly difficult to maintain that rate of work collectively for the whole number. Having however observed the time with his watch, he rather thought that the full amount of work was done by each of the drills. As shown in Plates 50 and 52, the drills were all driven by an endless rope; and it would be interesting if the author could give the velocity of the rope in feet per minute in relation to the number of drills and the work done. In multiple drilling it had always been very difficult to get a number of drills working together, without a great reduction in the amount of work done by them collectively. It would be seen that the drill used was of a kind having a turned-up

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(Mr. Joseph Barrow.)

lip, such as was used in ship-yards. He also wished to refer to the very ingenious withdrawing motion employed in connection with the feed motion, by which any number of the drills were stopped while the rest were going on. There were also a large number of other practical points of great interest to mechanical engineers, which the Members would have the opportunity of examining in their visit to the works.

Mr. DANIEL ADAMSON, Vice-President, said he had originally been led to drilling by the difficulties in dealing with angle-iron or angle-steel; and he was so well satisfied with its desirability and its excellence when adopted on a small scale that for very many years past he had adopted drilling altogether. He had then made a series of experiments showing that violence of any sort was injurious to a steel plate, and that punching was deleterious and ought not to be adopted. The most important thing that had impressed him in connection with the present paper was the riveting appliances. It would be interesting to hear from the author whether there was any uniformity in the force required for closing rivets of different diameters. If for example a given force was required for closing a rivet of one inch diameter, did it require four times the force to close a rivet of two inches diameter, being four times the area? In his own experience he had not been able to satisfy himself that this was the case. All his riveting was done by steelyards, so that he knew exactly the force that was brought to bear upon the rivet; and he should be thankful to get some rule for the force requisite to close rivets of different areas. Taking the diameter in eighths of an inch, and representing by 64 the force required for an inch rivet, was it to be inferred that for a $\frac{3}{4}$-inch rivet a force of only 36 was all that would be required? That was not the result of his own experience, for he had found it required much more to close a $\frac{3}{4}$-inch rivet in proportion to its area than it did to close an inch rivet. In the author's large experience, with such excellent machinery and such a variety of diameters of rivets, he must have obtained a great deal of information that was not in the possession of engineers dealing with a more limited range of riveted work.

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Mr. A. B. BROWN believed the author had been the first to devise a complete set of portable tools for the purpose of putting a bridge together; he had previously employed that system for erecting the Broomielaw Bridge in Glasgow. At the Forth bridge almost every tool was exceedingly handy, and answered its purpose remarkably well. The only objection that he had to any of the tools was the general use of leather packings in the hydraulic machines; and his objection to the use of leather packings was that when it was necessary to renew a leather the machine required to be taken to pieces. Otherwise he considered the tools described in the paper were exceedingly good.

Mr. CHARLES COCHRANE, Vice-President, enquired with reference to the use of accumulators, whether the work was done by one set of pumps with an accumulator to distribute the water-pressure over the whole of the works, or whether there were several accumulators in different parts of the works; or whether recourse was had to any new appliance for providing hydraulic power, such as a set of triple pumps with fly-wheel, delivering a stream of water which merely circulated as long as the tool was not called into operation; but the moment pressure was wanted and the tap was turned on, the whole momentum of the fly-wheel on the pumps came into play, so that in the riveting machines the head of the rivet was driven home with remarkable efficiency.

Mr. W. SILVER HALL would be glad if the author could give some figures from which to calculate the power required for bending a plate of given thickness to a certain extent. He presumed the plates were all bent at a low red heat, not at a very high temperature.

Mr. T. HURRY RICHES, Member of Council, enquired with regard to the column-riveting machine shown in Plates 54 and 55, how the central pillar or holder-up for the riveting machine was adjusted into the proper position, so that the thrust of the riveter outside the column might exactly coincide with that of the holder-up on the

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(Mr. T. Hurry Riches.)
inside. He wished to know how the two points were adjusted so as to meet the rivet on both sides.

As to the pressure required for closing rivets of different sizes, from his own experience it appeared that not only did the diameter of the rivet enter into the question, but also the thickness of the plate or plates through which the rivet was being closed. Where thicker plates were used, larger rivets were also generally used, though not necessarily in all cases. But in every case where thicker plates were used, it became necessary to employ a higher pressure in order to ensure the thorough closing of the plates and rivets, even when the rivets were not larger in diameter than those used for thinner plates.

Mr. C. J. APPLEBY, having already visited the bridge and seen the machinery there used, was of opinion that similar appliances might certainly be profitably employed in many other undertakings of a very different character. The remarkable ingenuity displayed in the adaptation of the different tools could be realised to some extent from the drawings illustrating the paper; but would be appreciated still more highly when the works themselves were inspected. From these machines he was quite sure that many valuable ideas would be gathered, which could be used under other circumstances with great advantage to all concerned.

Mr. BENJAMIN WALKER, Member of Council, had nothing but praise for the machinery described by the author, which he regarded as remarkable even more for its common-sense character and for its adaptability to the work to be done than for the ingenuity displayed in its design.

Mr. ARROL said the speed at which the ropes were generally run for driving the drilling machines was 1500 or 1600 feet per minute. This high speed was adopted more with a view to the life of the ropes than for getting greater power, because a rope running at a lower speed did not last nearly so long. The ropes running at 1600 feet per minute would last about two years. A great amount of

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power was absorbed by the friction of the pulleys necessary to carry long ropes. The longest ropes he was using were 700 feet in length. On account of the number of different appliances, and the facilities for moving the machines about, it was more advantageous to have a good long rope working over a long stretch.

With regard to riveting, there were various sizes of machines for various sizes of rivets. There was a great deal of difference in riveting steel and iron rivets. Steel rivets required a machine about an inch bigger in diameter than iron rivets of the same size; where a 9-inch ram would suffice for iron rivets, a 10-inch ram was required for steel rivets. The heating of the rivets of course made a great deal of difference also; when a rivet was cold it required a great deal more power to get it in, and it was left unshapely.

The PRESIDENT asked how the rivets were heated.

Mr. ARROL replied they were heated in small furnaces, in which both coal and oil had been tried. Latterly cheap crude oil from the gas works had been adopted, and it had worked successfully. Many riveting furnaces had been made, and their size had been reduced to the smallest possible, about 4 feet long by 15 inches high and 12 inches wide. One of these small furnaces could heat rivets for two machines.

For the packings of the hydraulic machines he had not yet found anything better than leather. Metallic packing had been tried, but it was of no use. The hydraulic machines were worked by a loaded accumulator in the ordinary way. A steam accumulator was also used, but was not worked regularly. Different sets of pumps and accumulators were employed for each part of the works, one on the south side and one on the north. In sinking the caissons the hydraulic power for working the digger in the chamber at bottom had been limited, as the shops had required it all at that time; and a steam accumulator had been used, which was a handy tool. He had used two of these, one at the Tay bridge at Dundee, and the other at the Forth bridge.

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(Mr. Arrol.)

The plate bending of course, just like the riveting, required a heating apparatus, and suitable presses having always plenty of power for bending the plates with the least possible trouble.

In regard to the large riveting machine for riveting the vertical columns of the piers, Plate 55, there were ten upright beams B inside the column C; against five of these the angle frames F of the machine butted, and transferred the pressure to the outside ring girder W, which had wedges between it and the column C, opposite to the points of bearing within the column. Both the outer and inner frames were strong enough to resist the whole force of the riveting cylinders. As the outer frames W were exactly opposite the inner F, the whole thrust from the riveting cylinders went right through from one pair of frames to the other. As soon as the man inside the column had put the red-hot rivet into the hole, he adjusted his riveting cylinder to close it, and at the same time the man outside did exactly the same with the outside riveting cylinder, independently of the inside man. When the outside man was ready, he gave two taps as a signal; then a boy turned on the water, and the two riveters closed up together upon the rivet, the same water supplying both machines simultaneously.

The PRESIDENT enquired whether the difference could be stated between the cost of riveting under the special circumstances here existing, and the cost in ordinary shop work.

Mr. ARROL said there were here so many different kinds of work to be done that it was hardly possible to answer that question. In ordinary bridge work it would make very little difference in cost whether the riveting were done in the shops or on the bridge itself.

The PRESIDENT was sure the Members would be glad to return Mr. Arrol their hearty thanks, both for the excellent paper he had given them, and also for what he was going to show them in their visit to the works this afternoon.

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ON ELECTRO-MAGNETIC MACHINE-TOOLS.

By Mr. FREDERICK JOHN ROWAN, of Glasgow.

The Electro-Magnetic Machine-Tools devised by the author and forming the subject of the present paper are the result of his endeavour to overcome the difficulties of riveting the plating of ships by other means than hand labour. Many interesting attempts, commencing with the steam riveter of Mr. J. McFarlane Gray in 1863 (Proceedings 1865, page 129), have been made to introduce mechanical appliances into that branch of constructive engineering, with varying success. The conditions of the work itself involve the separation of the riveting or hammering portion of the apparatus from the bolster or holder-up, while on the other hand the conditions of the process of riveting require that the two portions of the machine should be rigidly held together; and in consequence of these conflicting requirements, the application of machine riveting to this class of work has not been a promising field for experiment.

Almost the only method hitherto possible of uniting the two parts of the riveting apparatus has been by bolting them together by bolts passing through the rivet holes. It has been found however that this requires too much labour and time; and it also leaves a number of vacant holes which cannot be reached by the machine, and must therefore be filled up and have the rivets closed by hand. One of the most successful of the machine ship-riveters was that introduced by Mr. John McMillan of Dumbarton in 1876. The necessity for very frequent shifting of the attaching bolts was obviated by having the steam striker carried on a horizontal slide, which was bolted at its ends to the side plating of the ship and

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embraced about the length of a plate; no method of mechanical holding-up was included in the plan. This arrangement however still left some rivets to be closed by hand; and continued to require manual labour for the holding-up, which has been proved to be the most severe portion of the riveter's work.* In spite of these drawbacks the machine did some excellent work, and proved to the satisfaction of the surveyors of the Board of Trade and of Lloyd's Register that the quality of the riveting done by machines in shipbuilding is superior to that of hand work, in so far as regards the filling up of the rivet holes, on account of the machine blows being much heavier and more direct than those given by hand hammers. The comparative efficiency of riveting done by different methods is dealt with in the appendix.

Electro-Magnetic Riveting.—The use of electro-magnets for the purpose of attaching the machine to its work satisfies the requirements in a very complete way. It gives a rapid method, practically instantaneous, of fixing the riveting portion of the machine to the work; and leaves no rivet holes to be afterwards filled up by hand. The bolster or holder-up is as quickly attached on the other side of the plating. When the magnets are properly arranged on opposite sides of the plating with the two poles of unlike denominations facing each other, they are drawn towards each other, thus pressing the plates together and ensuring the proper condition for riveting. The effect of bolting the two portions of the machine together through the rivet holes is thus obtained without any attendant drawbacks; and the distressing work of manual holding-up can be reduced to a minimum.

In Figs. 1 to 3, Plate 56, are shown two forms of the electro-magnetic riveting machine; AA are the holding-on magnets, and M the motor, which by means of the gearing G and cam C lifts the hammer H against a spring. The amount of compression imparted to the spring in lifting is regulated by the position of the disc or

* See Dr. Barr's paper in the Proceedings of the Philosophical Society of Glasgow, vol. xvii, page 223.

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piston D, which can be adjusted by hand by means of the screw spindles R and spur-gearing W; the same mode of adjustment is equally applicable where springs are used in tension instead of in compression. The striking mechanism may of course be worked by other means than the cams shown in Figs. 1 to 3. Hammers driven by steam, compressed air, water, or gas, can be used with holding-on magnets; or the motor may be apart from the magnets, and the power transmitted by flexible shafting. The same remark also applies to the driving of the rest of the tools subsequently described.

The holder-up is shown in Figs. 4 and 5, Plate 56; AA are the holding-on magnets, and the bolster or dolly B is kept to its work by the spring S, which compensates the flattening of the rivet-head during the operation of riveting. A curved arm or attachment E, Fig. 5, carries a small subsidiary bolster and spring, for insertion under the reverse bars of ships' frames or into confined spaces.

Drilling.—The application of the same principle to drilling, tapping, and other tools, became apparent to the author as soon as the idea had occurred to him of constructing a riveter in this way. The application to drilling is he thinks even more important than to riveting, and is capable of a wider range of employment; because while an electro-magnetic riveter must compete with hydraulic, steam, and power machines, where these are practicable, the case is different with regard to drilling. The want of suitable drilling tools for shipbuilding work has prolonged the continuance of the more imperfect system of punching; and the hand ratchet, which is in many cases the only alternative to the punching machine, is a very slow and inefficient appliance.

The importance of substituting drilling for punching in the preparation of structures composed of plates and bars of steel, and even of iron, has been, by inference at any rate, very fully established. The evidence is on record of many investigations which have been made since the year 1850 into the strength of riveted joints composed of both punched and drilled plates. The list is a long one, and shows that the best engineering talent of this country has been employed in the work. Professor W. Cawthorne Unwin has

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recorded all the principal memoirs on the subject prior to 1881* in his preliminary Report to the Research Committee of this Institution on Riveted Joints (see Proceedings 1881, page 303); while that Report and the accompanying and subsequent records of investigations by Professor Alexander B. W. Kennedy (Proceedings 1881, 1882, and 1885) completely summarise the existing information regarding the comparative effects of punching and drilling upon iron and steel plates, and regarding important collateral points. From a careful examination of the voluminous Tables given in Professor Unwin's Report, the results of the greater number of the experiments made on iron and steel plates lead to the general conclusion that, while thin plates, even of steel, do not suffer very much from punching, yet in those of ½ inch thickness and upwards the loss of tenacity due to punching ranges from 10 to 23 per cent. in iron plates, and from 11 to 33 per cent. in the case of mild steel. Mr. Parker has recently stated † the loss of tenacity in steel plates to be as high as fully one-third of the original strength of the plate. In drilled plates on the contrary there is no appreciable loss of strength. It is even possible to remove the bad effects of punching by subsequent rimering or annealing; but the speed at which work is turned out in these days is not favourable to supererogatory or multiplied operations, and as a consequence such additional treatment is seldom practised. These facts lead irresistibly to the conclusion that the introduction of a practicable method of drilling the plating of ships and other structures, after it has been bent and shaped, is a matter of very great importance. If even a portion of the 30 per cent. deterioration of tenacity can be prevented, a much stronger structure results from the same material and the same scantling. This has been fully recognised in the modern practice of the construction of steam boilers with steel plates: punching in such cases being almost entirely abolished, and all rivet holes being drilled after the plates have been bent to the

* In the appendix to the present paper are mentioned subsequent memoirs that have appeared since the date of Professor Unwin's list.

† Transactions of the Institution of Naval Architects, 1886, p. 133.

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desired form. The magnitude of the interests which are dependent upon the strength and therefore upon the security of ships is little, if at all, less than that of those which are affected by boiler safety.

Electro-magnetic drilling machines offer practically the same facilities for the work of shipbuilding and for other operations as are already possessed in boiler-making; but they differ from the drilling machines used in the latter process in this respect, that in using the electro-magnetic drilling machines it is necessary to move only the smaller weight of the machine, instead of the larger weight of the boiler or other structure. This of course renders them applicable also to boiler-making and other engineering work.

In Fig. 6, Plate 57, is shown a simple form of drilling machine, in which AA are the holding-on magnets, M the motor, D the drill spindle, and F the feed of drill. After several trials of other forms, it has been found better to work either hammer or drill through an opening cut in the centre of the yoke joining the two magnet cores, and to have the hammer-shaft or drill-spindle between the magnet poles instead of beyond the line joining their centres. The thrust of the hammer or drill is thereby distributed equally over both magnet poles. In some exceptional positions however, convenience of working requires other forms; and machines may be made which will work satisfactorily, although the above arrangement is departed from. An instance of such alteration in form is given in Fig. 7, which illustrates a drilling machine now at work with good results, the drill projecting beyond the magnets. Multiple and radial drilling machines and several other kinds of machine tools have also been designed on this system.

In Fig. 8, Plate 58, is shown the magnetic attaching apparatus, combined with a drilling machine worked by hydraulic power on M. Marc Berrier-Fontaine's plan, or by steam or compressed air in a Brotherhood three-cylinder engine.

Tapping.—The operation of tapping stay-bolt and other holes can also be carried out rapidly by power by means of electro-magnetic machines, instead of very slowly by hand as at present. The use of an electro-motor for working the tapping bar has the advantage that

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its direction of motion is easily and quickly reversed, as is requisite for the rapid withdrawal of the tapping bar. In Fig. 9, Plate 58, is represented a tapping machine which is similar in general design to the drilling machine shown in Fig. 6. No feeding screw is required in this case, as the tapping bar T feeds itself forward as soon as a thread is formed. Consequently only a lever L is provided, for giving the needed pressure on the head of the tapping bar in order to start the cut.

Caulking and Chipping.—These operations are also quite under the control of electro-magnetic machines. Frames to serve as guide-bars are attached to the work by electro-magnets or otherwise, in such a position that a long range of seam or surface is commanded by the machine when moved along these guides. The chipping or caulking tool is regularly and quickly struck by a power hammer, which is worked by an electro-motor or by a solenoid or otherwise, as is convenient. In Figs. 10, 11, and 12, Plate 59, are shown forms of caulking and chipping tools, that in Figs. 10 and 11 being worked by a small motor, and that in Fig. 12 by solenoids. An electro-magnet is shown attached to each of these tools; and in Fig. 17, Plate 60, is shown the guide-bar arrangement, by means of which the tools without holding-on magnets can be moved along through a considerable range.

A general idea is given in Fig. 14, Plate 59, of the application of the tools to the side plating of a ship, with the individual machines held on by their own magnets; while Fig. 15, Plate 60, showing part of the side plating in sectional plan, illustrates several tools working on the same guide-bars or frame, one being a steam-riveter, one a spring-hammer worked by an electro-motor, and one an electric hammer worked by solenoids. The frame or guide G is further shown in Fig. 16; and at JJ in Figs. 13 and 14, Plate 59, are shown guide-bars attached to the bottom of a ship, for facilitating the handling of the hammer or other tool, as lifting tackle could not readily be applied in such a position. When the holding-on magnets of the tool are released, the tool drops down on the guide-bars, along which it can then be shifted; and the attractive force of the magnets is sufficient to raise it back again to its working position.

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Practical Results.—With a view to ascertaining practically the conditions essential to successful work, one or two trial machines were constructed, which although imperfect were useful in enabling experience to be acquired of the kind desired. The first successful examples are the electro-magnetic machines introduced by Mr. John McMillan, Jun., into the practical work of his ship yard, from which on 19 May 1887 was launched the s.s. "Albania," having a portion of the rivet-holes in her shell drilled by these machines. After a very small amount of practice the men working the machines drilled the $\frac{7}{8}$-inch holes in the shell with great rapidity, doing the work at the rate of one hole every 69 seconds, inclusive of the time occupied in altering the position of the machines by means of differential pulley-blocks, which were not conveniently arranged as slings for this purpose. Repeated trials of these drilling machines have also shown that, when using electrical energy in both holding-on magnets and motor amounting to about $\frac{3}{4}$ H.P., machines of the form illustrated in Fig. 6, Plate 57, have drilled holes of 1 inch diameter through $1\frac{1}{2}$ inch thickness of solid wrought-iron, or through $1\frac{5}{8}$ inch of mild steel in two plates of $\frac{13}{16}$ inch each, taking exactly $1\frac{3}{4}$ minute for each hole. The machine illustrated in Fig. 7, which has magnets of less holding power, when using only about 0·6 H.P. of electrical energy took the same time to drill holes of $\frac{11}{16}$ inch diameter through wrought-iron of $\frac{13}{16}$ inch thickness. As regards speed of drilling, the author believes these results are equal to any obtained by machines using much greater power.

With the hammer shown in Fig. 1, Plate 56, using an electro-motor giving out $\frac{1}{2}$ brake H.P., from 100 to 150 blows per minute have been obtained, with a force of impact equal to about 180 foot-lbs. per blow, as nearly as could be ascertained. This is much greater than the force of blow given by hand hammers weighing 6 lbs. and striking as heavily as is possible in staving up. At the works of Messrs. Immisch in March last, this riveter was seen closing 1-inch rivets in 10 seconds each.

The electro-motors used by the author in the machines constructed for Mr. McMillan, with which these results have been

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obtained, were of Messrs. Immisch's design and manufacture; and the author believes they will not readily be surpassed.

After seeing the machines at work in Messrs. McMillan's yard, Messrs. William Denny and Brothers constructed an electrical drilling machine having a modification of the traversing frame illustrated in Figs. 13 and 15, Plates 59 and 60, but without holding-on magnets; and applied this machine to drilling the rivet holes in the butt joints of a large steamer. The drilling machine illustrated in Fig. 6, Plate 57, has also been successfully used for drilling holes of $1\frac{1}{4}$ inch diameter in the engine-seat of the s.s. "Pukaki," under the direction of Mr. Archibald Denny, of whose co-operation and assistance the author has had the benefit in the early working of his machines.

In designing the earliest machines on this system the author was without any data which were of use as a guide in determining sizes of electro-magnets or of electro-motors for the various requirements of different machines. Most of the investigations into the elements of electro-magnets have hitherto been directed to questions affecting their use under the conditions found in dynamo machines. Consequently expressions of their efficiency, which are to be found in published treatises, are given in terms chiefly of the intensity of the magnetic field, and not with reference to their holding, or, as it is called, lifting power, which is the quality made use of in the machines here described. From a number of experiments which he has made with apparatus of different dimensions, the author has however obtained results which promise to yield the elements for the statement of a general law for the construction and holding power of electro-magnets. This investigation is not yet completely worked out, but it is under consideration; and the author reserves an account of it, together with further results from the working of the machines now described, for another paper.

The introduction of these electro-magnetic machines presents also some interest from an economic point of view, in addition to their practical advantages in carrying out engineering work. Until now the shipbuilding industry of this country has been to a great extent

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controlled by the trades union of the riveters, so that employers of labour have been unable always to regulate the cost of work as affected either by the rate of wages or by the speed at which the work was completed. This has told most heavily against them in busy times, especially when an abundance of work has followed quickly on a period of depression. Hence it is of great importance that they should possess such a means of controlling both the cost of the work and the rate of construction as the author believes is furnished by these electro-magnetic machines.

The subject of the present paper forms the threshold of the still larger subject of the electrical distribution of power for engineering operations in general; and the author believes it will be found both economical and otherwise convenient to adopt electrical distribution in engineering workshops, instead of the existing system of shafting and belts, or even hydraulic distribution of power.

APPENDIX.

Comparative efficiency of riveting done by different methods.

The valuable information on riveted joints recently presented in the excellent Reports of Professors Unwin and Kennedy to this Institution (Proceedings 1881, 1882, and 1885) goes very far to establish the four following points:—

1. That the shearing resistance of rivets is not highest in joints riveted by means of the greatest pressure;

2. That the ultimate strength of joints is not affected to an appreciable extent by the mode of riveting; and therefore,

3. That very great pressure upon the rivets in riveting is not the indispensable requirement that it has been sometimes supposed to be.

4. That the most serious defect of hand-riveted as compared with machine-riveted work consists in the fact that in hand-riveted joints visible slip commences at a comparatively small load, thus giving

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such joints a low value as regards tightness, and possibly also rendering them liable to failure under sudden strains after slip has once commenced.

From a review of the evidence the author concludes that, provided the plates or other materials are held together with sufficient power during riveting and during the cooling of the rivets, and provided also there is brought to bear on the rivets (either by pressure or by heavy blows) sufficient force to ensure their being expanded so as to fill the rivet holes completely, then the best results as to ultimate strength and tightness of the joints will be realised, and no increase in either of these respects is to be expected from merely exceeding the necessary force.

Professor Unwin's Report on the form of riveted joints (Proceedings 1881, p. 329) contains the following:—"In Messrs. Greig and Eyth's experiments three strips were connected by a rivet so that the rivet was in double shear. The riveting was done by different machines, and then the rivet was broken by shearing. It appeared that the shearing resistance was highest with joints riveted by the machines which worked with the greatest pressure. With steel rivets $\frac{5}{8}$ inch diameter, in $\frac{11}{16}$ inch drilled holes, the pressure on the rivet when riveting and the shearing stress were as follows:—

	Pressure on Rivet. Tons.	Shearing Resistance. Tons per square inch.
Steam riveter	37	25·74
Stationary hydraulic riveter . .	39	23·80
Portable hydraulic riveter . .	20	22·78
Power riveter, light . . .	31	22·50
Power riveter, heavy . . .	52	23·76 "

Messrs. Greig and Eyth's conclusion, as to the connection between high riveting pressure and high shearing resistance, is however not supported by their own tabulated results; for the highest resistance, 25·74 tons per square inch, results from a riveting pressure of 37 tons obtained with a steam riveter which is only third in the ascending scale of riveting pressures. On the other hand the machine having the highest riveting pressure, or 52 tons, namely the "power riveter,

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heavy," gives joints with a shearing resistance of only 23·76 tons per square inch, or only third in an ascending scale of shearing resistances. Still further, the stationary hydraulic riveter, giving a pressure on the rivets of 39 tons, produces a shearing resistance in joints which is 2 tons per square inch *less* than that possessed by joints made with a pressure 2 tons less: and the portable hydraulic riveter giving a pressure of 20 tons produces joints of *higher* shearing resistance than the power riveter giving 31 tons pressure. It is evident that beyond a certain point there is no relation between pressure given by the riveter and resulting strength of joints. Professor Unwin evidently does not accept Messrs. Greig and Eyth's conclusions, for he remarks:—"If there is a real difference in the shearing resistance with different riveting pressures, it must be due to friction, or to some change in the strength of the material in the process of riveting. The difficulty in ascribing it to the former cause is this, that it is not probable that a red-hot rivet can retain the compression it receives from the riveting machine. It has hitherto generally been assumed that the clipping together of the plates which produces friction is due to the contraction of the rivet in cooling, and not to the pressure put upon it by the riveting machine. Mr. Kirk has recently shown to the Reporter some joints cut through after riveting. These appear to show that in thick plates a tighter joint is obtained by continuing the riveting pressure for a sensible period, instead of removing it at once as in ordinary machine-riveting. The point is not quite clearly made out, but it deserves further investigation. It does not seem at all impossible that thick plates may spring a little, while the rivet is still red-hot, and it would be very objectionable if this were really the case."

With regard to the point raised by Professor Unwin in the concluding portion of these remarks, it is evident that the result he desires to obtain can be secured by maintaining a pressure upon the plates themselves, instead of upon the rivet and plates. The maintenance of the pressure upon the plates themselves alone, while keeping them rigidly together, would at the same time give the rivet a better chance of cooling quickly.

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The following figures of mean results, taken from Professor Kennedy's Tables 29 to 32 inclusive (Proceedings 1885, pp. 218–225), give a comparative view of hand and hydraulic riveting, as regards their ultimate strengths in joints, and the periods at which in both cases visible slip commenced :—

Total Breaking Load.		Load at which Visible Slip began.	
Hand Riveting.	Hydraulic Riveting.	Hand Riveting.	Hydraulic Riveting.
Tons.	Tons.	Tons.	Tons.
86·01	85·75 77·00	21·7	47·5 35·0
82·16	82·70 78·58	25·0	53·7 54·0
149·2	145·5 140·2	31·7	49·7 46·7
193·6	183·1 183·7	25·0	56·0 69·0

In these figures hand riveting appears to be rather better than hydraulic riveting, as far as regards ultimate strength of joint; but is very much inferior to hydraulic work, in view of the very small proportion of load borne by it before visible slip commenced.

It is important thus to learn that there is nothing inherent in the mode of riveting which interferes with the strength of the work: so that, if improved as regards tightness, riveting done by means of hammer blows would be as good as that produced by continuous pressure.

List of Memoirs on Riveting
subsequent to those enumerated in Proceedings 1881, *pages* 303–305.

"On Riveting, with special reference to Ship-work." By M. le Baron Clauzel, of Toulon. Proceedings Inst. M. E. 1881, pp. 167–204.

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"Results of Experiments on Riveted Joints." By Professor Alexander B. W. Kennedy. Proceedings Inst. M. E. 1881, pp. 205-299, 712-721; 1882, pp. 138-143; and 1885, pp. 198-291.

Contributions as appendices to above and in discussion. By R. H. Tweddell, W. John, C. H. Moberly, W. Silver Hall, R. V. J. Knight, &c.

"First Report to the Council of the Committee on the Form of Riveted Joints." By Professor W. C. Unwin. Proceedings Inst. M. E. 1881, pp. 301-368.

Tests of Riveted Joints. By C. H. Moberly. Proceedings Inst. C. E. 1882, vol. 69, p. 337; and 1883, vol. 72, p. 226.

Forms of Test Pieces. By William Hackney. Proceedings Inst. C. E. 1884, vol. 76, p. 70.

"The Influence of Punching Holes in Soft Steel." By V. N. Beck-Guerhard. A series of experiments carried out at the Poutiloff Works, St. Petersburg. Journal of the Iron and Steel Institute 1884, pp. 290-295.

"The Influence of Holing upon the Strength of Wrought-Iron." By Professor L. Tetmajer of Zürich. Schweizerische Bauzeitung, 1886, p. 33. Abstract in Proceedings Inst. C. E. 1886, vol. 85, p. 421.

"The present Aspect of Mild Steel for Shipbuilding." By John Ward. Transactions of the Institution of Naval Architects, 1886, pp. 65-122.

"Report on the Effect of Punching, Drilling, and Riming Mild Steel Plates." By William Parker and William John. Transactions of the Institution of Naval Architects, 1886, pp. 415-422.

Discussion.

Mr. ROWAN exhibited one of the electro-magnetic drilling machines which had been employed in the shipbuilding yard at Dumbarton.

Mr. T. HURRY RICHES, Member of Council, said the employment of electro-magnetic machine-tools involved several points that deserved very careful attention. There was first the cost of the machine itself, and then the cost of the motive power. Another very important matter was the influence of the magnetism upon the ships, particularly those made of steel. As was well known, if any

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(Mr. T. Hurry Riches.)
magnetic force was applied to iron, it became a temporary magnet, but ultimately lost its magnetism. It was not so however with steel. Everyone connected with shipping knew that there was a great deal of trouble in the adjustment of the compasses in steel ships, and that they suffered a great deal of disturbance whenever any riveting or hammering of the hull took place. It occurred to him that possibly the act of bringing to a steel ship a very powerful storage of magnetic force might practically convert the ship into a gigantic magnet, and being built of steel she would then become inevitably a permanent magnet. This was a matter that he thought should receive attention before such powerful magnets were used. With respect to boilers, it was well known that electricity exercised a very considerable influence, particularly on steel boilers, in regard to pitting; and electrical contrivances had been designed for the purpose of preventing the deposit of carbonate of lime and other objectionable substances on the surfaces of the plates, and in that way preventing injury to the boilers. The employment of electricity was therefore a question of importance, especially to steel boilers, owing to the fact that the steel became a permanent magnet when once magnetised. The introduction of additional magnetic influence to act upon the plates or other parts of a multitubular steel boiler suggested the probability that it would materially affect the action of the chemical constituents of the water upon the boiler during the remainder of its existence.

As to the removal of the machines from point to point, it was easy in a shop to deal with the question of transport; but alongside a ship he thought it would be a very long and troublesome process to have to de-magnetise and re-magnetise every time the drill or riveter was required to be adjusted to the next hole. No doubt a certain amount of time would be saved in the actual drilling or riveting; but to have to magnetise and de-magnetise such large magnets on every occasion appeared to him to be a very large item in dealing with the riveting of ships.

Mr. L. STERNE mentioned that he had worked at this subject some years ago, and referred to the paper read before the Institution

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in Birmingham (Proceedings 1875, page 38) on an electro-magnetic chuck for holding special work in lathes. At that time there was only one powerful dynamo in England, which belonged to M. Gramme, and had been brought over for experimental purposes. The greatest difficulty was experienced previously in getting the required magnetic power to last long enough with batteries only; they were not of sufficient duration to ensure success. In this connection he might add that he had found great advantage from agitating the batteries by means of an eccentric raising the plates out of the liquid at each revolution. Another great difficulty with drilling and cutting tools was that the magnetic power at the cutting edges of the tools attracted the disengaged particles of metal, interfering with work to such an extent that the tools had to be taken out and sharpened every few minutes. Perhaps the author had found the means of insulating the tools so that they should not be charged with such a strong magnetic influence at the edges.

Another difficulty which he had experienced was that the entire body and working parts of the tool—the planing machine, lathe, or drilling machine—had to be insulated. Otherwise, during work and for days afterwards, everything placed on the tool was attracted; and it remained, as Mr. Riches had pointed out, charged with residual magnetism so long that ultimately this system had to be abandoned as not practicable. It was however adopted for one purpose, where it answered very well, namely for grinding circular knives or discs which were so thin that no mechanical appliance could be made to hold them in the lathe. As mentioned in the paper referred to, while holding them on the magneto-electric chuck they were prevented from slipping by a small stud, and could then be ground with such precision for cutting the india-rubber threads for elastic webbing that when the thread was stretched to twelve times its normal length no trace of irregularity in thickness could be seen in it. The superiority of elastic webbing depended entirely upon the regularity of the cut thread. There was no other mode of doing such fine work; and that was the only use for which this magnetic appliance had ever been proved successful and continued in use at present.

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Mr. R. PRICE-WILLIAMS, Member of Council, could entirely confirm the remarks of Mr. Sterne, whose former careful experiments and researches he had watched with great interest; and they had naturally recurred to his mind in connection with the present paper, from which he was glad to gather that the difficulties previously experienced had now been effectually surmounted. He should much like to hear how the attraction of the cuttings to the point of the tool had been got over; in the earlier trials this had proved so great a trouble that it had quite neutralised the advantage of the magnetic chuck.

With regard to the riveting machine shown in Fig. 1, Plate 56, he enquired whether the percussive action of the hammer blows on the rivet head had been found to produce any detrimental effect upon the steel rivets; he was under the impression that the time had arrived when percussive action for riveting, especially with steel rivets, had been practically abandoned. Many years ago, when Bessemer steel was originally introduced, he believed he had been the first to recommend the abandonment of percussive action in working the ingots. It was at that time considered essential that the ingots should be hammered. But after exhaustive experiments at Mr. Fox's works at Stocksbridge the conclusion was arrived at that hammering was a mistake, causing injury to the steel. It had consequently been abandoned there, and he believed those works had been the first to roll rails direct without any hammering of the ingots at all. Carrying out to its legitimate conclusion M. Tresca's beautiful theory of the flow of solids, it appeared to him that a percussive action on rivets was a mistake.

Mr. W. FALCONER KING considered that, while the author had gone to work in a very good way, he had not allowed quite sufficient power for the machines shown in the drawings. This however was a mere matter of detail, which would no doubt be improved later on. The amount of magnetism that would be available appeared to him to be not enough for bringing the two plates close together before riveting.

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Mr. Benjamin A. Dobson, Member of Council, asked whether under any circumstances there would be any danger to the workmen attending these machines from the current of electricity passing through them. Also what precautions were taken with the holding-on magnets for ensuring a sufficient amount of contact; and whether any slip had been experienced from the vibration of the machine under work. If the contact was all over the surface of the ends of the holding-on magnets, it was clear that there would be a considerable surface available for holding, and the holding power would then be very great; but as neither plates of steel nor plates of iron had their surfaces absolutely true, there could only be a small portion of the magnet in absolute contact, and in that case it appeared to him that the amount of holding power would be greatly reduced.

Mr. W. Ford Smith asked whether the drills used were twist drills, and whether they had been working at their full power when drilling $\frac{7}{8}$-inch holes in 69 seconds each, as mentioned in the paper (page 329). From many hundreds of experiments that he had made, he had found it possible to drill a hole 1 inch in diameter through iron plates 1 inch thick in 46 seconds, or little more than half the time given by the author. He had also found that 75 holes $\frac{1}{2}$ inch diameter and $2\frac{3}{4}$ inches deep could be drilled through iron made of hammered scrap with this same excessively heavy feed, before the twist drill required to be re-ground.

Mr. Sydney F. Walker was sure the feeling of electrical engineers in regard to the present paper was one of hearty congratulation to the author on the success he had achieved. All were looking forward to the electrical transmission and distribution of power generally; and he believed those who had studied the matter were agreed that what was wanted in order to compete with tools at present in existence was the introduction of appliances of the kind now described. Many of the machines and tools now used for engineering work were self-contained, like a pump; it was only necessary to bring steam to them, and they would work independently of any other connections. At present, so far as he

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(Mr. Sydney F. Walker.)
knew, the tools described in the paper were the only self-contained electrical tools in existence; and he thought their advent marked a distinct epoch in the history of the electrical transmission of power. What had been done in past years, when the Gramme machine was first brought over to England, could hardly be taken as serviceable for present guidance, because much that had been thought impossible only two or three years ago had now become a practical success.

As to the question very properly raised by Mr. Riches, he had himself purposed asking the author whether any increase of power had been found to be necessary, after detaching the drilling or riveting machine from its first piece of work, for then attaching it to the second. If not, or if the increase of power necessary were practically not appreciable, it seemed quite evident that the plate could not have taken up much magnetism, or not sufficient to do any harm. It was well known that steel and iron, particularly the former, took up magnetism and kept it; but it took it up very slowly and with great difficulty. It was a difficult matter to get a good piece of hard steel to magnetise at all. In the construction of apparatus in which steel magnets were used, there was very great difficulty in getting steel of any kind to magnetise properly. The known laws with regard to the magnetising of iron seemed none of them to have any bearing upon steel, owing to the great difficulty of getting it to magnetise. Seeing therefore that ships were now being built of steel principally, he considered there would not be sufficient magnetism left in the steel to affect the compasses or to affect the pitting in the boilers. As to the question of magnetising and de-magnetising the magnets for the holding-on arrangement, it was done every day for other purposes; and there was no difficulty in it if the electro-magnet was properly constructed, having sufficient iron put into it, and if it was properly insulated. It would be a very different matter if the magnetic circuit were completed.

It was stated in page 330 that the author had had no data for his guidance as to the holding power exerted by the magnets, and that such information as existed was applicable only to the conditions under which electro-magnets were used in dynamo machines. It might perhaps be of service to mention that from experiments made

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by himself the same general laws appeared to be equally true for magnets of all kinds, whether the largest magnets used in the most powerful dynamo machines, or the smallest magnets used for such light work as ringing the electric bells in colliery shafts. After the enunciation of the law of magnetic resistance by Mr. Kapp eighteen months ago, he had himself set to work on the colliery bells which he had previously been fitting up, to see whether the same law held true for them, and whether any saving could be effected in their construction; and he had found that the same general law did hold true exactly:—namely that the magnetic power, whether it were the holding-on power or whether it were the lines of force in the armature of the dynamo machine, varied directly as the exciting power, and inversely as the magnetic resistance; and that the magnetic resistance varied directly as the length of the magnetic circuit, and inversely as the area of its cross section. Practically the result at which he had arrived was that, in magnets of the construction shown in the drawings, which were similar to the little magnets used for working colliery bells, the magnets themselves could be very much shortened, and could be made of increased sectional area, to the extent of about three times the area at present adopted. The cost of manufacture was then less, and a considerably better pull was the result.

He enquired what dynamo had been used as a generator for working these machines; and whether there was any difficulty in handling the tools. Also whether there was any difference in the power required for working one of the caulking and chipping tools by an electro-motor, as shown in Figs. 10 and 11, Plate 59, and another by a solenoid, as in Fig. 12. A solenoid was known to be a very wasteful appliance, not giving out anything like the power that was put into it; but on the other hand it had the advantage of acting direct, whereas the motor acted through gearing. Had the author made any experiments showing which was the most economical?

Mr. Rowan said that as to the cost of the machines he could only at present give approximate figures. The riveting or drilling machines represented in Figs. 1 and 6, Plates 56 and 57, would cost

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(Mr. Rowan.)
roughly about £100 each. Their size was small, as their power was only about ½ HP.; although the motor was capable of exerting from ¾ to 1 horse-power of actual work. A dynamo machine of about 4 HP. for working three or four machines could be got for about £60. For an installation comprising a large number of machines, say as many as twenty-five, which would be capable of completing the whole of the rivet holes in a large ship of 300 or 400 feet length in about thirty days, the whole of the machines including the dynamo and cable would cost about £3000. The same appliances would of course be available for the work of constructing a large number of ships. The first cost seemed something considerable; but against that, the reduction in thickness of plating which would probably be allowed, in consequence of the increased strength due to the absence of deterioration by punching, would amount to a considerable sum in each ship. Labour charges would be about the same as at present.

As to riveting, all that he could gather in the way of comparison between the work done by these machines and that done by other machines and in boiler works showed that the work was done in about the same time. The closing of a rivet took about eight seconds in the very best boiler work with hydraulic machines; and in ordinary work with the electro-magnetic riveter the same rivets had repeatedly been closed in from eight to ten seconds.

The cost of the motive power was difficult to arrive at, because it was simply a question of taking so much power from the engine to drive the dynamo; or, where the power was not available in that way, of supplying the necessary steam-power.

The influence of magnetism on ships was really very much a matter of imagination. It was easily understood that the magnetism produced by the attachment of these machines embraced only a small area; and in working over a ship's side or a boiler shell the magnetism was continually reversed and practically destroyed by the north pole of the holding-on magnet succeeding to the position occupied just previously by the south pole, or *vice versâ*. The amount of residual magnetism found in the side of a steel ship was therefore extremely small. Instead of the ship being turned into one huge magnet, there were so many poles mixed up all over the plates that

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the compasses could not be in any way affected even if the plates were permanently magnetised, which was very unlikely not only on account of the facts stated by Mr. Walker, but also because, although the material used in ship and boiler construction was popularly called steel, it was well known to be simply a fine quality of iron, very unlike tool steel. The probable effect on steel boilers of magnetism induced in the plates by the use of these machines had been spoken of by Mr. Riches; but in ascribing to them in this way the power of increasing the action of corrosion in boilers, it was evident that magnetism had been confounded with galvanic action, which latter was sometimes a cause of corrosion and had been proposed as a preventive in certain cases. Magnetism exerted on water no action of a chemical nature, such as galvanism or a galvanic current was capable of producing; and therefore, even if the plates should retain some permanent magnetism, this could not act in setting up any galvanic action, or in increasing the energy of corrosive agencies which might be present in a boiler.

Reference had been made by Mr. Sterne to the American plan of an electro-magnetic chuck, which was a simple method of applying magnetism to a lathe-chuck or planing-machine bed by making one portion of the chuck to form one pole of the magnet and the other portion the opposite pole. But in that case the holding power of the magnet was used in the very worst way in which it could be applied, namely to hold the work against force tending to produce a sliding movement; and he had found a magnet was of no use at all for such a purpose. With the machines described in the paper the magnets were used principally to hold against force acting directly against their pull; and it had been found that there was very little slipping down the side of the ship or the boiler, due to the weight of the machine, the tendency to slipping being easily overcome with sufficient magnetism. In working on any such structure as a ship's side, the tools had necessarily to be suspended by some slight slinging arrangement, just like the drilling machine now exhibited hanging from a support overhead, so as to guard against all possible risk of danger to the men working underneath; and any slip due to the weight of the machine, which weight would

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(Mr. Rowan.)
really be a mere trifle in comparison with the holding power of the magnets, would be taken up in that way, even though the machine were ten times heavier than it was.

There was no danger at all in working with the ordinary electric currents, which of course could be made use of in machine work of that sort. The same current which was used in many establishments for electric lighting was quite applicable to working the electro-magnetic tools. It was well known that continuous currents of up to 150 volts potential were quite harmless. He had repeatedly seen the men take the whole of the current through their bodies without the slightest inconvenience, except a little tingling of the joints and muscles, which taught them rather to respect the machines than to be afraid of them.

The stroke of the hammer in the electro-magnetic riveter that had been made was 5½ to 6 inches; and he had not found any bad results on the rivets themselves from the percussive action. The question of dealing with ingots was rather a different matter. Mr. Price-Williams had spoken of the evil effect which he had found from hammering Bessemer ingots; but it was well known that steel when first cast was in a very different state physically from that which it afterwards acquired in the course of being worked.

In the electro-magnetic drilling machine he had commenced with twist drills; but these were thought to be too expensive for ordinary ship-building work, and consequently only ordinary drills had been used in the ship-yard, namely flat drills with a cutting angle formed more or less acute according to the speed at which the work was being done. The holes spoken of in the paper as $\frac{7}{8}$ inch diameter (page 329) were $1\frac{1}{8}$ inch deep, and the time stated included what was required to move the machine from hole to hole; so that the speed of drilling them was very much the same as had been mentioned by Mr. Ford Smith.

The shavings or cuttings, which had proved so troublesome in Mr. Sterne's trials, had not been found to occasion the slightest difficulty in the electro-magnetic drilling machine. The whole of the framework of the machine above the yoke joining the two magnet cores was made of brass or phosphor-bronze, so that the

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magnetism was not conducted away through the frame-work, but was confined to the wrought-iron yoke and the magnets, between which the magnetic circuit was completed through the plates. The drill-holder worked through this insulated framing. It was consequently found that, although the drill itself was slightly magnetised by induction from the plate, the magnetism in the poles of the magnets was so much stronger than any induced magnetism in the drill that the shavings actually flew out of the hole as though they were being blown out, and clustered themselves upon the magnets. The effect was positively to clear the hole, and thereby to render the lubrication of the cutting tool much easier. When the drill was between the magnet poles, as in Fig. 6, Plate 57, the cuttings flew out on opposite sides to both magnets alike; and when the drill projected beyond the magnets, as in Fig. 7, the effect was still the same in clearing the hole, although there was only one pole of the magnet near enough to attract the shavings.

The question of the comparative efficiency of solenoids he had not yet gone into. In reply to the enquiry about dynamos, any good dynamo machine was suitable for working the machines. In one case a shunt-wound dynamo of Messrs. Immisch's construction had been used; and in another case one of the Phœnix series-wound machines used for lighting had been employed.

The surmise (page 338) about the magnetism in the riveter and holder-up being insufficient to draw the plates together was not correct. As illustrating the extent to which the magnets affected each other through the plates, he had found that, when the electrical connections were incorrectly made, so that poles of like denominations faced each other on opposite sides of plating of $1\frac{1}{8}$ inch thickness, neither magnet held with sufficient strength to do the work, that is to say both magnets were weakened by induction. This proved the existence of considerable inductive effect, in addition to the holding-on power, which when properly directed must draw the magnets and the intervening plates together. He had not however measured the extent of this action with magnets of the size shown; and it would of course be governed by the proportionate mass of the plates forming a keeper to the magnets.

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The President invited the Members to pass a hearty vote of thanks to Mr. Rowan for his excellent practical paper. No doubt if he succeeded in persuading shipbuilders to drill holes instead of punching them, it would add materially to the strength of ships; the holes would be correctly opposite one another, and the rivets would then be put in so as to fill them perfectly.

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DESCRIPTION OF THE ELECTRIC LIGHT ON THE ISLE OF MAY.

By Mr. DAVID A. STEVENSON, F.R.S.E., of Edinburgh.

The Lighthouse situated on the Isle of May, at the mouth of the Firth of Forth, Plate 61, has recently been lighted with electricity; and as this light, besides being, the author believes, the most powerful in the world, possesses several novel features, he has the pleasure of offering the following notes regarding it, trusting that they will prove of interest in connection with the visit to be made to the lighthouse on the occasion of the present meeting.

Previous Lighting.—The Isle of May was originally lighted in 1636 with an open coal fire. In 1816 the Commissioners of Northern Lighthouses, having previously purchased the island with the right to levy tolls for the lighthouse, altered the light to argand lamps with silvered parabolic reflectors. In 1836 it was converted to the dioptric system, with a first-order fixed-light apparatus, and a four-wick burner; and on 1st December 1886 the electric light was substituted, and shown in connection with a dioptric condensing apparatus. For the last fifteen years the Commissioners of Northern Lighthouses, acting under the advice of their engineers, Messrs. Stevenson, had been anxious to establish an electric light on the Scottish coast; but it was not till 1883 that the Board of Trade were able to sanction the expenditure, and suggested its introduction at the Isle of May on the ground that "there was no more important station on the Scottish shores, whether considered as a landfall, as a light for the guidance of the extensive or important trade of the neighbouring coast, or as a light to lead into the refuge harbour of the Forth."

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Notwithstanding the difficult access and isolated position of the Isle of May, distant five miles from the Fife shore, which is the nearest land, as shown in Fig. 1, Plate 61, it was resolved to accept the view of the Board of Trade, and to introduce the electric light there. The necessary plans and specifications were accordingly prepared by Messrs. Stevenson; and the works, begun in June 1885, were completed, and the new light installed by 1st December 1886.

Site.—The existing establishment, Fig. 2, Plate 61, consisted of a lighthouse tower with accommodation for three keepers, placed on the summit of the island; and the additional buildings which it was necessary to provide were dwellings for three more keepers with their families, an engine house, boiler house, chimney stalk, workshop, coal store, &c. It was decided to place the whole of the new buildings and machinery near the base of the island, and to lead the current up to the tower by conductors. This decision was arrived at, because it was considered that the fact of being able to place the engines close to the small natural fresh-water loch, situated 270 yards from the light and 175 feet below it, from which fresh water for feed and condensing purposes could be readily obtained, and also the saving which would be effected by not having to convey the fuel to the top of the island or to pump up water, would compensate for the loss of energy, due to such a length of conductor; while the saving of the cost of carriage of the materials and machinery to the top of the island, and of piping and pumping machinery, would more than counterbalance the original cost of the conductors.

The buildings were constructed in a plain and substantial manner of fire-brick, built in Portland cement, and roofed with concrete and val-de-travers, carried on rolled beams and buckled plates. This part of the work was executed in an expeditious and satisfactory manner by the contractors, Messrs. Stratton, Edinburgh, notwithstanding the difficulty of getting materials taken to and landed on the island.

Generators. — It was originally intended to use the Brush compound-wound Victoria dynamo, giving a continuous current, and supplying a single automatically fed arc-lamp with the

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positive carbon *below*. This system was selected as being at once cheaper, and as giving a stronger light-power for the engine-power applied, than the magneto-electric machines, which had hitherto been exclusively used with success in lighthouses. The placing of the positive carbon below was adopted in order that the strongest light might be thrown upwards, so as to be dealt with by the upper part of the dioptric apparatus, and thus be more effectively utilised. The Brush Company at once set to work to produce a lamp of the above description, giving, with a current of 100 ampères and 70 volts, a light of 30,000 candle power in the horizontal line, steady and suitable for burning in a lighthouse. This unfortunately they were unable to accomplish, even after numerous trials; and at last, as the buildings on the island were nearly completed and it became necessary at once to procure reliable apparatus, recourse was had to the more expensive alternate-current machines of De Meritens, which, though not so powerful, are admirably steady in working, and had given excellent results in several lighthouses and also at the South Foreland experiments.

The generators at the Isle of May are two of De Meritens' alternate-current magneto-electric machines of the L type, and are of the largest size hitherto constructed, weighing about 4½ tons each. The induction arrangement of each machine consists of five sets of twelve permanent magnets, sixty in all; and each magnet is made up of eight steel plates. The armature, which makes 600 revolutions per minute, is 2 ft. 6 ins. diameter, and is composed of five rings with 24 bobbins on each, arranged in groups of four in tension and six in quantity.

With the circuit open, each machine develops an electromotive force of 80 volts, measured at the distributor; and with the circuit closed through an arc, 40 volts. An average current of 220 ampères is developed, thus yielding an electrical energy of 8,800 watts, or 11·8 HP. in the external circuit. The five rings are so arranged that one-fifth, two-fifths, three-fifths, four-fifths, or the whole of the current of a machine can at pleasure be sent to the distributor for transmission to the lantern; and further, the two machines can be coupled, and the full current from both be employed.

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Engines.— The machines, Figs. 3 to 7, Plates 62 and 63, are placed in the engine-room, bolted down to concrete foundations, and are driven through a countershaft by belting from the engines. These are a pair of horizontal surface-condensing steam-engines, each with two cylinders of 9 inches diameter and 18 inches stroke, making 140 revolutions per minute, and each indicating 17·7 HP. with 40 lbs. steam pressure above atmosphere and 11 lbs. vacuum. To provide against accident or failure of water-supply, they have been arranged so as to be capable of being worked either condensing or non-condensing. Either of them is sufficient to drive one machine, the other engine being idle; or the two can be used together for driving both machines in thick weather. The steam to both cylinders is regulated by an equilibrium throttle-valve, which is controlled by a high-speed governor, adjusted for the engine to run at the normal speed of 140 revolutions per minute. Single, in place of compound, engines were adopted, because they are less complicated and better suited for the less skilled attendance of ordinary lightkeepers. Probably also greater regularity in driving has thus been secured, which is of course a matter of the greatest importance in electric lighting, especially where, as in this case, there is only a single arc-lamp in the circuit forming the resistance. The result has been eminently satisfactory; and the engines, which were built by Messrs. Umpherston, of Leith, are a most excellent piece of work.

Boilers.—There are two steam boilers, of which only one is in use at a time, the other being spare. Each is 20 ft. long, and 5 ft. 6 ins. diameter, with one furnace-flue 3 ft. diameter and 8 ft. long, having six cross Galloway water-tubes. The shells are of "best best" $\frac{3}{8}$-inch steel plates, with the longitudinal joints double-riveted; and they were tested up to 110 lbs. per square inch, the working pressure being 40 lbs. The feed is principally rain water collected from the roofs and the pavement of the court; but water can, if required, be taken from the small loch, which is also used for condensing purposes. The coal consumption is 1 cwt. per hour of lighting, which includes banking the fires during the day.

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Conductors. — The current generated in the engine-room is conveyed to the lantern by leads, which consist of copper rods of 25 millimetres or 1 inch diameter, covered with a double water-proof wrapper. This is the first time that copper rods have been used for conducting the current for lighthouse illumination. They are constructed in 14 ft. lengths, the joints being formed with a zigzag scarf screwed up tightly by gunmetal coupling-boxes having four bolts in each. They are carried by timber bearers, placed in a groove made for them in the side of a concrete wall running from the engine-room to the tower, Figs. 10 and 11, Plate 65. The total distance to the lantern is 880 feet. Several bends are introduced to allow for expansion and contraction due to changes of temperature. The loss in the leads was expected not to exceed one-sixth of the total energy generated; but it is considerably more than this, amounting to at least one-fifth. It is hoped however that an improvement will yet be made in this particular.

Lamps.—The lamps, of which there are three, one in use and two spare, are of the Serrin-Berjot type, with some modifications: notably the shunt or bye-pass, first introduced in the South Foreland experiments on the suggestion of Dr. Hopkinson, whereby a large percentage of the current goes direct to the lower carbon, and only an amount sufficient to regulate the carbons is passed through the lamp. This is a great improvement, and prevents injury to the lamp from heating. The weak point about it, in the lamps sent to the Isle of May, was that the contact between the lower carbon-holder and the bye-pass, being necessarily a sliding contact, was effected by copper-wire brushes; and these were found to wear out rapidly. On the suggestion of Mr. Munro, the engineer in charge of the station, a simple form of mercury contact has been substituted, and works quite satisfactorily.

Carbons.—The carbons in use are 40 millimetres or 1·6 inch diameter; but if desired 50 mm. or 2-inch carbons can be used when both machines are running. They are Siemens make, and have a core of soft pure graphite, which has the effect of causing

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them to burn with greater regularity and steadiness than they otherwise would, and of preventing a crater from forming and remaining at one side. The rate of consumption of the 40 mm. carbons is $1\frac{1}{4}$ inch per hour, or 2 inches including waste. The power of the arc is estimated at 12,000 to 16,000 candles, when one machine only is running.

Dioptric Apparatus.—The dioptric apparatus, Figs. 8 and 9, Plates 64 and 65, which was manufactured from Messrs. Stevenson's designs by Messrs. Chance of Birmingham, is of a novel description, the condensing principle being carried further than in any apparatus previously constructed. This principle consists in darkening certain sectors by diverting the light from them, and throwing it into the adjoining sectors so as to reinforce their light. Thus the power of the light is increased in proportion as the dark arc is increased. The light gives four flashes in quick succession every half minute; and during the bright periods the effect of this concentration of the rays is that the light radiating naturally from the focus is increased in power 15 times in azimuth in addition to the vertical condensation, excepting of course the loss due to reflection and absorption. The apparatus which effects this result is a second-order fixed-light apparatus F of 1400 mm. or 55 inches diameter, which operates on the rays in the vertical plane. Outside of this there is a revolving cage C of straight vertical prisms, extending the full height of the fixed apparatus, or $5\frac{1}{2}$ feet, and composed of two panels on opposite sides of the centre, each operating in the horizontal plane on 180 degrees of the light coming from the fixed apparatus, in such a way as to condense the whole 180 degrees into four flashes of 3 degrees each, that is, 45 degrees into 3 degrees, with the proper intervals of darkness between them, Fig. 9. This cage of glasswork C is caused to make one complete revolution every minute round the fixed apparatus, thereby producing the characteristic of four flashes every half minute. The fixed-light apparatus is not of the ordinary Fresnel section, but has the refracting portion confined to an angle of 10 degrees, the upper and lower reflecting prisms being carried

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nearer to the focal plane. This design, although involving the loss of some light, facilitated the adoption of the late Mr. Thomas Stevenson's proposal of dipping lights in fog, so as to be able to direct the strongest part of the light to the horizon in clear weather, and in fog to a point only three to five miles distant. Such a change could be most easily produced by simply raising and lowering the level of the radiant in the apparatus; but there was a difficulty in doing so in an ordinary optical apparatus, inasmuch as, when the position of the radiant was altered, the rays from the reflecting prisms, above and below the refractor, would be sent in an opposite direction to those coming from the refractor. This form of the fixed-light apparatus was also specially necessary at the time the apparatus was designed, because it was then intended, as already mentioned, to use a continuous-current machine with the positive carbon below; and consequently the strongest part of the light would have been dealt with by the upper reflecting prisms. By making the apparatus almost entirely of totally reflecting prisms, instead of refracting and reflecting combined, all the prisms act in the same way: so that by lowering the radiant the whole of the light from every part of the apparatus can be dipped simultaneously to any required extent, with the exception of a small piece in the centre, which is a refractor, and which will send light to the horizon when the other part of the apparatus is dipped. In clear weather the three upper prisms send their light from ½ degree above the horizon to 3 degrees below it; the rest of the upper prisms and all the lower ones send their light to the horizon; and the refracting portion from 3 degrees to 5 degrees below the horizon. The dipping of the light during fog has not yet been used; but as soon as the lightkeepers, who, with the exception of the engineer, were the ordinary keepers in the service and knew nothing of electric lighting, have become thoroughly familiar with their duties, it is intended to introduce it, and probably in the same way to employ a less powerful current, and say 25 mm. or 1-inch carbons in very clear weather; while both machines with 50 mm. or 2-inch carbons will be used in very thick weather.

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Lamp Changing and Revolving Arrangements.—Standing in the centre of the light-room is a circular case A, Plate 64, 5 ft. 8 ins. diameter and 5 ft. 4 ins. high, formed of cast-iron pilasters filled in between with glazed doors. The top of this case carries the fixed-light apparatus F, as well as a steel roller-path 5 ft. 10 ins. diameter, on which the carriage supporting the cage C of vertical prisms travels on twelve steel rollers. The top of the case also serves as the service table S, on which the electric lamp L stands when in focus. Access to the interior of the apparatus and to the lamp is obtained from the inside of the case, through a trap in the top of it. Some difficulty was experienced in devising a suitable system of readily substituting one lamp for another, when it may be desired to change them, or in the event of the one in focus going wrong. The difficulty arose from the necessity of keeping the spare lamp out of the apparatus entirely, so as to prevent its interfering with the light emanating from the lamp in use, as the light shows all round the horizon. The change is accomplished by means of an arrangement of rails, and three turn-tables or shunt-tables T, on which the lamps can be freely run, and which are placed on the service table S. One of these is in the centre of the apparatus; and one is on a trap door, working vertically in guides and counterbalanced, in the manner of a hoist, whereby a lamp can be lowered from the level of the top of the case to the floor of the light-room. Here the lamp is again received on rails, on which it can be conveniently run out of the case, to be re-carboned and adjusted. In this way a lamp can be raised from the floor of the light-room into the apparatus, the lamp in the focus withdrawn on to one of the turn-tables and the fresh lamp run into focus, and the original lamp shunted on to the hoist and lowered out of the apparatus, all in about eight seconds.

A three-wick paraffin oil-lamp is kept trimmed and ready for use, in case of a failure of the electric current; and it can be lighted and put in the focus in about three minutes.

Within the case, and placed at one side of it, is a train of wheel-work W, actuated by a weight with a fall of 60 feet down the centre of the tower. This machine drives the revolving cage C of vertical prisms by a shaft H which passes up through the top of

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the case, with a pinion working in an internal wheel of 4 ft. 10½ ins. diameter secured to the carriage of the cage. This machine is carefully boxed in, to prevent the dust from the incandescent carbons finding its way into the bearings, whereby great trouble has been caused at various lighthouses lighted by electricity.

Power of Light.—The resulting beam of light from this apparatus is about 3 million candles when one machine is in use, and with both machines 6 millions; that is, about 300 and 600 times more powerful than the old fixed oil-light. When the three-wick oil-lamp is put in the focus of this apparatus, the emergent beam is more powerful than the old fixed oil-light with a four-wick lamp, which was 9,446 candles. The light has been picked up and recognised by sailors at forty and fifty miles off, by the flashes illuminating the clouds overhead, although the geographical range of the light is only 22 miles.

The engine-room is connected by telephone with the light-room; and the houses of the keepers are connected by air whistles or electric bells with either the light-room or the engine-room.

Men employed.—The establishment consists of an engineer, four keepers, and an occasional or auxiliary keeper. The engineer, who is responsible for the management of the station, does not take a regular watch, but visits the engine-room and light-room occasionally during the night. Two of the keepers attend to the light-room duty, and two have charge of the engines and boilers, relieving each other in regular watches. The auxiliary keeper does any odd duties, such as carting fuel &c.; and in the event of any of the others being ill takes his place. Since the light was first exhibited, the machinery and electrical appliances have worked without a hitch, and recourse to the oil-lamp has been unnecessary. This is the more gratifying when it is remembered that, as already stated, the men in charge, with the exception of the engineer, were new to the work, and that the light was started at a period of the year when the time of lighting was longest, namely sixteen hours.

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Cost.—The new buildings, engines, electric machines, lamps &c. have cost £15,835; and the buildings, lantern &c., previously on the island, which have been utilised, may be valued at £6,600. Thus the total cost of the installation may be taken at £22,435; and the cost of maintenance will not exceed £1,050 per annum. These figures are very moderate, considering the great power of the light, and the isolated position of the lighthouse. To compare the cost of this installation with what it would have been if oil were the illuminant, there must be added to the above £6,600 for buildings a sum of £2,925 for the cost of the apparatus and machine &c., making a total of £9,525, while the cost of maintenance would have been £330 per annum. Taking these figures, and adding to the maintenance 3½ per cent. on the original outlay, it is found that while the oil-light would cost 3·49 shillings per hour and 0·00017 penny per candle power per hour, the electric light costs 9·66 shillings per hour or 2¾ times more, and 0·000038 penny per candle power, or less than one quarter of what the oil light would cost per candle power. This is taking the electric light power of one machine.

Surprise has frequently been expressed by masters of vessels, and by residents on the neighbouring shores who live in view of the Isle of May light, that this light, which is so extremely brilliant in clear weather as to cast shadows at a distance of ten and fifteen miles, is so cut down by fog that some even go the length of believing the old oil-light was better in fog. All who have experience of the electric light are quite prepared for the first part of this statement; while the last, it need hardly be said, is a mistake, inasmuch as the electric arc has been proved both by experiment in natural and artificial fog, and also by observations on existing lighthouses lighted by electricity, to be in all circumstances of weather the most penetrating. Every night at twelve o'clock the lightkeepers at St. Abb's Head, 22 miles distant, where there is a first-order flashing light and one of the most powerful oil lights in the service, observe the Isle of May light, while the keepers there also observe the St. Abb's Head light. The result of the last five months' observations is that the Isle of May light is seen one-third oftener from St. Abb's Head than the St. Abb's Head light is seen from the Isle of May. It is perfectly true however

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that the superiority which is so apparent in clear and rainy weather is very much reduced in hazy weather, and practically disappears in very dense fog. Looking to this fact and to the large first cost and annual maintenance, the author feels that the conclusion arrived at by the Trinity House is sound, namely that electricity should be used only for important landfall lights.

If however the most powerful light is desired independently of cost, then the electric arc has no rival. And if the further expense is to be incurred of introducing biform, triform, quadriform, or even double quadriform lights, then the electric light is better adapted than any other illuminant, because, on account of its focal compactness and other properties, it can be so dealt with by suitably designed dioptric apparatus that the whole light evolved is effectually utilised. This is not the case with the large gas or oil flames generally used in the multiform system, in which for this and other reasons a considerable loss of light is incurred. Moreover the coolness of the electric arc renders multiform lights really practicable; and this can hardly be said to be the case either with gas or with oil.

Hyper-radiant Apparatus.—In the author's opinion however it is only in very exceptional cases indeed that electricity should be used; and he considers that a single oil or gas burner placed in the focus of a proportionately sized dioptric apparatus is sufficient for the generality of cases; and that any additional outlay which can be permitted should be expended in establishing a powerful sound signal to be used during fog when the light is obscured, and when for all practical purposes even the electric light itself would also be obscured. This is specially the case since the introduction, on Messrs. Stevenson's suggestion, of hyper-radiant apparatus suited for use with burners of large diameter. As the result of experiments made in Edinburgh in 1869 they pointed out that the effectiveness of the large Wigham burner was to a great extent lost in revolving apparatus, because much of the light was ex-focal. A year or two ago, when the Commissioners of Northern Lighthouses resolved to increase the size of the burners in some of their lights, an experimental lens of 1,330 mm. or 52⅜ inches focal distance, designed by their engineers,

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was constructed by Messrs. Barbier and Fenestre, and by the courtesy of the Trinity House was fully experimented upon at the South Foreland, on the termination of the experiments conducted there with electricity, gas, and oil. From experiments made by Sir James Douglass and the author, and from photometric observations by Mr. Harold Dixon, the expectations of Messrs. Stevenson were fully borne out, and the following conclusions seem warranted:—that a single burner, shown in a complete panel of a revolving apparatus of the hyper-radiant kind, would give a more powerful light than burners and ordinary Fresnel lenses, arranged as biform, and would be of equal power to triform; while the consumption of oil or gas would be one-half or one-third respectively. Moreover all the disadvantages of superposed lenses, including excessive heat in the lightroom, difficulty in the management of the burners, and obstruction of light by the necessary ventilating tubes, would be avoided.

The result of the above experiments has so conclusively established the advantages of the hyper-radiant apparatus that the American Lighthouse Board have since ordered a complete apparatus of this kind; while the Trinity House and the Irish Lighthouse Board have adopted this size of lens in lights recently ordered by them on Mr. Wigham's biform principle.

Discussion.

Sir JAMES N. DOUGLASS, Member of Council, considered the subject of the present paper was one of the most important that could possibly engage the attention of mechanical engineers. The establishment of good coast guides concerned not only the professional mariner but society generally; and perhaps the full importance of the subject was only realised when ships were caught in dangerous seas with imperfect coast signals, and when it became

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doubtful whether they would ever reach their destined port. He thanked the author most heartily for having brought this subject before the Institution, and for having offered the Members an opportunity, which so seldom occurred, of seeing a lighthouse in the latest state of scientific development, especially in so important a locality as the Firth of Forth, and on a site from which originally had been sent the light of an open coal fire. All who visited the lighthouse in the excursion arranged to the Isle of May would he was sure enjoy a great treat.

The subject of coast lighting was one that was unfortunately not generally understood; and it was very desirable that mechanical engineers at any rate should realise its importance, because what was at present wanted was a cheap electric light. After an experience of nearly thirty years of electric lighting, he agreed with the author that, in consequence of the high cost of installation and maintenance, the electric light was at present restricted to those of the most important positions where the large expenditure of money could be incurred by the responsible authority. It was stated in the paper (page 356) that the Isle of May light would cost per hour $2\frac{3}{4}$ times more than an oil light. But how were the public generally to be assured that the greater cost was being beneficially utilised? especially when sailors so often declared that the electric light dazzled them in clear weather. The problem was now being solved with the electric and other lights by giving just sufficient light in clear weather, and as much as possible in thick weather; but still with the electric light this involved the larger relative cost, nearly as stated in the paper. The relative value of oil, gas, and electricity for lighthouse purposes was a question which had received the earnest consideration of the lighthouse authorities of this country ever since the first starting of the electric light in December 1858 at the South Foreland by Faraday and Holmes, whose names should never be forgotten in connection with the electric light and the production of the first practical dynamo for coast lighting. At that time an arc light was obtained of about 700 candle-power, while the first-order light whether of oil or of gas did not exceed 230 candles: so that the intensity of the electric light

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(Sir James N. Douglass.)
was at once treble that of oil or gas, and it thus became a formidable competitor at sea, as it had been in every direction on land. That result stimulated many improvements in coast lighting; and the consequence had been that at the present time with oil or gas about forty times the intensity or energy could be placed in the focus of optical apparatus for the service of mariners that had been possible at the date of starting the electric light. In order therefore to compete with gas and oil, an electric light was now required much more powerful than formerly; and this was provided for at the present time when an electric light of 30,000 or 40,000 candles was available in single focus. There appeared indeed to be no limit to the intensity of light which by means of electricity could be provided for the benefit of the mariner, if only the funds could be obtained; but unfortunately for this important work, as for many others, money was scarce, and it was necessary to go on as economically as possible whilst the mercantile marine continued in its present depressed state. Moreover mariners appeared to agree that oil and gas at their present maximum intensity were sufficient for ordinary purposes; therefore what appeared to be required was an electric light for specially important positions, of higher available maximum intensity than oil or gas, but not greatly exceeding the cost of installation or annual maintenance of these illuminants. If the cost of electricity could thus be reduced, there would doubtless be a very large field for it; and it was therefore a tempting opportunity for mechanical engineers in the present depressed state of trade to endeavour to produce a cheap electric light for lighthouse purposes.

With regard to the optical work, he should have preferred a single apparatus for both vertical and horizontal condensation and distribution of the light. He knew that the late Mr. Thomas Stevenson was never satisfied with the use of two apparatus, where one could be designed to do the work; and he had hoped that with his well known talents in optical engineering he would have succeeded in this rather difficult case. It was doubtless a very beautiful apparatus, and one which it would be difficult to surpass for the purpose. The optical treatment of the arc light was an important matter for the consideration of electricians and engineers.

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It appeared that the apparatus described in the paper had first been designed for use with a continuous current; but in consequence of failure to obtain a suitable lamp for this current, the alternate-current machines and lamp of De Meritens as used at the late South Foreland experiments had been adopted. These were found to be very reliable and efficient machines for lighthouse work, and the only known objection to them was their high price. One had been in nightly use for seven years at the Lizard, and the whole cost of repair during that period had been very trifling. With a continuous current there was formed at the carbons a single crater, which with the usual arrangement was formed at the point of the upper or positive carbon, as shown in Figs. 12 and 13, Plate 66. For the Isle of May light the position of the carbons was intended to be reversed, the positive carbon with its crater being placed below, with a view of radiating the most intense light upwards; and the dioptric apparatus was beautifully designed for utilising the light most effectively. In consequence of the failure of the continuous-current lamp, it had been necessary to resort to a machine and lamp giving alternating currents. The two carbons were then pointed nearly equally, as shown in Figs. 14 and 15, thus giving a more efficient radiant for utilising optically. Alternating currents therefore appeared to him to be the most perfect for lighthouse illumination.

For some time past his attention had been directed to the improvement of the carbons; because whether alternating or continuous currents were used, there was still the objectionable crater, which had the effect of locking up the most intense portion of the light generated, and preventing the most efficient optical disposal. This subject was exceedingly interesting. The improvement of large carbons by Messrs. Siemens, in providing them with a soft graphite core, had been very important and efficient in holding the arc central and more steady than previously; but in spite of this there occurred the formation of the craters and sudden outbursts of the arc in different directions all round the points, notwithstanding that the carbons themselves were kept perfectly in line. Wherever there was an outburst of the arc there was a maximum intensity of light in that direction, and unfortunately

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(Sir James N. Douglass.)
on the opposite side of the points there was at the same time a minimum intensity. These irregularities were very troublesome to deal with. The optical refinements described in the paper were intended for producing at half-minute periods four flashes in quick succession; these flashes were required to be of equal intensity and duration; but how was this to be done with such an unsteady arc as resulted from these irregular outbursts? His own idea was to make the carbons fluted, as shown in Figs. 16 to 19, Plate 66; and he was glad to say that this simple expedient had entirely fulfilled his expectations. For some time past he had been experimenting with fluted carbons up to 50 and 60 millimetres diameter (2·0 and 2·4 inches), and they had worked with the arc nearly as steady as a candle flame, with an intensity of about 40,000 candles; and he was of opinion that carbons of this description could be used in producing a steady arc light up to an intensity of a million candles. With these fluted carbons he found that good points were maintained without the formation of a crater; and thus the arc was maintained perfectly central, and the irregularities of the light with cylindrical carbons, due to their crater, were avoided. Carbons of this form were now being manufactured by several firms. Some little difficulties were experienced at first; but when the tools were properly prepared, it was found that the manufacture was as simple as with the cylindrical carbons. Another important advantage of the fluted carbons was that they were baked more uniformly and with less internal fracture.

Mr. Arthur Paget, Vice-President, hoped that, inasmuch as in the present case an open coal fire had been ultimately replaced by the electric light, the author would be able to state, approximately at all events, the cost per candle-power of the coal when burnt direct in an open fire as in 1636, and the comparative cost at the present time, when, thanks to science and mechanical engineering, the coal was transmuted into light by the agencies of steam and electricity. Mention had been made by Sir James Douglass of a complaint made by the sailors that the electric light was now too strong when the ship was near the lighthouse: this appeared to mean that a light was

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asked for which would give less light near than far off. Instead of trying to solve so difficult a problem, would it not be more simple to educate the sailors not to look at the light too long when they were close to it?

The appeal made by Sir James Douglass to mechanical engineers, to produce an electric light which would be cheap enough to justify the expenditure of public money upon it, was one which he could not reconcile with the statement in the paper (page 356) that the cost of the electric light at the Isle of May was only 0·000038 penny per candle-power per hour, or less than one quarter of what the oil light would cost. In view of this statement, he could not understand how it was more expensive to supply electric lighting than oil lighting.

Another point which also puzzled him was that in page 350 it was stated that "single in place of compound engines were adopted"; and in the next sentence it was stated that "probably greater regularity in driving has thus been secured." This opinion he thought would not be shared by those who were conversant with compound engines.

Mention was made on page 351 of a simple form of mercury contact, which had been substituted for a sliding contact, and was working quite satisfactorily. He wished to ask whether that was the ordinary form of mercurial contact generally used, or whether there were any special features in it, and if so what they were; because he understood that Sir James Douglass had for some time used for his lights a form of mercurial contact which was quite satisfactory.

Mr. William Geipel mentioned that experiments had lately been carried out by the Brush Corporation with a view to obtaining a lamp which would burn the positive carbon below. The difficulty was that the flame of the arc was apt to fly away from the positive carbon when underneath; whereas when the positive carbon was above, the flame was held round it in suspension and assisted materially in reducing the resistance of the arc. The flame flying away from the arc caused heavy variations in the resistance, whereas the mode first experimented upon by the Brush Corporation of

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(Mr. William Geipel.)

controlling the arc was compatible with only a very small variation. The carbons had always previously been burnt the other way up, with the positive carbon above. Since these trials however, a better result had now been obtained by resorting to a more active regulation which was not quite so sensitive, but which at the same time answered the purpose very well. It was simply the old form of the Serrin lamp slightly modified, which gave great satisfaction notwithstanding the positive carbon being underneath.

As to the resistance of the conductors, which was stated in page 351 to amount to at least one-fifth of the total energy generated, he calculated that it should not be more than half as much. The loss of power to the extent of one-fifth, or 20 per cent., might be attributable to two causes: first to the low conductivity of the copper; and secondly to the joints, which occurred at intervals of only 14 feet. Those joints necessarily introduced a serious resistance, however tightly they might be screwed up; and he could not see the object of resorting to a number of rods so coupled, instead of using one continuous cable such as was ordinarily employed in electric lighting. The cable might be insulated or not. An ordinary insulated cable could well rest on the wooden supports which were here used for carrying the stiff copper rods.

Another point, already referred to by Mr. Paget, was the opinion expressed in page 350 that probably greater regularity in driving was secured with a simple engine than would have been obtained with a compound. For the electric light at the Lyceum Theatre in Edinburgh he had recently put up a small compound engine, indicating from 20 to 30 horse-power, and using 4 lbs. of common coal per horse-power per hour, which did not vary more than 15 revolutions in 800 of the dynamo, being less than 2 per cent. A simple engine he thought would not govern with any greater sensitiveness than that.

Mr. Alan Brebner said that, although the De Meritens alternate-current electro-magnetic machines were more expensive and less powerful than the continuous-current dynamo, his own experience was that they were found to be the safest and most reliable. As

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regarded the lamp constructed by the Anglo-American Brush Company for utilising the continuous current from one of their Victoria No. 2 dynamos, it proved after about a year's experimenting to be a complete failure. It was desired to burn the positive carbon below, in order that the light from the crater might be thrown upon the upper prisms of the optical apparatus, the most important part of which was above the horizontal axis. He had had an opportunity of testing the lamp at the South Foreland, and on the first trial a certain portion of the metal work was fused and burst into brilliant flame; on the next trial the brushes on the machine became red hot; and thus the matter ended, as time for further experimenting could not be given. As compared with a compound engine for lighthouse purposes, his own impression was that the simple engine was the best and the safest, and the most regular in its action; and the saving of fuel on such a small engine was really not worth considering, especially when put in the balance against certainty of action.

Mr. Wilson Hartnell considered that the problem of providing an electric light on a small scale, not much greater than the present oil lamps and at a moderate cost, had been solved already, and solved effectually. Turning to the cost of the light described in the paper, it would be seen that a very large sum had been spent —more than £15,000. Of this amount the engines, dynamos, and lamps he should think would form but a very small fraction. Why in putting down an electric light it should be thought necessary to have so many more persons in charge, he could not understand, except on the supposition that very little confidence was as yet felt in the electric light. For lighthouses it appeared to him that the best practice had not yet been attained in regard to electric lighting. The De Meritens machine was no doubt an excellent one, and he had nothing to say against it; it had been a good machine some years ago, but there were now many works capable of constructing dynamos which would give equal results at much less cost. Comparing the cost per candle-power as given in page 356 with that of the electric plants supplied to the admiralty, it seemed very

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(Mr. Wilson Hartnell.)

great. The engine here supplied might no doubt be a good simple engine, but compound engines could now be produced which were perfectly trustworthy and governing excellently. The whole plan described in the paper struck him as being good at the date it was planned, two years ago; but it was now distinctly behind the time, and he certainly thought that the engine and the whole of the electric-light apparatus were neither the best nor the cheapest, and by no means represented what might have been done. Naturally enough, large public bodies like the various Lighthouse Boards would not dare to take up what they considered the latest practice, without feeling that they incurred a grave responsibility; they preferred to go slowly forward, and to be, as they thought, very safe. But the trustworthiness of electric arc-lamps had now been abundantly proved; and if the authorities would have applied to any of the principal electrical engineers in this country, they might readily have obtained tenders for the whole of the electrical plant at a cost far below that given in the paper, and the engineers supplying the work would have been willing to take the whole responsibility of its success for a period of one or two years. So that the problem of smaller cost was really settled already.

Professor RYAN enquired, with regard to the choice of the dynamo in the present instance, whether the competition between the De Meritens and the Brush machine had here been on equal terms; and wherein exactly it was that the Brush Co. had failed in the endeavour mentioned on page 349 to produce a lamp giving, with a current of 100 ampères at 70 volts, a light of 30,000 candle-power. Did the alleged inability to accomplish this object, even after numerous trials, refer to the production of any kind of lamp of that efficiency, or only of a lamp which should be steady and suitable for a lighthouse? It was in regard to steadiness and reliability he imagined that the Brush lamp failed to meet the requirements of the case. It was satisfactory at any rate to know that electrical engineers had had a chance given them of superseding the old form of machine; at the same time it was rather disappointing to learn that the old form of machine had not been superseded here. The

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lamp efficiency however, required of the Brush Co., amounting to nearly 4·3 candles per watt, was much higher than that which was finally accepted. The candle-power actually given by the present lamp was stated on page 352 to vary from 12,000 to 16,000; taking the latter as the highest candle-power recorded, and dividing it by the 11·8 horse-power or 8,800 watts given in page 349, the result was only 1,356 candles per horse-power, less than 2 candles per watt; or, taking account of one-fifth loss in leads (page 351), about 2·3 candles per watt. It seemed hardly consistent that the Brush Co. should have been hampered by so much higher a standard of efficiency; and he wished to ascertain what was considered to be the precise nature of their failure.

Mr. JEREMIAH HEAD, Past-President, having occasionally been at sea, had always regarded lighthouses in relation to sea traffic in the light of signal-posts in relation to railway traffic, and he considered them as of equal importance. In clear weather he thought that the main interest of any important light was before it could be fully seen: when indeed the first glimmer began to be visible, and when every one was looking out for it. In the present paper therefore he had been particularly struck by the fact that the lenses were so arranged that they did not all send their light direct to the horizon, but some deflected it rather upwards and some rather downwards. It was evident that in clear weather those rays which were directed above and below the horizon would ultimately go respectively against the sky and against the sea, and would then be reflected again and again. To this reflection was due the glimmer seen from a long way off, before the light itself became directly visible. As to any reserve power or expense being directed to fog signals, that was evidently of the greatest possible importance. It had been recognised in ancient times when open fires were used; for there was at the same time the bell rock with its warning to mariners in case of fog. Whether all lighthouses now had sound signals he was not aware; if they had not, he thought they ought to have them. The disaster which had recently occurred to the Victoria steamer when off the French coast near Dieppe showed the importance of

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(Mr. Jeremiah Head.)
fog signals being maintained ready to be put in action the moment a fog appeared.

As to the use of compound engines, it had occurred to him, as to others, that in a place like an island with a lighthouse on it, where all the fuel had to be conveyed at a considerable expense, no arrangement could be regarded as permanent which did not include the means of utilising the fuel as economically as possible. A single condensing engine therefore, working with a comparatively low steam-pressure, could hardly be considered a permanent arrangement. In regard to regularity of motion, he could not but think that a good compound engine with high-pressure steam must be as advantageous in regularity of motion as it was in economy of fuel; this therefore seemed to him to be the form of steam-engine that must ultimately be used under such circumstances. As to greater complication and possible break-down, it had been contended, and very justly, that a properly made compound engine was not more liable to break down than any other. But even supposing it were so, it would be seen that the engines described in the paper were so arranged that a single one of the pair was competent to do the work in case of need; and a compound engine, by introducing the boiler steam direct into the low-pressure cylinder in the event of a break-down of the high-pressure one, could also be made to work, though of course with less than the full economy. There was such a thing however, he thought, as over-providing against casualties. It was stated in page 354 of the paper that there was an oil-lamp kept trimmed and ready for use, which could be lighted and put into the focus in three minutes. Would it not be better to use this oil-lamp as a final resource in case of trouble or break-down of any kind, rather than have so costly an intermediate resource as duplicate engines? And then would it not also be better to have a compound engine of the best kind and working in the best way, and to employ it for the regular work under ordinary circumstances? and if anything happened to the engine, would not the best thing be simply to substitute temporarily the oil-lamp, having it all ready and a sufficient store of oil to keep it alight until the engine could be repaired and the electric light got to work again?

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Mr. Sydney F. Walker considered that, if the conditions were made equal for oil lighting and electric lighting, there would be no difficulty in providing electric lights for lighthouses at the same cost as oil lights or even less. According to his own experience, the introduction of electricity had always been at first more expensive; but as the use of it had continued, the expense had come to be considerably less, in regard both to first cost and to working cost, than that of the apparatus which it superseded. Thus far electric lighting had always had to meet the difficulty that those who used it were never satisfied; they always wanted more. In the case of the old oil lamp, or gas, or even the Davy lamp in the pit, the users had been satisfied with anything from one-tenth of a candle up to 300 candles; but no sooner was electric lighting spoken of than they wanted almost an unlimited amount of light, and they would not go into electric lighting unless they could get it not only at the same cost as with the old apparatus, but also a great deal more powerful at the same cost. The problem to be dealt with did not depend upon the dynamo machine; as himself a dynamo manufacturer he was able to say that there was no difficulty in turning out a machine which would produce any current up to 1000 ampères under whatsoever conditions might be imposed. But the difficulty lay in constructing a lamp to utilise the current; and this was where he gathered from the paper that the Brush Company had found their difficulty, hampered especially as they were by having to put the positive carbon underneath. He questioned whether a shunt-wound dynamo was the most suitable for the work, owing to the great reduction in the electro-motive force when the external resistance was reduced, as for instance when the carbons were in contact. If more time had been allowed, he expected the problem might have been solved; indeed he understood that it had been solved already.

It was gratifying to see that the transmission of energy by electrical conductors had here been so fully recognised. Instead of the engines and boilers and dynamo being brought alongside the light, they were put at a place where it was most convenient, and the current was conveyed to the lamp by means of conductors. It

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(Mr. Sydney F. Walker.)

had been constantly objected to electric power, that it could not be transmitted economically. The present instance however was at any rate a recognition of the progress which had already been made in the transmission of power by electricity. The progress had perhaps been slow, but there had certainly been a distinct step in advance. He wished to ask why the conductors had been made of jointed copper rods. That appeared to him to be a singularly bad arrangement; because it was always found in practice that the measured resistance exceeded the calculated resistance, and a margin was always allowed in an estimate, the principal reason being that it was impossible correctly to estimate what the resistance of the joints was going to be. A joint could not be made homogeneous, like a rod or other continuous conductor, and it was therefore desirable to have as few joints as possible: instead of which there appeared in this case to be an unnecessarily large number of joints. Not only were joints a source of resistance in the first instance, but they were possible sources of failure afterwards: they got dirty and led to all sorts of trouble.

With regard to carbons, he wished to ask whether any experiments had been made in measuring the amount of light with a given current and a variable size of carbon. In his own practice he had found that, with a given current, the larger the carbon up to a certain point the greater was the amount of light.

He desired to thank the author for having offered them the opportunity of seeing the apparatus described in the paper, and for the careful account he had given of the employment of large currents in arc lamps, of which few electrical engineers had had any experience.

Mr. David A. Stevenson said that in place of two agents (page 360) a single agent might of course have been employed; but that plan would have added considerably to the expense, and he did not think the result would have been so good.

The reason why it was desired to place the positive carbon below was because with a continuous-current machine the best part of the

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light would be thrown on the upper portion of the dioptric apparatus, where it could have been utilised to greater advantage.

The De Meritens machine, he agreed with Sir James Douglass, was an excellent one. During the past six months it had not given the slightest trouble, nothing having gone wrong with it. The only reason for wishing to use the Brush machine had been that it was expected to get a much stronger light from it.

For the simple form of mercury contact used at the Isle of May he was indebted to Mr. Munro. It was not in use at the South Foreland or elsewhere.

With reference to the conductors, it was true they were not so continuous as cables would have been; but the copper rods were employed on the recommendation of Professor Grylls Adams, than whom there could not have been a better authority.

In no way had the Brush Company been restricted in regard to the lamp. They undertook to produce a lamp of the kind desired, and they did their very best; but they found it impossible to accomplish the object after a year's experiments, and gave it up.

With all deference to the opinions expressed regarding the engines employed, he still thought that the simple engines for such a place as the Isle of May were the best to put into the hands of men who were not engineers; while from the economical point of view it should be borne in mind that the engines were small, only 16 horse-power, and in such a case he thought the saving by the use of compound engines was imaginary; and he was inclined to think that the Members would be of the same opinion when they had visited the place.

He was sorry he had no information for enabling the cost per candle-power of the old coal fire (page 362) to be compared with that of the electric light. The statement made by Sir James Douglass as to the great cost of electric lights was quite consistent with the remarks in the paper; for although the cost per candle-power of the electric light was so small, yet it was impossible to have an electric light except at a much greater cost than oil.

It was also impossible to work the electric light without a larger staff than an oil light (page 365), because it was necessary to have two

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(Mr. David A. Stevenson.)
men on duty constantly, whereas an oil light required only one. As to going slowly forward, lighthouse authorities had been and still were the pioneers in all lighting matters, and specially as regarded electricity. All the principal electric-light companies had been applied to when the Isle of May installation was planned, and at first they saw no difficulty in providing what was wanted, namely a single continuous-current powerful arc-light, capable of being maintained for several hours consecutively. This however they had ultimately found it impossible to accomplish, and he could not learn that the problem had been solved yet. The Isle of May installation could therefore hardly be said to be out of date at present.

The PRESIDENT noticed it was stated in page 356 that the lightkeepers at St. Abb's Head perceived the light at the Isle of May, and *vice versâ*. He wished to ask whether there was any telegraphic communication between the two lighthouses, so that they could communicate every night what their observations were.

Mr. STEVENSON said there was not; but the observations were made simultaneously, and monthly returns of them were sent to the Northern Lighthouse office.

The PRESIDENT had much pleasure in proposing a vote of thanks to Mr. Stevenson for his interesting paper, which had led to a very valuable discussion. Those who were about to visit the Isle of May lighthouse would be very glad to have heard this paper, because they now knew something of what they were going to see.

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DESCRIPTION OF THE NEW TAY VIADUCT.

By Mr. FLETCHER F. S. KELSEY, Resident Engineer.

Site.—The new Viaduct across the Tay near Dundee, Plate 67, which has once more established direct railway communication between the counties of Fife and Forfar after an interval of nearly eight years, is situated throughout the extent of the straight portion, which forms four-fifths of its total length, at a distance of 60 feet centre to centre from the old structure, as shown in the perspective views, Plates 68 and 73. At the north end of the straight a curve of 21 chains radius gradually reduces the distance between them, until they join in a common centre line at the point where they cross the esplanade at Dundee. Unlike the old viaduct, the new one carries a double line of railway, Plate 69, and consequently gains enormously in stability from the greatly increased width of the piers.

Dimensions.—The chief dimensions of the new work are as follows, Fig. 1, Plate 67:—

South end of Wormit arching to high girders . .	3,585 feet.
High girders	3,156 „
North end of high girders to north end of viaduct .	3,786 „
Total length = 33 feet short of 2 miles =	10,527 feet.

	Ft.	Ins.
Width between parapets	25	6
Maximum width of piers at base	55	0
Minimum „ „	36	0
Maximum headway above high water . . .	77	0
Maximum height of rails above high water . .	83	0
Minimum „ „ „ „ . . .	25	0
Maximum height of piers from foundations to top .	141	6

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There are in all eighty-six spans, five of which consist of brick arches, and the remainder of girder-work. Of the brick arches, four of 50 feet span are situated at the southern end of the viaduct, and one of 25½ feet at the northern end.

Piers.—Seventy-three of these have cylinder bases, and may be divided into two groups, thus:—

Group 1, comprising 49 constructed with wrought-iron cylinder bases.
Group 2, comprising 24 " " cast-iron " "

The former are in the straight, and the latter in the curved portion of the viaduct.

Cylinders.—The portion of the pier below low water consists of two of these cylinders, Plates 69 and 70, which, in the case of the piers for the thirteen large spans in the centre of the river, are placed at a distance from each other of 32 feet, as shown in Plate 69, and in the rest of the piers 26 feet, centre to centre. Except in the case of those for piers Nos. 5–14, the cylinders are all splayed at the base, and have a base diameter varying from 10 feet up to 23 feet. The 10-ft. cylinders, which form the bases of twenty-four of the piers in the curve, are of cast-iron, all above this size being of wrought-iron, and made of such a length that when sunk to the required depths the tops might project slightly above low-water level. They are all lined with brickwork filled in with concrete.

Blue-brick Shafts and Connecting-piece.—From low-water up to high-water level the piers in group 1 consist of two circular blue-brick shafts, of 12 inches less diameter than the cylinders, Plates 69 and 70. They are filled in with concrete, and joined together at high-water level by means of a strong connecting-piece, which also consists of blue brickwork filled in with concrete, the portion between the shafts resting on cast-iron girders. In the cast-iron cylinder piers (group 2) the cylinders are continued up to the connecting-piece, and cast-iron segments of cylinders and plates take the place of the blue brickwork in the connecting-piece itself.

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Base of pier superstructure.—On the top of the brickwork, Plates 69 and 70, and forming part of the connection, a wrought-iron framework made chiefly of channel irons is placed, and securely attached to the shafts below by means of sixteen holding-down bolts of 2½ inches diameter and 20 feet length, which are embedded in the masonry. This framework forms the base for the upper portion or superstructure of pier, which is riveted to it.

Superstructure of Piers.—In the case of piers Nos. 5–64, the superstructure consists of two wrought-iron octagonal shafts, Plates 69 and 70, joined together near the top in the form of an arch; and is composed of plates connected at the angles by means of two splayed channel-irons on the outside, and an obtuse angle-iron on the inside. Outside and inside T irons cover the other vertical joints, and serve to stiffen the structure, which is further strengthened by means of bracings and horizontal diaphragms placed at intervals inside the shafts. Short cross girders near the top support the cast-iron bedplates for the main girders. The height of these pier superstructures varies from 20 to 68 feet. In piers Nos. 65–77 the superstructure and connecting-piece are combined, on account of the reduced height of the piers, and assume the form of a tapered box stiffened with channels and tees in the same way as the rest of the piers.

Cylinder sinking.—In sinking the cylinders down to their several depths below the bed of the river, pontoons specially designed for the purpose were used, Plates 71 and 72. They were constructed with two apertures in them, of sufficient size to admit of the pair of cylinders C passing through them at their proper distance from each other; and were also provided with four cylindrical legs L, capable of being lowered down to the bed of the river or lifted off it by hydraulic power. During the greater part of the time that cylinder sinking was going on, four of these pontoons were employed, the dimensions of the largest being 80 ft. × 67 ft. × 7 ft. deep. The work of cylinder-sinking was carried out as follows. A pontoon having been floated into position and its four legs lowered down to the bed of the river,

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the two cylinders C for the pier were suspended in the apertures; and after having been lined with brickwork were gradually lowered down to the bed of the river by means of hydraulic jacks. The excavation for the cylinders was then proceeded with by means of a subaqueous digger D worked by a crane on the pontoon. Owing to the nature of the strata through which the cylinders passed, it was necessary to weight them in order to force them down as the excavation proceeded; in some cases as much as 400 tons were placed upon the cylinder for this purpose. Where silty sand was met with, the use of a centrifugal pump was found to be of great assistance: the continual pumping of the water from inside the cylinder caused the sand beneath the cutting edge to be scoured towards the centre of the cylinder, where it could be more readily got at by the digger. When sunk to their required depths, the cylinders were filled with concrete; and the pontoon was then floated away to the next pier.

Depths of Foundations.—The depths of the foundations vary from 6 ft. to 38½ ft. below the river bed, as the average for the pair of cylinders. The shallowest foundations are at piers 7 and 8, where the cylinders rest on red sandstone; and the deepest at pier 20, which is founded on sandy clay. Thirty-three of the piers, including those for the thirteen large spans, rest on sand foundations, and the average depth to which these cylinders are sunk below the river bed is 26½ feet. The work of sinking the seventy-three pairs of cylinders occupied nearly three years and a half, having been commenced on 1st February 1883, and completed on 20th July 1886.

Testing of Foundations.—All the foundations of the cylinder piers have been subjected to a weight 33 per cent. heavier than that which they will be required to carry. The test load, consisting of iron blocks weighing ½ ton each, was applied at the level of the tops of the cylinders before building the blue-brick shafts upon them. The load on the pair of cylinders varied from 608 up to 2438 tons. Under the gross weight of the test load and the cylinders themselves, the minimum pressure per square foot on the foundations was

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3·80 tons, and the maximum 6·80 tons. The subsidence of the cylinders in the latter case was only 1½ inch. The labour in carrying out these testing operations was very considerable, involving as it did the shifting of about 180,000 tons of weights.

Girders.—Including the wrought-iron arches near the north end, there are eighty-one girder spans. The following are the lengths of the girders, taking them in the order in which they are placed in the viaduct from south to north, Fig. 1, Plate 67 :—

	No. of Spans.		Length of Girders.	
South end	1	of	113 ft.	
	10	„	129 „	continuous in sets of 4 and 2.
	13	„	145 „	„ „ 3.
High Girders, 13 spans.	5	„	245 „	
	1	„	227 „	
	2	„	245 „	
	1	„	227 „	
	4	„	245 „	
	1	„	162 „	
	11	„	129 „	continuous in sets of 4 and 3.
	24	„	71 „	
	1	„	56 „	
	2	„	85 „	wrought-iron arches.
	4	„	66 „	continuous over the 4 spans.
North end	1	„	108 „	high girder.

From piers 4 to 28, 41 to 78, and 80 to 84, each span consists of four lattice girders with top and bottom members parallel, the roadway being carried on the upper members. The outside girders, excepting for six of the spans, are those which carried the roadway in the old viaduct. From piers 28 to 41 and 84 to 85, where additional headway is required, two girders only are used in each span, having curved top members, and the roadway is carried on the lower members. See Figs. 2 and 3, Plate 67.

Transferring Girders from old to new viaduct.—In the four-girder spans the first operation, after completing the piers, was to transfer the girders from the old to the new viaduct. This was effected, as

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shown in Plate 73, by means of two large pontoons P, 80 ft. × 27½ ft. × 8½ ft. deep, securely attached to each other at a distance of 20 ft. apart by means of connecting girders B. Each pontoon was provided with two wrought-iron columns C, the upper parts of which were telescopic and capable of being raised or lowered about 13 ft. by means of hydraulic rams attached to the fixed portion of the columns. These two adjustable parts were connected together at the top by a cross girder G, upon which the girders of the old viaduct rested while in the act of being transferred to the new one.

The operation of transferring them was carried out in the following manner. About the time of low water the pontoons were placed immediately beneath the pair of girders to be transferred; and the telescopic portions of the columns having been adjusted to the required height, the pontoons gradually rose with the tide, and lifted the two girders, with their cross bracing and roadway above, clear of the piers. The pontoons with their load were then floated in between the new piers, upon which the girders were let down by lowering the columns. In this position, and with rails laid along the top booms, the old girders formed a roadway, as shown in Plate 74, upon which the new girders, slung between two travellers T, were run out, and were then lowered down between them on to the tops of the piers. All four girders were then opened out to their respective positions in width on the piers, and the cross bracing and decking above were proceeded with.

Floating out the High Girders.—The work of floating out the girders for the thirteen large spans near the centre of the river, and of lifting them to the tops of the piers, was still more interesting. All these girders, with their deck-plating and top cross-bracing, thus forming completed spans, were erected and riveted on a jetty J constructed for the purpose on the south side of the river, Plate 68. The jetty was of sufficient size to allow of two of these complete spans being constructed simultaneously and side by side; and was provided with two openings or docks D extending across it, at right angles to the direction in which the girders were built. Upon the completion of a span, the piers for which it was intended having also

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been finished up to the level of the top of the blue-brick connections, the same pontoons P which had been used in transferring the old girders, as just described, were again made use of, but stripped of their columns and connecting-piece, and thus made independent of each other. These pontoons having been floated into the docks at low water, and placed in position immediately beneath the girders about to be floated out, rose with the tide, and lifted the girders clear of the blocks upon which they had been built. They were then towed out on the east or lower side of the viaduct by four steam-tugs; and when opposite to and parallel with the position they were to occupy, were allowed to drift slowly up with the flowing tide until the centre line of the decking was exactly in the centre line of the viaduct. In this position the ends of the girders were made fast to the piers, and were allowed to take their bearings with the fall of the tide.

Lifting the High Girders.—The girders having been placed on the piers at this level, the next proceeding was to erect round and over their end posts the wrought-iron pier superstructures, Plates 69 and 70, in which the plates that would interfere with the lifting operations were only temporarily bolted in their places, so that they might be removed when necessary. For erecting these superstructures, a crane of sufficient height to command the whole work was fixed on the decking between the girders. As soon as the erection of the superstructures was completed, the next operation was to construct inside each of the four shafts a temporary column, composed of steel angles ($8 \times 4\frac{1}{2} \times \frac{7}{8}$ inch) braced together, the four columns being of sufficient strength to carry the whole weight of the span, about 520 tons. The raising of the girders up these columns was performed by means of four $13\frac{1}{2}$-inch hydraulic rams, attached to the columns, and placed one under each of the end posts of the girders; and as the whole span gradually rose in $7\frac{1}{2}$-inch lifts, the bolted plates in the pier superstructure immediately above the girder ends were removed, to allow of their passing up the shafts, while those below were at the same time replaced and riveted up. On arriving at their full height, the riveting of the piers having also been completed, the ends of the girders were transferred from the

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lifting columns to the piers themselves, and the lifting columns were taken down and removed. The raising of the thirteen large spans occupied nine months, or an average of three weeks per span.

Decking.—The decking or flooring is of the ridge and trough type. In the case of the high girders, where there are only two girders to the span, it is constructed with plates and channels; the troughs are 16 inches deep and 30 inches from centre to centre. In the rest of the viaduct, where the decking has the support of four girders, the depth is reduced to 8 inches, and the troughs are formed of corrugated plates, shaped in a hydraulic press and connected on the ridges by cover strips. The whole decking is of steel, and forms a continuous flooring from end to end of the viaduct, excepting at the expansion joints.

Expansion.—The allowance for expansion is divided over thirty-two different places in the whole length, the sum of the calculated allowances amounting to 3 feet 8 inches. As a matter of fact however, the spaces provided admit of a much greater variation than this. Where provision is made for expansion, the girder ends rest upon rockers.

Parapets.—The parapets or wind screens are of lattice work, made of $3 \times \frac{5}{16}$ inch bars, with standards about every 16 feet, and finished off at the top with an oak coping. The effect they have in breaking up the force of the wind and thereby protecting the roadway is very remarkable.

Permanent Way.—The permanent way is laid with cross sleepers, which are bedded in ballast in the troughs of the flooring; and is provided with special expansion joints placed over those piers where the girders rest upon rocker bearings. The gradients are as follows, Fig. 1, Plate 67:—

From south end to commencement of high girders at pier 28 .	1 in 762 falling.
From pier 28 to pier 32	Level.
From pier 32 to north end	1 in 114 falling.

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Materials.—The various materials used in the construction were subjected to frequent testing throughout the work. In the case of the wrought iron, the test was that it should withstand a tensile strain of 22 tons per square inch with an extension of 6¼ per cent. The following are the amounts of material used:—

Wrought iron in girders and piers	19,337 tons.
Steel in flooring	3,540 „
Cast iron	2,470 „
	25,347 „

Concrete (cement)	37,000 cubic yards.
Brickwork	25,700 „ „

Wind Pressure.—The calculations for wind pressure are based on a pressure of 56 lbs. per square foot; and in estimating the area exposed to the wind, the bevelled ends of the piers are considered as flat surfaces, the wind screen as a solid surface, and 50 per cent. is added to the area of the outside girders. Until this pressure is brought to bear on the structure, the holding-down bolts in the base of the pier superstructure do not come into play.

Testing of Viaduct.—The viaduct has recently been subjected to very severe tests by the Board of Trade inspectors, the result being highly satisfactory. The tests were made with sixteen heavy locomotives, the aggregate weight of which amounted to 955 tons. The maximum deflection of the high girders was 1⅝ inch, when the span was loaded with engines close together on both roads from end to end.

Time occupied in construction.—The construction of the viaduct was commenced on 22nd June 1882, and it was opened for passenger traffic on 20th June in the present year, the work having thus occupied exactly five years. The engineers for the work were Messrs. W. H. Barlow and Son, Westminster; and the contractors Messrs. Arrol and Co., Glasgow.

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Discussion.

Professor BARR asked what special reason there had been for lining the pier cylinders with brickwork before they were filled up with concrete. Also with regard to the iron superstructure of the piers, what special reason there had been for making that structure in the form of an arch. It seemed to him that the arch as such could add little to the strength of the structure; but it might have been so designed with a view to appearance.

From the statement on page 381 that until the wind pressure of 56 lbs. per square foot acted upon the bridge the holding-down bolts did not come into play, he inferred that up to that pressure the weight of the structure, the whole being considered as perfectly rigid, was calculated to be sufficient for its stability; he should be glad to know whether that view was correct. In what way the parapet lattice work protected the roadway (page 380) he did not quite understand; and he asked what kind of protection was referred to.

Mr. CHARLES COCHRANE, Vice-President, pointed out that the observation in the paper with regard to the effect of the wind screen in breaking up the wind must have reference simply to the effect on anyone walking along the bridge. In the case of the old bridge when the wind was blowing he had himself felt it dangerous to walk along it with such a feeble barrier as had then been provided, consisting only of a bare handrail carried on uprights at intervals, without any lattice bracing. But in estimating the area exposed to the wind, it was stated in the paper (page 381) that the bevelled ends of the piers were considered as flat surfaces, and the wind screen as a solid surface; thus the importance of the wind screen had been fully recognised in calculating the wind pressure on the bridge.

Mr. R. PRICE-WILLIAMS, Member of Council, noticed that the expansion here allowed for (page 380) was 3 feet 8 inches in the total length of 10,527 feet, or one inch in every 239 feet; whereas in the Forth Bridge it had been stated that the amount allowed was one

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inch in every 100 feet. It was also stated that the spaces provided in the Tay Viaduct admitted of a much greater variation than 3 feet 8 inches; and that the ends of the girders rested upon rockers. Many years ago, being desirous of ascertaining the amount of expansion in the Menai tubular bridge, he had obtained permission from Mr. Robert Stephenson to examine it, and had pointed out to him, and he had recognised the fact, that the travel of the roller carrying the free end of the tube showed an expansion of about half an inch to 100 feet. This had been already stated to be the amount calculated for in the Forth Bridge, although an allowance had there been made for a full inch per hundred feet. He should therefore be glad to know how the additional provision for expansion in the Tay Viaduct had been made, beyond the small calculated allowance of less than half an inch per hundred feet.

Mr. George B. Lloyd enquired why the old structure of Sir Thomas Bouch had not been made use of to a larger extent than seemed to have been the case. It had been stated in the paper (page 373) that the new viaduct carried a double line of railway, and consequently gained enormously in stability from the greatly increased width of the piers. It was well known that the only part of the old structure which had failed had been the high-level central portion, which in a gale of wind had been torn up by the roots and blown over; while the remaining part of the structure, about four-fifths of the whole, had stood perfectly well to the present time. An enormous addition to the cost seemed to have been incurred by removing the old structure some 60 feet up the river, athough using the old girders over again. As a matter of fact he believed the original design of Sir Thomas Bouch had been for a double line of railway, and that it had been the great cost which had enforced its reduction to a single line. In all probability therefore the original structure might have been standing to the present day, if it had been erected on the double width. If that were so, he wished to know why the present viaduct had not been made by simply doubling the width of the old piers, at any rate throughout that portion of the length which had stood perfectly

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(Mr. George B. Lloyd.)

well. A very large expenditure he should think might have been saved by simply doubling the width in that way, and bracing the old work to the new, instead of pulling down the whole of the original structure, and moving it 60 feet up the river.

Mr. KELSEY replied that the cylinders had been lined with brickwork in order that, in the event of anything happening to them, the concrete inside might still have a facing of brickwork. In addition to this, the weight of the brick lining, and the extra stiffness it gave to the cylinders, assisted the sinking operations very considerably.

With reference to the arched portions of the pier superstructure, the arch not only connected the two shafts of the pier superstructure at the top, but in the case of the four-girder spans it also supported the inside girders.

In regard to the wind pressure on the bridge, Professor Barr was right in the inference he had drawn (page 382) as to the stability of the structure independently of the holding-down bolts.

Although the total length of the viaduct was 10,527 feet, 549 feet of this consisted of brickwork, and required no allowance for expansion. The exact length therefore, for which expansion had to be allowed, was 9978 feet. The 3 feet 8 inches mentioned in the paper (page 380) was the sum of the calculated allowances for expansion when the temperature rose above 45° Fahr., the rockers upon which the expansion ends of the girders rested being set vertical at about this temperature; and as a corresponding contraction could take place when the temperature fell below 45°, the total allowance for expansion and contraction was twice 3 feet 8 inches, that is 7 feet 4 inches. From daily observations, extending over six months, it had been ascertained that the variation in the length of ironwork caused by change of temperature amounted to 1–154,800th of the length for every degree Fahr.; so that in the 9978 feet of the viaduct 0·77 inch for every degree should be the allowance for expansion and contraction, or 5 feet 1 inch for 80° variation in temperature. From this it would be seen that the calculated allowance was considerably in excess of what was actually required;

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and as stated in the paper the spaces actually provided would admit of a much greater variation than even the calculated allowance.

The question of making use of the old bridge by widening it had been very carefully considered by Mr. Barlow; but after weighing well the advantages and disadvantages of adopting that course, he had decided that it was advisable to erect an entirely new structure, which should be quite clear of the old foundations.

The PRESIDENT was sure the Members had been greatly interested in the present paper, which had given them a great deal to think over. No doubt when they saw the bridge itself on the following day, all the information that had now been given would be of great service in helping them to appreciate the engineering details of this magnificent work. He begged to propose a hearty vote of thanks to Mr. Kelsey for his paper.

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ON THE DREDGING OF THE LOWER ESTUARY OF THE CLYDE.

By Mr. CHARLES A. STEVENSON, F.R.S.E., of Edinburgh.

Clyde Estuary.—From the year 1768 to the present time the river Clyde has been converted from a fordable stream into a maritime canal, capable of taking up to Glasgow in one tide vessels of 5,000 tons burden and drawing 24 feet of water. This almost unique work has been accomplished chiefly since 1836 by dredging and widening the channel. It is however with the works and plant employed in improving the Lower Estuary of the river, namely the reach between Port Glasgow and the sea, that the present paper deals. This portion of the river was placed under the jurisdiction of the Clyde Lighthouses Trustees in 1871; and in the following year they instructed their engineers, Messrs. D. and T. Stevenson, to make a survey of the estuary, and to report what works were necessary for its improvement. Their report, recognising the importance and difficulty of the subject, as there were weighty interests involved—including the navigation of the river to Glasgow and the other important harbours to which in its course it affords access, especially those of Port Glasgow and Greenock—recommended a line of channel which would not interfere with any of these interests, and advised that the first work to be undertaken should be the removal of the foreshore of Garvel Point, with the view of easing the bends at this part of the navigation. The work was begun in 1873, and carried on with hired plant till 1880, when the Trustees resolved to push on more expeditiously, and for this purpose applied for borrowing powers to the extent of £80,000. The work authorised in 1880 was the same as that of 1872, so far as the line of channel was concerned, but with the more costly mode of improvement by dredging alone, instead of by low-water training-walls as originally recommended by

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Messrs. Stevenson, whose experience of similar works which they had carried out at other places had satisfied them that the cost both of construction and of maintenance would thereby have been diminished, owing to the increased scouring power which would have attended the use of training walls.

Scheme of Improvement.—The scheme of improvement, as shown in the plan, Fig. 1, Plate 75, was to dredge a channel 18 feet in depth at low water, from the "Tail of the Bank" at the Albert Harbour, Greenock, up to Port Glasgow, hugging the shore the whole way; and in the centre of this channel to form a cut 5 feet deeper or 23 feet in depth at low water, and 200 feet in breadth, from the Albert Harbour to the entrance to the James Watt Dock immediately above Greenock. As shown in the transverse section, Fig. 2, the 18 feet channel is 600 feet in breadth at low water, with slopes of 3 to 1, making its breadth at bottom 492 feet. In 1881 powerful plant was obtained from Messrs. Simons and Co. of Renfrew, comprising one steam screw dredger costing £19,250, and three screw hopper-barges costing in all £22,571. The employment of a fixed dredger was decided upon, in preference to hopper-dredgers which themselves convey the dredged material to the place of deposit. This decision was arrived at from the experience already gained at the site of the dredging operations, in the working both of the hopper-dredger "Greenock," and also of the fixed dredger "Greenore"; from which it was apparent that for this work it would be cheaper and more expeditious to adopt the fixed-dredger system. In certain cases however, especially where the cessation of dredging is imperative during a portion of the day—either to permit of traffic, or from the state of the tide interfering with dredging—the hopper-dredger may be cheaper, because during the idle hours of dredging she can go away and discharge her cargo.

Dredger.

Hull of Dredger.—As shown in Figs. 3 to 6, Plates 76 and 77, the dredger has a single ladder L working through a well W amidships. The length over all is 164 feet, breadth 30 feet, depth 10 feet, and draught of water 9 feet aft. She is clinker-built,

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except the well which is carvel-built; the plating varies from $\frac{3}{4}$ inch to $\frac{7}{16}$ inch, and the frames are of angle-irons $3 \times 3 \times \frac{3}{8}$ inch spaced 21 inches apart. The floor beams are $13\frac{1}{2}$ inches in depth, one to each frame; as are also the deck beams, which are of bulb iron, 6 inches wide by 7 inches deep. Elm fenders, 16 inches deep by 7 inches wide, extend round the vessel; and four keels of greenheart, 12 inches wide by 6 inches deep, run along the bottom. Two sister keelsons extend the whole length, and a main keelson runs fore and aft of the well. The vessel is divided into five water-tight compartments, with bulkheads $\frac{3}{8}$ inch thick. The bunkers hold about 30 tons of coal. The bottom of the vessel up to the upper turn of the bilge is plastered with Portland cement. The decks are of pitch pine $3\frac{1}{2}$ inches thick. The main framing G is constructed to carry the top tumbler T at a height of $24\frac{1}{2}$ feet above the deck. The framing G and sheers H are of box form, measuring 14 inches on each side, and built of $\frac{3}{8}$ inch plates and angle-irons $3 \times 3 \times \frac{3}{8}$ inch. Davits of $4\frac{1}{2}$ inches diameter are placed at both ends for shifting anchors. The accommodation consists of two cabins for the master and engineer, and fourteen berths for the crew.

Engines.—The engines E are compound surface-condensing, and work up to 350 indicated horse-power with 80 lbs. steam. The cylinders are 23 inches and 44 inches diameter with 30 inches stroke, and make 65 to 70 revolutions per minute. The condenser has brass tubes $\frac{3}{4}$ inch diameter, giving 950 square feet of surface. The valves are worked by link-motion, fitted with expansion gear on the high-pressure cylinder; there is a fly-wheel and governor. The starting gear is on the deck-level; the clutches are arranged so as to engage and disengage the engines from the propeller and dredging machinery respectively. The piston-rods, connecting-rods, and cranks are of best-selected scrap-iron, and the bolts of Lowmoor iron.

Boilers. — There are two circular multitubular boilers B with horizontal iron tubes, working at 80 lbs. steam pressure per square inch and tested to 160 lbs. Each has two furnaces, with 1500 square feet of heating surface and 60 square feet of grate area. They are connected by a cylindrical steam-chest overhead, provided with valves so that either boiler can be used. The plating in contact

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with the fire is of Lowmoor iron, and the remainder of Staffordshire; the shell and ends are double-riveted.

Machinery.—There are two donkey engines arranged to draw from the bilge, wash the decks, and drive the two crab-winches; and when doing repairs an auxiliary engine A in the engine-room is used for driving the hoisting gear and stern crane, and for turning the main gearing and buckets. A strong treble-power crab-winch R is placed at each end of the vessel, adapted for working straight on end or by side cutting at pleasure. The bow crab has three independent barrels driven either by the main engines or by the donkey, and having friction change-gear for hauling in 10, 15, or 25 feet of mooring chain per minute. The stern crab also has three separate barrels. The two crabs work either separately or conjointly.

Bucket Gearing.—For driving the buckets the first-motion wheels at the engine are grooved friction-wheels F, and the motion is conveyed to the top tumbler T by means of an upright shaft S and bevel and spur gearing. In addition to the friction gearing, there is also a friction clutch, 7 feet diameter, which can be tightened or slackened as required, and is used in ordinary working for relieving the engine and buckets in the event of the buckets coming against a heavy boulder or anything which might cause a breakdown. The spur and pinion wheels are interchangeable, so as to give two speeds of ten and fifteen buckets per minute. The upper tumbler T is five-sided, the body being of cast-steel with steel shaft, and the journals working in brass bushes with cast-iron covers. The five sides are covered with hard steel plates 2½ inches thick and solid at the angles, bolted on and secured with 2½ inch square rings shrunk on at the ends. The lower tumbler M is six-sided, having cheeks of cast-iron 3 inches thick with cast-steel bars; the shaft is of wrought-iron, with steel thimbles working in cast-iron bushes.

Buckets.—The dredger is provided with two sets of buckets, those for the hard stuff having only 7 cubic feet capacity, and those for the soft stuff 20 cubic feet; the smaller are discharged at the rate of ten per minute, and the larger at the rate of fifteen per minute. After many trials of different forms, the buckets are now made as follows. The backs are of cast-steel, the quality of which is of the very

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greatest importance; if a good quality is got, the buckets should rarely break. The mouths are of steel 13 inches wide and $1\frac{1}{4}$ inch thick at the peak. The bottoms are now being made of steel plate. The buckets are shaped somewhat conical, so as to discharge themselves more readily into the shoots, which are at a slope of 60 degrees. The pitch of the bucket-chain is 36 inches. The links are of the best malleable scrap-iron, bored out and finished at the works, only the forgings being got from the manufacturer; they are bushed with double-shear steel. The pins are of forged steel, and can be welded a number of times.

Ladder.—The ladder L is 83 feet in length, formed of two plate-girders 5 feet deep at the centre and 2 feet at the ends, very strongly braced diagonally and vertically. Its upper end is centred upon a strong forged iron shaft, which is fitted to the pedestal-frame of the upper tumbler. The lower end is suspended by chain tackle from the sheers H; the upper sheaves are carried on the sheers, and the lower are fitted to a strong crosshead connected with the ladder by side-rods 6 inches diameter. The lifting chain is $1\frac{3}{8}$ inch diameter, and winds on a grooved barrel V which is driven from the main engine through the friction change-gear, whereby the lower end of the ladder is raised at the rate of 8 feet per minute. The winding barrel is under the control of a friction brake with compound lever, for holding the ladder or lowering it as required. When the angle of the ladder is 45 degrees, the lips of the buckets are 41 feet below water-level.

Hopper Barges.

As shown in Figs. 7 to 9, Plate 78, the three barges are each $153\frac{1}{2}$ feet in length, 26 feet in breadth, and 13 feet in depth, with a draught of 11 feet aft when loaded. The hopper is 60 feet long, 20 feet wide at top, and 9 feet at bottom, having a capacity of 11,000 cubic feet, equivalent to 550 tons of dredged material. A box-girder G spans the hopper fore and aft for carrying the door chains C, which are worked by winches. There are twelve doors D, which are made of elm 7 inches thick, and are weighted to prevent them from floating up and jamming the chains. There are

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two cabins for the captain and engineer, and six berths for the crew and firemen. The engines E are inverted-cylinder compound surface-condensing, working up to 250 I.H.P.; the cylinders are 19 and 36 inches diameter, with 24 inches stroke. The condenser has 630 square feet of tube surface. The boiler B is circular multitubular with horizontal iron tubes, and, like the engines, is constructed for a working pressure of 80 lbs. per square inch. It has two furnaces, and 1000 square feet of heating surface and 40 square feet of grate area. The boilers were tested with cold water up to 160 lbs. per square inch. When loaded, the barges can steam at the rate of 9 knots per hour.

RESULTS OF WORKING.

During one year's working in soft stuff the dredger removed 408,895 cubic yards at the rate of 212 cubic yards per engine hour, and at the cost of 2·54 pence per cubic yard, including repairs &c. and interest and depreciation at 10 per cent. Conveying and depositing the stuff in Loch Long, 7 miles distant, cost 2·47 pence per cubic yard. The total cost of dredging and depositing was therefore 5·01 pence per cubic yard. During four years' working the average rate was 166 cubic yards per engine hour. In clay and sand the work for many days consecutively has been 3500 tons per day of ten hours, or at the rate of 350 tons per hour; but with careful manipulation 500 tons can be raised in 51 minutes easily, and this has once been accomplished in 45 minutes. In dredging the "hard" of Garvel Point however, which is a very stiff clay packed with boulders—presenting the most severe ordeal that a dredger could be put to—the work fell as low as 57 tons per hour, costing 18·03 pence per cubic yard, or more than three times what it cost to dredge the soft. In the present instance the dredger being specially designed for this heavy work has been performing it without any complete breakdown, although the engines have constantly to be stopped for lifting out the boulders which the buckets bring up, but which it is not safe to discharge into the barges.

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The repairs of buckets, links, pins, &c., are executed in the Trustees' workshops at Port Glasgow, which are specially fitted up for this purpose, as well as for making gas to supply the lighted buoys, fog signals, engines, &c.; all of these, as well as the channel itself seaward of the Clyde Navigation Trustees' boundary, are under the jurisdiction of the Clyde Lighthouses Trustees.

Discussion.

Mr. JAMES DEAS quite agreed with the author in his estimate of the comparative value of hopper dredgers and fixed dredgers. As the paper dealt with only the estuary of the river Clyde, and as members were invited to send in any remarks they might have for publication in the Proceedings with the discussion, he had drawn up a short history (page 402) of the improvement of the Clyde from Port Glasgow, where the author's jurisdiction ended, up to the highest tidal flow. It would no doubt be found interesting, as it gave some of the leading details of what had been done to the Clyde within the last hundred years, in deepening the channel from about 15 inches at low water at Glasgow with a depth at 12 miles below Glasgow of only 2 feet at low water, to a stream having now a depth of 18 or 20 feet at low water from Glasgow to the sea. A hundred years ago high water was only noticeable at Glasgow by its coming rippling up, but now there was 11 feet range of tide; and a great deal of the depth had been obtained, not by raising the high-water level, for it had not been much raised within the last hundred years, but by digging out the bottom; and 7 feet 10 inches of the whole range of the tide had been created in this way. The river bed was now virtually level from Port Glasgow up to Glasgow. Practically there was no scour in it, and dredging alone was had recourse to for maintaining and improving the channel which had thus been secured. Another interesting feature was that, while a hundred years ago

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high water was three hours later at Glasgow than at Port Glasgow, it was now only one hour later. Yet another matter, showing the recent great improvement of the Clyde, was the fact that, while in 1871 as many as fifty-nine groundings took place between Glasgow and the sea, of which five were in the territory dealt with by the author, the maximum draught of the vessels being 21 feet 7 inches, the groundings last year were only sixteen, of which six happened within the author's jurisdiction, the maximum draught being 24 feet 9 inches. Again, in the summer of 1858 a float put into the river at Glasgow Bridge on the beginning of the ebb took 537 hours or 43½ tides to reach Port Glasgow, a distance of 19½ miles; while in the summer of 1881 a float under exactly similar conditions reached Fort Matilda below Greenock, a distance of 23½ miles, in 86 hours and 20 minutes, or 7 tides.

Mr. Andrew Brown, of Messrs. William Simons and Co., Renfrew, said the paper showed how to cut successfully with a powerful bucket-dredger hard material which a few years ago would not have been attempted at all. Part of the dredging done between Greenock and Port Glasgow by this dredger was in very hard stiff clay containing boulder stones; consequently the steel buckets had hard work to do. Dredging in sandstone, freestone, and limestone had been very successfully performed by vessels of this kind within the last few years. There was still a great deal of this kind of work to do, and it was necessary that it should be done speedily. The dredger described in the paper was fit for any class of work.

Respecting the strain on the bucket-gearing when the bucket met with large stones or were otherwise obstructed, it was taken up by two sets of friction connections, namely the friction-clutch of 7 feet diameter on the shaft driving the upper tumbler, and the pair of grooved friction-wheels on the first-motion shafting next the engines. Either or both of these frictional connections slipped under any excessive strain on the bucket-gearing.

As to whether hopper-dredgers or stationary dredgers attended by hopper barges were the cheapest and most expeditious for doing the work, he might instance two 850-ton hopper-dredgers now

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(Mr. Andrew Brown.)
engaged in cutting a new channel in Belfast Lough. These vessels, illustrated in Plate 79, had together in one week's time, working double shifts, dredged 40,000 tons of soft soil and deposited it in the sea at ten miles distance at a cost of 2·17 pence per ton, including repairs and all working expenses; adding 10 per cent. for interest and depreciation, the total cost was 2·39 pence per ton dredged and deposited. In clay and sand these vessels under ordinary circumstances could easily dredge and deposit at seven miles distance five loads each or 4000 tons each per day of ten working hours. In dealing with hard stiff boulder clay he believed they would again have considerable advantage over the ordinary dredger with attendant barges; for while in the latter case the dredger was only raising say 57 tons per hour, or taking nine hours to fill a 500-ton barge, two hopper-dredgers would raise twice that amount. Another advantage in favour of the hopper-dredger was that it could continue work in rough weather, when the fixed dredger would have to be stopped because it would not be safe to have barges lying alongside. The original cost of the plant in each case was about the same.

Mr. W. G. STRYPE considered the improvement of the Clyde was an instance of the progress of engineering of which engineers might justly be proud. It was one of the earliest efforts of civil engineering, and had been attended with a great deal of success; the works on an extensive scale had been started about forty years ago. From the present paper it appeared that the work of dredging was here divided into two operations:—first, that of removing the silt deposited in the river from the sewers and upland waters; and second, that of extending the accommodation of the port, and thereby diminishing the accidents of vessels grounding. The operation of removing the silt might be looked upon as a work of maintenance; and the proportion of silt to the whole annual work of the dredging was an interesting point. In a paper on the river Clyde by Mr. Deas in 1873* the whole quantity of dredging in the year 1872 had been

* Proceedings Institution of Civil Engineers 1873, vol. xxxvi, page 149.

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given as 992,354 cubic yards, or about 1,240,000 tons, of which it was estimated that 299,446 cubic yards was the result of silt and deposit from the sewers. So that approximately 300,000 cubic yards per annum might be looked upon as the work of maintenance under those two heads. In the discussion upon a paper recently read by Mr. Webster on dredging operations and appliances * it had been stated by Mr. Vernon-Harcourt that the quantity of silt deposited in the river Clyde amounted to 700,000 cubic yards per annum. There was a great discrepancy between these two amounts. The accounts of the Clyde Trustees for the year 1886 showed that the removal of the annual quantity of silt was not such a serious thing. The total year's expenditure on the Clyde amounted to about £279,000, and the cost of maintenance, or that portion of the dredging which might be looked upon as pertaining to silt, amounted to only £9,346 for the year; so that after all, so far as concerned mere maintenance, the Clyde could hardly be said to be a river that depended altogether upon dredging, the cost of maintenance amounting to little more than 3 per cent. of the whole annual expenditure. Assuming the work of dredging the silt to be the easiest or least expensive operation, and taking the cost at fivepence per cubic yard as given in the paper (page 391), the quantity dredged in the year would be 448,000 cubic yards as the amount of deposit from the silt. A more recent determination of the actual quantity of this silt than that given in 1872 would be interesting.

Mr. WILSON HARTNELL mentioned that he had been concerned for many years in looking after the construction of dredgers for Mr. Burt, first in connection with the Amsterdam canal, and afterwards for most of the dredging done at St. Petersburg. In early years a large portion of Mr. Burt's time had been occupied with the details of the buckets, ladder, and tumbler. They were continually breaking and tearing away, in a manner which would not be readily conceived, unless it was borne in mind that when working at a slow speed the strain on a bucket amounted to several tons. He had accordingly been much surprised to learn that there had

* Proceedings Institution of Civil Engineers 1887, vol. lxxxix, page 34.

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(Mr. Wilson Hartnell.)
been very few breakages in the dredger, when doing the heavy work described in the paper. No doubt when the dredger was inspected it would be found that there was good reason for praising Messrs. Simons for its construction. The dredgers he had himself been concerned with were chiefly driven by belts, and the wheels also were furnished with frictional gear. The top tumbler had five sides, the angles of which were protected by bars of chilled iron carefully bedded and secured by bolts and keys, the whole forming a most expensive work. The buckets were all constructed of steel, and the bushes were made of steel chilled in cooling; they wore out in large quantities. The shape of the buckets was something like the ace of hearts in a pack of cards, having a pointed nose rounded off into the sides. The dredgers were swung in working, so that the buckets cut the material sideways, like an engineer's tool. In the bed of the St. Petersburg canal the top clay was so hard that dredgers fitted with one large scoop-bucket dropping vertically from a crane failed to pierce it. The buckets of the ladder dredgers easily dealt with this hard surface clay by undermining it. Less power was found to be required in this system of cutting sideways than was required on the Clyde or Tyne, where they cut more with the front of the bucket and traversed more ahead. Although the engines could indicate 180 HP., it was seldom that more than from 30 to 50 HP. was required for dredging only; power was also required for stirring the clay with water and bringing it to a semi-fluid state, and pumping it through floating pipes over the canal bank. This enabled the dredger to work night and day continuously during the season, without the aid of barges. He wished to ask whether the author adopted the plan of traversing sideways along the bank to be dredged; or whether, as appeared from the paper, the dredger went straight ahead, with the buckets cutting in front.

The PRESIDENT was sure the statement in the paper, that the depth of the Clyde had been increased from a few inches to more than 24 feet, must be an encouragement to Mr. Adamson, who was the pioneer of the Manchester Ship Canal, and who, whether that

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scheme proved a great success or not, deserved great credit for the pluck and perseverance with which he had stuck to it. They would all be glad to hear his views, because he must have had this question of dredging often under his consideration.

Mr. Daniel Adamson, Vice-President, had had very great pleasure in listening to the present concise description of an interesting mechanical appliance and its application on the Clyde. If Mr. Messent had been present from the Tyne, and Mr. Fowler from the Tees, all the most important dredging operations in this country, whether as regarded the cost of dredging or the size and character of the dredgers employed, would have been here represented. The one thing more interesting than others to himself was that dredging was the cheapest mode of excavation hitherto known to mankind. Whether it was in soft stuff like silt and sand, or whether it was in clay with large boulders, the work of excavating was done more cheaply by dredging than it could be done even in railway cuttings. In some cases there was clear evidence that Mr. Messent's dredger had dredged the solid sandstone rock of the coal measures cheaper than it could be done on railways. It was a most encouraging feature that the work could be done so cheaply; and it was especially satisfactory to Scotland that so much had been done towards increasing the value of the Clyde. It had often been stated before the parliamentary committee on the Manchester Ship Canal that the Clyde had made Glasgow, and that Glasgow had made the Clyde. It was this fact which had strengthened him to carry on the effort in behalf of a large water-way to Manchester, believing as he did that the dredger would do the work better than it could be done by any other method of excavation. As stated in the paper (page 391), the stuff was dredged at the cost of only 2·54 pence per cubic yard, and carried seven miles at 0·35 penny per mile. If done on a railway a fair price would be one shilling per cubic yard for excavating and one penny per mile for haulage.

In old times even the calicoes of Manchester had been carried into the city on men's backs. Then came the pack-horse, followed by the cart and wagon; and these again had been superseded by

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(Mr. Daniel Adamson.)
railways, reducing the cost of carriage from sixpence per ton per mile by horse and cart to one penny by the railway. But there was clear evidence, he believed, to show that at the present time steamships were carrying traffic across the Atlantic at a maximum rate of one penny per ton for ten miles, and sometimes for fifty miles, and exceptionally for a hundred miles. The advantage therefore to the community was enormous if they could get the benefit of deep-water carrying power. For enabling this country to hold its own in the competition with the rest of the world, he was persuaded that its merchandise and raw materials must be brought right into the centres of manufacturing industry for distribution, and its manufactured products must be carried thence, both at the least possible cost. Great thanks were due to those who had constructed dredgers to work so economically as to render the waterways and river courses more advantageous than they could have been before. At the same time he was sure all the credit had not been given that was due to the construction of training walls. Although the Clyde was not a river carrying a great deal of silt, yet it silted sufficiently to require continual dredging; but if training walls had not been constructed to direct the current, there would have been a great deal more deposit left in the bottom of the river, and a great deal more dredging to do than at present. It was due to the training walls that a high velocity of current was obtained for carrying off the silt at low water into the deep water. There must be more silt coming down the river than into the estuary; and if there was only a small quantity to be dredged out, it showed that the construction of the training walls had been most satisfactory and practical. An enormous increase of value had been given to the shipping interest of Glasgow by means of the present excellent waterway. It was surprising indeed to hear from Mr. Deas that, whereas formerly there was only 15 inches depth of water, now ships drawing 24 feet hardly ever got aground. Steam-ship construction on the Clyde had been promoted by the deepening and widening of the river. At the same time no doubt the fact that foreign tariffs had precluded the importation of the best British iron and steel into other countries had led those other nations to come to

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this country, in order to buy untaxed steam-ships of English manufacture, and to steam round the world under the British flag at the least possible cost. It was therefore the perversity of other nations, as well as the deepening of the river, that had given Glasgow such a pre-eminent position in the construction of steam-ships for ocean traffic.

When he had called the first meeting at his own house on 27th September 1882 for carrying out the Manchester Ship Canal, he had taken care to have longitudinal sections of the Suez Canal, the most important work that had been constructed for a deep waterway; and also of the Clyde, thanks to Mr. Deas, who had always been liberal enough to give anything that was required in the way of skilled evidence, putting before the parliamentary committees facts that could not be controverted, and thus helping materially to get the bill through parliament. He had also had the benefit of sections of the Tees, and the support of those who were connected with that river. Lancashire he was sure ought to be thankful to the engineers of these great works, to whose efforts it was largely owing that the act had ultimately been obtained. At some future period, when the Institution of Mechanical Engineers met in Manchester or Lancashire, he trusted they would have the satisfaction of sailing up the improved water-way, for which the necessary capital had now been subscribed. The Bridgewater Canal, the most important of the small inland navigations in the country, was being taken over by the Ship Canal at a cost of £1,710,000. There was therefore no longer any obstacle to prevent the work from being ultimately carried out; and if fortunately spared till its completion, he trusted to be present at the opening, together with Mr. Deas and other engineers connected with the principal rivers of the country, who would certainly rejoice over the accomplishment of a work towards which they had so largely contributed. The paper which had now been read would put into the hands of engineers yet further means of judging as to the best and cheapest appliances for dredging.

Mr. T. Hurry Riches, Member of Council, mentioned that in Cardiff also a considerable amount of work had been done in

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(Mr. T. Hurry Riches.)
dredging. Within his own recollection 21 feet of water at the pier head had been looked upon as a good tide; but there was now not less than 35 to 38 feet, the difference being entirely due to dredging. During the last twenty or twenty-five years nearly as much material he believed had been removed at Cardiff as from the Clyde. The question of the cost of removing material by dredgers was one on which there had always been more or less difference of opinion. The quantity of the material dredged was usually measured by the capacity of the boats which carried it away; and he should like to know whether that was the method adopted by the author, and if so what allowance had been made for the quantity of water contained by those barges. In his own experience, which extended over twenty years, he had found that so low a cost as only fivepence per cubic yard was very rarely reached. The quantity of water to be allowed for in the barges amounted to almost 33 per cent.; and this item he considered should be deducted in working out the cost of dredging. Although in Cardiff the same description of dredger was used, obtained in fact from the same makers, the work had not been done at so low a price as that named; and from the information which he had gathered from various sources he believed it was not done in any other part of the kingdom at that price.

Mr. CHARLES A. STEVENSON was sure the account given by Mr. Deas of the work done in the higher part of the Clyde would prove most interesting, as furnishing a complete statement of the operations of deepening the river.

With reference to silt, there was none to speak of in the lower estuary of the river; the silt was confined to the higher part, with which Mr. Deas had to deal.

In regard to the cost of dredging, the results given in the paper were made up exclusive of water; experiments had been carefully made for ascertaining the exact quantity of solid matter in the barges. The same results had been obtained practically by Messrs. Stevenson in dredging the channel in Loch Foyle to Londonderry. The system of cross dredging was adopted.

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The PRESIDENT said the Members had listened to a most interesting paper; and if the fact were realised that material could be dredged for 2½*d.* per cubic yard, no doubt such work would be carried out much more cheaply than hitherto. He begged to propose a hearty vote of thanks to Mr. Stevenson for the trouble he had taken in preparing this paper. He would also invite the Members to thank Mr. Deas for the supplementary statement (page 402) which he had so kindly contributed for publication in the Institution Proceedings.

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ON THE IMPROVEMENT OF THE CLYDE ABOVE PORT GLASGOW.

By Mr. JAMES DEAS, Engineer of the Clyde Navigation.

In response to the kind invitation of the Council of the Institution, the author has much pleasure in presenting a few facts bearing upon the improvement of the Clyde from Port Glasgow up to Glasgow, which with Mr. Charles A. Stevenson's paper on the dredging of the lower estuary of the Clyde will form a general account of the improvements that have been effected in the channel from deep water up to the highest navigable part.

In 1769 James Watt found the depth of water in Glasgow harbour to be 14 inches at low water; and on Dumbuck Ford, 12 miles below Glasgow, to be 2 feet. In 1806 Thomas Telford, in a report on the further improvement of the river, notes that on 14th February of that year the "Harmony" of Liverpool, drawing 8½ feet of water, came up with the ordinary spring tide. In 1812 the "Comet," drawing 4 feet, required to leave both Glasgow and Greenock at or near high water, in order to prevent grounding in the river. In 1821 vessels drawing 13½ feet could come up. In recent years there have been built on the banks of the river many celebrated large steamers, including the "Alaska," the "Servia," the "Austral," the "Aurania," the "Oregon," the "Umbria," the "Etruria," and the "Ormuz"; while the "City of Rome," the largest steamer afloat except the "Great Eastern," has been in Glasgow for graving dock accommodation. But for the public spirit of the magistrates of Glasgow in 1770, and of their successors in office, the Clyde Trustees, shipbuilding on the Clyde above Dumbarton would still have been limited to fishing wherries, and Glasgow would still have been a fourth or fifth-rate provincial town. Glasgow and the Clyde of

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to-day mutually testify to the truth of the apt and familiar saying that "Glasgow has made the Clyde, and the Clyde has made Glasgow."

The minimum depth in the centre of the channel between Port Glasgow and Glasgow is now from 17 to 18 feet at low water, while in many places the depth is 20 feet. The bed of the river from Port Glasgow to Glasgow is now virtually level throughout. In 1755 the range of tide at Glasgow was only 2 feet 5 inches; now there is a tidal range of 11 feet. High-water level has risen in Glasgow 9 inches since 1853; and low-water level has fallen 23 inches since 1853 and 7 feet 10 inches since 1755. In 1800 the time of high water was three hours behind Port Glasgow; now it is only one hour. In the summer of 1858 a float put into the river at Glasgow at the beginning of the ebb took 537 hours or 43½ tides to reach Port Glasgow, a distance of 19·4 miles; while in the summer of 1881 a float under exactly similar conditions reached Fort Matilda below Greenock, a distance of 23·5 miles, in 86 hours and 20 minutes, or 7 tides. As showing in another way the progress of the deepening of the river, in 1871 the number of groundings of vessels between Glasgow and deep water was fifty-nine, of which five were below the Clyde Trustees' jurisdiction, and the greatest draught was 21 feet 7 inches; while in 1886 the groundings were only sixteen, of which six were below the Clyde Trustees' jurisdiction, and the greatest draught was 24 feet 9 inches.

Dredging.—While much was done by jetties or groins and training walls in the early amelioration of the river, its improvement above Port Glasgow has been almost entirely effected by dredging; and Golborne of Chester, the first engineer who did anything effective in the improvement of the river, refers so early as 1781 to the machines which he used having cut through a stratum of clay into the sand. Up to 1824 the dredging of the river was accomplished first by large rakes worked by hand capstans; and subsequently by dredgers with small buckets on a ladder, worked by hand and afterwards by horses. In 1824 the first steam dredger was started, which dredged to only 10½ feet depth; now several of the

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dredgers employed can work in 30 to 35 feet of water. The dredging plant now consists of five steam dredgers, one steam digger, eighteen steam screw hopper-barges, two diving bells, one of which is worked entirely by steam, and one tug steamer. Their cost and repair up to 30th June 1886 amounted to upwards of £700,000; while on Dalmuir workshops, where these repairs are executed, £27,000 has been expended.

In 1792 the quayage of Glasgow harbour was only 382 yards in length, and the water area 4 acres. In 1840 the quayage was 1,973 yards in length, and the water area 23 acres. In 1869, when the writer became the engineer of Glasgow harbour and the Clyde navigation, the quayage was a few yards less than 3 miles, and the water area 75 acres. To-day the quayage is fully 6 miles in length, and the water area 154 acres; while within the last eighteen years from 3 to 4 feet have been added to the available depth of the navigation the whole way down from Glasgow to Port Glasgow, a distance of eighteen miles, and the channel has been widened in some places to nearly double it previous width.

The total quantity dredged from the harbour and river during the last forty-three years amounts to 32,261,000 cubic yards, the quantity dredged last year being 1,319,000 cubic yards. The details of dredging for the latest year to which they have been made up—the financial year 1882–83—show that the cost of dredging, including 10 per cent. for interest and depreciation, ranged from 3·684 pence to 21·883 pence per cubic yard. The material lifted varied from hard silt, sand, and sewage, to blasted trap rock; while the cost of depositing in Loch Long by steam hopper-barges, including 10 per cent. for interest and depreciation, amounted to 5·421 pence per cubic yard.

Removal of Elderslie Rock.—In addition to the construction of Queen's Dock, which has upwards of 3,300 lineal yards of quayage (included in the total of six miles of quayage already mentioned) and 33 acres of water space—and of two graving docks, each capable of taking in the "City of Rome"—the most important work executed within the last eighteen years has been the removal of Elderslie

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Rock, which had previously obstructed the passage of the increasingly large vessels using the waterway. At this place, where eighteen years ago one half of the channel was only 14 feet deep at low water and the other only 8 feet, there is now 20 feet depth at low water, or 31 feet at high water. Elderslie Rock is situated a short distance above Renfrew, and about four miles west of the Broomielaw, opposite to what was once known as the King's Inch. In the early reports on the condition of the Clyde no mention is made of this rock; but the "Blawarthill sand," one of the many shallow fords in the river, was situated where the rock was subsequently found; and in 1755 there was a depth on this sand of 18 inches at low water and 4 feet 9 inches at high water. It was not till 1854 that the existence of the rock was discovered by the grounding on it of the "Glasgow," one of the first steamers trading between Glasgow and New York, which, while passing up the river, knocked a hole in her bottom on the rock. It was at first thought it might be a large boulder that had done the damage; but borings showed that it was rock, and that it extended over an area of the bed of the river 925 feet in length by about 320 feet in breadth, and that it was a hard whinstone or trap dyke. From the time of its discovery till the beginning of 1869, boring from a movable stage and by diving bell, and blasting with gunpowder, had given a depth of 14 feet for half the width of channel at an expenditure of upwards of £16,000; but it was not till 1880 that the removal of the rock, so as to give a uniform depth of 20 feet over every portion of the channel, was commenced by Colonel Beaumont with his diamond drills. In addition to the novelty of using diamond drills, there was the further novelty that the holes were bored, charged, and exploded, from a floating barge without the aid of divers: a mode of blasting subaqueous rock which had never before been adopted.

The boring was done in longitudinal belts of five rows of holes; the rows were 2½ feet apart, and the holes were spaced 5 feet longitudinally and were opposite one another in the alternate rows. After the holes had been charged and fired, the dredger followed immediately behind the boring barge, cleared up the broken rock, and left an open face for the next belt of holes. The deeper portions

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of the rock were taken in two depths or breaks; the first depth was bored to 17 feet at low water, and blasted and dredged; and then the second boring was carried down to 22 feet. Where the depth of hole was more than 10 feet, it was early found that the rock was not sufficiently disintegrated to allow the dredger to clear it freely away to the bottom of the bore. The longitudinal belts of holes were continued from the south side outwards into the middle of the river, until the whole ground in the southern half was cleared away to 20 feet at low water. The traffic was then diverted from the north into the new south channel, which was marked by three of Pintsch's compressed-gas buoys, capable of burning for three months continuously. The operations were then continued northwards until the whole width of the river bed was cleared to 20 feet depth.

The explosives used were dynamite, blasting gelatine, tonite, and potentite. Dynamite was found most satisfactory. Blasting gelatine proved the most powerful explosive, but when frozen was more dangerous to handle, and more difficult to explode thoroughly. Tonite and potentite were found to be less powerful than dynamite, and failed to explode unless kept quite dry.

The boring barge was fitted up with machinery for manipulating eight drills at one time. Two horizontal engines, supplied with steam from two boilers, drove the main shafting, which ran the whole length of the barge.

The diamond boring tool was a hollow steel tube or annular ring, 2¼ inches diameter and ½ inch thick, studded with diamonds overlapping one another. This annular ring or crown was screwed on the bottom of the boring rod, which in suitable lengths was carried inside an iron guide-tube extending down to the bottom of the river bed; the rod was connected at top to a drill bar suspended from the diagonal framework on the barge. Rotary motion was given to the drills by means of phosphor-bronze bevel-wheels, working in a frame, and driven from the main shaft on deck by an ingenious arrangement of ropes and loose pulleys, which allowed for any lateral or vertical movement of the drill owing to rough weather, to the rise and fall of the water, or to the ranging of the barge through the suction of passing steamers. The drill bar was driven

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at the rate of 400 revolutions per minute; and during the whole time that the boring was proceeding water at a pressure of 40 lbs. per square inch was forced down through the hollow boring rod to wash out the detritus, and keep the face of the diamond crown cool. The pressure on the drill varied according to the rock being bored, and was put on by means of counterbalance weights. In the hard blue whinstone the boring of the holes of $2\frac{1}{4}$ inches diameter proceeded at the rate of 2 feet per hour, and 5 feet per hour in softer stone. When the necessary depth of hole was bored, which was ascertained by sounding the hole and comparing the depth with that on a tide gauge adjoining the works, the drill bars were detached and slung aside, the rods were withdrawn, and the dynamite charges were lowered through the guide tubes into the bottom of the holes. The dynamite charges were fitted with detonators and primers, and attached to each charge were electric cables which were led up to the surface of the water. All the charges were then connected, and the shot-hole wires at either end were attached to a main cable, which was carried to the positive and negative poles of a Siemens high-tension electric exploder. The barge was then withdrawn about 60 feet from the place of the explosion, and the five rows of eight holes each were fired simultaneously, resulting in the displacement of something like 100 tons of rock; the only disturbance was a slight upheaval of water. An ordinary central-well single-ladder dredger, capable of dredging in 31 feet of water, followed close behind the boring barge, and raised from the river bed the broken rock. The greatest amount lifted in one day was 280 tons. The diving bell afterwards went over the ground, and removed any large stones that had been left by the dredger.

More readily to convey an idea of the amount of labour involved in the removal of the rock, it may be stated that something like 16,000 holes were bored, equal to about 90,000 lineal feet. About 110,000 tons of whinstone and boulder clay were dredged. About 76,000 lbs. of dynamite and other explosives were used, without loss of life or damage to limb; and were exploded by means of about 35 miles of electric cable and shot-hole wire. The cost from first to last was £70,000. The whole operations were carried on without

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interfering in any way with the traffic of the river, the width at that part being only 410 feet between bank and bank; during the time the work was being carried on the traffic went on at all hours of the day and night, and in all weathers, fair and foul. The total traffic during the time the work was going on amounted to 180,000 vessels, representing a tonnage of 33,000,000 tons. The vessels which passed through the narrow channel included the largest steamers afloat, such as the "City of Rome," "Umbria," "Etruria," the Russian ironclad "Peter the Great," and others.

In conclusion, as showing the financial results of the improvements of the river, the gross revenue has risen from £1980 in 1786 to £287,933 in 1887. The total amount paid as interest on money borrowed up to 1887 was £3,418,670, the amount paid for the year 1887 being £171,132; while the total debt on 30th June 1887 was £4,506,556.

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ON SHIP WAVES.

By Sir WILLIAM THOMSON, Kt., F.R.SS. L. and E., LL.D.,
President R.S.E.

Lecture delivered at the Conversazione in the Science and Art Museum, Edinburgh, on Wednesday evening, 3rd August 1887.

"Waves" is a very comprehensive word. It comprehends waves of water, waves of light, waves of sound, and waves of solid matter such as are experienced in earthquakes. It also comprehends much more than these. "Waves" may be defined generally as a progression through matter of a state of motion. The distinction between the progress of matter from one place to another, and the progress of a wave from one place to another through matter, is well illustrated by the very largest examples of waves that we have —largest in one dimension, smallest in another—waves of light, waves which extend from the remotest star, at least a million times as far from us as the sun is. Think of ninty-three million million miles, and think of waves of light coming from stars known to be at as great a distance as that! So much for the distance of propagation or progression of waves of light. But there are two other magnitudes concerned in waves: there is the wave-length, and there is the amount of displacement of a moving particle in the wave. Waves of light consist of vibrations to and fro, perpendicular to the line of progression of the wave. The length of the wave—I shall explain the meaning of "wave-length" presently: it speaks for itself in fact if we look at waves of water, as shown in Fig. 2, Plate 80—the length from crest to crest in waves of light is from one thirty-thousandth to one fifty-thousandth or one sixty-thousandth of an inch; and these waves of light travel through all known space. Waves of sound differ from waves of light in the vibration of the moving particles being along the line

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of propagation of the wave, instead of perpendicular to it. Waves of water agree more nearly with waves of light than do waves of sound; but waves of water have this great distinction from waves of light and waves of sound, that they are manifested at the surface or termination of the medium or substance whose motion constitutes the wave. It is with waves of water that we are concerned to-night; and of all the beautiful forms of water waves that of Ship Waves is perhaps the most beautiful, if we can compare the beauty of such beautiful things. The subject of ship waves is certainly one of the most interesting in mathematical science. It possesses a special and intense interest, partly from the difficulty of the problem, and partly from the peculiar complexity of the circumstances concerned in the configuration of the waves.

Canal Waves.—I shall not at first speak of that beautiful configuration or wave-pattern, which I am going to describe a little later, seen in the wake of a ship travelling through the open water at sea; but I shall, as included in my special subject of ship waves, refer in the first place to waves in a canal, and to Scott Russell's splendid researches on that subject, made about the year 1834—fifty-three years ago—and communicated by him to the Royal Society of Edinburgh. The diagrams copied from his paper in the Transactions of that Society will serve for a preliminary explanation or illustration of the meaning of the term "wave." I gave a very general and abstract definition; let us now have it in the concrete: a wave of water produced by a boat dragged along a canal. In Plate 80 is reproduced one of Scott Russell's pictures illustrating some of his celebrated experiments. In Fig. 2 is shown a boat in the position that he called behind the wave; and in the rear of the boat is seen a procession of waves. It is this procession of waves that we have to deal with in the first place. We must learn to understand the procession of waves in the rear of the canal boat, before we can follow, or take up the elements of, the more complicated pattern which is seen in the wake of a ship travelling through open water at sea. Scott Russell made a fine discovery in the course of those experiments. He found that it

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is only when the speed of the boat is less than a certain limit that it leaves that procession of waves in its rear. Now the question that I am going to ask is, how is that procession kept in motion? Does it take power to drag the boat along, and to produce or to maintain that procession of waves? We all know it does take power to drag a boat through a canal; but we do not always think on what part of the phenomena, manifested by the progress of the boat through the canal, the power to drag the boat depends.

I shall ask you for a time to think of water not as it is, but as we can conceive a substance to be—that is, absolutely fluid. In reality water is not perfectly fluid, because it resists change of shape; and non-resistance to change of shape is the definition of a perfect fluid. Is water then a fluid at all? It is a fluid because it permits change of shape; it is a fluid in the same sense that thick oil or treacle is a fluid. Is it only in the same sense? I say yes. Water is no more fluid in the abstract than is treacle or thick oil. Water, oil, and treacle, all resist change of shape. When we attempt to make the change very rapidly, there is a great resistance; but if we make the change very slowly, there is a small resistance. The resistance of these fluids to change of shape is proportionate to the speed of the change: the quicker you change the shape, the greater is the force that is required to make the change. Only give it time, and treacle or oil will settle to its level in a glass or basin, just as water does. No deviation from perfect fluidity, if the question of time does not enter, has ever been discovered in any of these fluids. In the case of all ordinary liquids, anything that looks like liquid and is transparent or clear — or, even if it is not transparent, anything that is commonly called a fluid or liquid—is perfectly liquid in the sense of exerting no permanent resistance to change of shape. The difference between water and a viscous substance, like treacle or oil, is defined merely by taking into account time. Now for some motions of water (as capillary waves), resistance to change of shape, or as we call it viscosity, has a paramount effect; for other cases viscosity has no sensible effect. I may tell you this—I cannot now prove it, for my function this

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evening is only to explain and bring before you generally some results of mathematical calculation and experimental observation on these subjects—I may tell you that great waves at sea will travel for hours or even for days, showing scarcely any loss of sensible motion—or of energy, if you will allow me so to call it—through viscosity. On the other hand, look at the ripples in a little pond, or in a little pool of fresh rain water lying in the street, which are excited by a puff of wind; the puff of wind is no sooner gone than the ripples begin to subside, and before you can count five or six the water is again perfectly still. The forces concerned in short waves such as ripples, and the forces concerned in long waves such as great ocean waves, are so related to time and to speed that, whereas in the case of short waves the viscosity which exists in water comes to be very potent, in the case of long waves it has but little effect.

Allow me then for a short time to treat water as if it were absolutely free from viscosity—as if it were a perfect fluid; and I shall afterwards endeavour to point out where viscosity comes into play, and causes the results of observation to differ more or less—very greatly in some cases, and very slightly in others—from what we should calculate on the supposition of water being a perfect fluid. If water were a perfect fluid, the velocity of progression of a wave in a canal would be smaller the shorter the wave. That of a "long wave"—whose length from crest to crest is many times the depth of the canal—is equal to the velocity which a body acquires in falling from a height equal to half the depth of the canal. For brevity we might call this height the "speed height"—the height from which a body must fall to acquire a certain speed. Examples: a body falls from a height of 16 feet, and it acquires a velocity of eight times the square root of the height, or 32 feet per second; a body falls from a height of 4 feet, the velocity is therefore only 16 feet per second; and so on. Thus in a canal 8 feet deep the natural velocity of the "long wave" is 16 feet per second, or about 11 miles per hour. If water were a perfect fluid, this would be the state of the case: a boat dragged along a canal at any velocity less than the natural

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speed of the long wave in the canal would leave a train of waves behind it of so much shorter length that their velocity of propagation would be equal to the velocity of the boat; and it is mathematically proved that the boat would take such a position as is shown in Fig. 2, Plate 80, namely just on the rear slope of the wave. It was not by mathematicians that this was found out; but it was Scott Russell's accurate observation and well devised experiments that first gave us these beautiful conclusions.

To go back: a wave is the progression through matter of a state of motion. The motion cannot take place without the displacement of particles. Vary the definition by saying that a wave is the progression of displacement. Look at a field of corn on a windy day. You see that there is something travelling over it. That something is *not* the ears of corn carried from one side of the field to the other, but *is* the change of colour due to your seeing the sides or lower ends of the ears of corn instead of the tops. A laying down of the stalk is the thing that travels in the wave passing over the corn field. The thing that travels in the wave in Fig. 2, Plate 80, is an elevation of the water at the crest and a depression in the hollow. You might make a wave thus. Place over the surface of the water in a canal a wave-form, made from a piece of paste-board or of plastic material such as gutta-percha that you can mould to any given shape; and take care that the water fills up the wave-form everywhere, leaving no bubbles of air in the upper bends. Now you have a constant displacement of the water from its level. Now take your gutta-percha form, and cause it to move along — drag it along the surface of the canal—and you will thereby produce a wave. That is one of the best and most convenient of mathematical ways of viewing a wave. Imagine a wave generated in that way; calculate what kind of motion can be so generated, and you have not merely the surface motion produced by the force that you applied, but you have the water-motion in the interior. You have the whole essence of the thing discovered, if you can mathematically calculate from a given motion at the surface what is the motion that necessarily follows throughout the interior; and that can be done,

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and is a part of the elements of the mathematical results which I have to bring before you.

Now to find mathematically the velocity of progression of a free wave, proceed thus. Take your gutta-percha form and hold it stationary on the surface of the water; the water-pressure is less at the crest and greater at the hollow; by the law of hydrostatics, the deeper down you go, the greater is the pressure. Move your form along very rapidly, and a certain result, a centrifugal force, due to the inertia of the flowing water, will now cause the pressure to be greatest at the crest and least at the lowest point of the hollow, Fig. 2, Plate 80. Move it along at exactly the proper speed, and you will cause the pressure to be equal all over the surface of the gutta-percha form. Now have done with it. We only had it in imagination. Having imagined it and got what we wanted out of it, discard it when moving at exactly this proper speed, and then you have a free wave. That is a slight sketch of the mode by which we investigate mathematically the velocity of the free wave. It was by observation that Scott Russell found it out; and then there was a mathematical verification, not of the perfect theoretic kind, but of a kind which showed a wonderful grasp of mind and power of reasoning upon the phenomena that he had observed.

But still the question occurs to everybody who thinks of these things in an engineering way, how does that procession require work to be done to keep it up? or does it require work to be done? May it not be that the work required to drag the boat along the canal has nothing to do with the waves after all? that the formation of the procession of waves once effected leaves nothing more to be desired in the way of work? that the procession once formed will go on of itself, requiring no work to sustain it? Here is the explanation. The procession has an end. The canal may be infinitely long, the time the boat may be going may be as long as you please; but let us think of a beginning—the boat started, the procession begun to form. The next time you make a passage in a steamer, especially in smooth water, look behind the steamer, and you will see a wave or two as the steamer gets into motion. As it goes faster and faster, you will see a wave-pattern spread out; and if you were on shore,

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or in a boat in the wake of the steamer, you would see that the rear end of the procession of waves follows the steamer at an increasing distance behind. It is an exceedingly complicated phenomenon, and it would take a great deal of study to make out the law of it merely from observation. In a canal the thing is more simple. Scott Russell however did not include this in his work. This was left to Stokes, to Osborne Reynolds, and to Lord Rayleigh. The velocity of progress of a wave is one thing; the velocity of the front of a procession of waves, and of the rear of a procession of waves, is another thing. Stokes made a grand new opening, showing us a vista previously unthought of in dynamical science. As was his manner, he did it merely in an examination question set for the candidates for the Smith prize in the University of Cambridge. I do not remember the year, and I do not know whether any particular candidate answered the question; but this I know, that about two years after the question was put Osborne Reynolds answered it with very good effect indeed. In a contribution to the Plymouth Meeting of the British Association in 1877 (see "Nature" 23 Aug. 1877, pages 343–4), in which he worked out one great branch at all events of the theory thus pointed out by Stokes, Reynolds gave this doctrine of energy that I am going to try to explain; and a few years later Lord Rayleigh took it up and generalised it in the most admirable manner, laying the foundation not only of one part, but of the whole, of the theory of the velocity of groups of waves.

The theory of the velocity of groups of waves, on which is founded the explanation of the wave-making resistance to ships whether in a canal or at sea, I think I have explained in such a way that I hope every one will understand the doctrine in respect to waves in a canal; it is more complex in respect to waves at sea. I shall try to give you something on that part of the subject; but as to the dynamical theory, you will see it clearly in regard to waves in a canal. If this drawing, Fig. 2, Plate 80, were continued backwards far enough, it would show an end to the procession of waves in the rear of the boat; and the distance of that end would depend on the time the boat had been travelling. You will

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remember that we have hitherto been supposing water to be free from viscosity; but in reality water has enough of viscosity to cause the cessation of the wave procession at a distance corresponding to 50 or 60 or 100 or 1000 wave-lengths in the rear of the ship. In a canal especially viscosity is very effective, because the water has to flow more or less across the bottom and up and down by the banks; so that we have not there nearly the same freedom that we have at sea from the effects of viscosity in respect to waves. The rear of the procession travels forward at half the speed of the ship, if the water be very deep. What do I mean by very deep? I mean a depth equal to at least one wave-length; but it will be nearly the same if the depth be three-quarters of a wave-length. For my present purpose, in which I am not giving results with minute accuracy, we will call very deep any depth more than three-quarters of the wave-length. For instance, if the depth of the water in the canal is anything more than three-quarters of the length from crest to crest of the wave, the rate of progression of the rear of the procession will be half the speed of the boat. Here then is the state of the case. The boat is followed by an ever-lengthening procession of waves; and the work required to drag the boat along in the canal—supposing that the water is free from viscosity—is just equal to the work required to generate the procession of waves lengthening backwards behind the boat at half the speed of the boat. The rear of the procession travels forwards at half the speed of the boat; the procession lengthens backwards relatively to the boat at half the speed of the boat. There is the whole thing; and if you only know how to calculate the energy of a procession of waves, assuming the water free from viscosity, you can calculate the work which must be done to keep a canal boat in motion.

But now note this wonderful result: if the motion of the canal boat be *more rapid* than the most rapid possible wave in the canal (that is, the long wave), it cannot leave behind it a procession of waves—it cannot make waves, properly so called, at all; it can only make a hump or a hillock travelling with the boat, as shown in Fig. 3, Plate 80. What would you say of the work required to

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move the boat in that case? You may answer that question at once: it would require no work; start it, and it will go on for ever. Everyone understands that a curling stone projected along the ice would go on for ever, were it not for the friction of the ice; and therefore it must not seem so wonderful that a boat started moving through water would also go on for ever, if the water were perfectly fluid: it *would not*, if it is forming an ever-lengthening procession of waves behind it; it *would* go on for ever, if it is *not* forming a procession of waves behind it. The answer then simply is, give the boat a velocity greater than the velocity of propagation of the most rapid wave (the long wave) that the canal can have; and in these circumstances, ideal so far as nullity of viscosity is concerned, it will travel along and continue moving without any work being done upon it. I have said that the velocity of the long wave in a canal is equal to the velocity which a body acquires in falling from a height equal to half the depth of the canal. The term "long wave" I may now further explain as meaning a wave whose length is many times the depth of the water in the canal—50 times the depth will fulfil this condition—the length being always reckoned from crest to crest. Now if the wave-length from crest to crest be 50 or more times the depth of the canal, then the velocity of the wave is that acquired by a body falling through a height equal to half the depth of the canal; if the wave-length be less than that, the velocity can be expressed only by a complex mathematical formula. The results have been calculated; but I need not put them before you, because we are not going to occupy ourselves with them.

The conclusion then at which we have arrived is this: supposing at first the velocity of the boat to be such as to make the waves behind it of wave-length short in comparison with the depth of water in the canal: let the boat go a little faster, and give it time until steady waves are formed behind it; these waves will be of longer wave-length: the greater the speed of the boat, the longer will be the wave-length, until we reach a certain limit; and as the wave-length begins to be equal to the depth, or twice the depth, or three times the depth, we approach a wonderful and critical condition of affairs—we approach the case of constant wave velocity. There will still be a

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procession of waves behind the boat, but it will be a shorter procession and of higher waves; and this procession will not now lengthen astern at half the speed of the boat, but will lengthen perhaps at a third, or a fourth, or perhaps at a tenth of the speed of the boat. We are approaching the critical condition: the rear of the procession of waves is going forward nearly as fast as the boat. This looks as if we were coming to a diminished resistance; but it is not really so. Though the procession is lengthening less rapidly relatively to the boat than when the speed was smaller, the waves are very much higher; and we approach almost in a tumultuous manner to a certain critical velocity. I will read you presently Scott Russell's words on the subject. Once that crisis has been reached, away the boat goes merrily, leaving no wave behind it, and experiencing no resistance whatever if the water be free from viscosity, but in reality experiencing a very large resistance, because now the viscosity of the water begins to tell largely on the phenomena. I think you will be interested in hearing Scott Russell's own statement of his discovery. I say his discovery, but in reality the discovery was made by a horse, as you will learn. I found almost surprisingly in a mathematical investigation, "On Stationary Waves in Flowing Water," contributed to the *Philosophical Magazine* (Oct. Nov. Dec. 1886 and Jan. 1887), a theoretical confirmation, 49½ years after date, of Scott Russell's brilliant "Experimental Researches into the Laws of Certain Hydrodynamical Phenomena that accompany the Motion of Floating Bodies, and have not previously been reduced into conformity with the known Laws of the Resistance of Fluids."*

These experimental researches led to the Scottish system of fly-boats carrying passengers on the Glasgow and Ardrossan Canal, and between Edinburgh and Glasgow on the Forth and Clyde Canal, at speeds of from eight to thirteen miles an hour, each boat drawn by a horse or pair of horses galloping along the bank. The method originated from the accident of a spirited horse, whose duty it was to drag the boat along at a slow walking speed, taking fright and

* By John Scott Russell, Esq., M.A., F.R.S.E. Read before the Royal Society of Edinburgh, 3 April 1837, and published in the Transactions in 1840.

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running off, drawing the boat after him; and it was discovered that, when the speed exceeded the velocity acquired by a body falling through a height equal to half the depth of the canal (and the horse certainly found this), the resistance was less than at lower speeds. Scott Russell's description of how Mr. Houston took advantage for his Company of the horse's discovery is so interesting that I quote it *in extenso*:—

"Canal navigation furnishes at once the most interesting illustrations of the interference of the wave, and most important opportunities for the application of its principles to an improved system of practice.

"It is to the diminished anterior section of displacement, produced by raising a vessel with a sudden impulse to the summit of the progressive wave, that a very great improvement recently introduced into canal transports owes its existence. As far as I am able to learn, the isolated fact was discovered accidentally on the Glasgow and Ardrossan Canal of small dimensions. A spirited horse in the boat of William Houston, Esq., one of the proprietors of the works, took fright and ran off, dragging the boat with it, and it was then observed, to Mr. Houston's astonishment, that the foaming stern surge which used to devastate the banks had ceased, and the vessel was carried on through water comparatively smooth with a resistance very greatly diminished. Mr. Houston had the tact to perceive the mercantile value of this fact to the canal company with which he was connected, and devoted himself to introducing on that canal vessels moving with this high velocity. The result of this improvement was so valuable, in a mercantile point of view, as to bring, from the conveyance of passengers at a high velocity, a large increase of revenue to the canal proprietors. The passengers and luggage are conveyed* in light boats, about

* This statement was made to the Royal Society of Edinburgh in 1837, and it appeared in the Transactions in 1840. Almost before the publication in the Transactions the present tense might, alas, have been changed to the past—"passengers *were* conveyed." Is it possible not to regret the old fly-boats between Glasgow and Ardrossan and between Glasgow and Edinburgh, and their beautiful hydrodynamics, when, hurried along on the railway, we catch a

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sixty feet long, and six feet wide, made of thin sheet iron, and drawn by a pair of horses. The boat starts at a slow velocity behind the wave, and at a given signal it is by a sudden jerk of the horses drawn up on the top of the wave, where it moves with diminished resistance, at the rate of 7, 8, or 9 miles an hour."

Scott Russell was not satisfied with a mere observation of this kind. He made a magnificent experimental investigation into the circumstances. An experimental station at the Bridge of Hermiston on the Forth and Clyde Canal was arranged for the work, as represented in Fig. 1, Plate 80. The experimental station was so situated that there was a straight run of 1500 feet along the bank, and three pairs of horses are seen galloping along. They seem from the drawing to be galloping on air, but are of course on the towing path; and this remark may be taken as an illustration that, if the horses only galloped fast enough, they could gallop over the water without sinking into it, as they might gallop over a soft clay field. That is a sober fact with regard to the theory of waves; it is only a question of time how far the heavy body will enter into the water, if it is dragged very rapidly over it. This however is a digression. The very ingenious apparatus of Scott Russell's is delineated in Fig. 1. There is a pyramid 75 feet high, supporting a system of pulleys which carry a heavy weight suspended by means of a rope. The horses are dragging one end of this rope, while the other end is fastened to a boat which travels in the opposite direction. It is the old principle applied by Huyghens, and still largely used, in clockwork. Scott Russell employed it to give a constant dragging force to the boat from the necessarily inconstant action of the horses. I need not go into details, but I wish you to see that Scott Russell, in devising these experiments, adopted methods for accurate measurement in order to work out the theory of those results, the general natural history of which he had previously observed.

I will now read certain results from Scott Russell's paper that I think are interesting. The depth of the canal at the experimental

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glimpse of the Forth and Clyde Canal still used for slow goods traffic; or of some swampy hollows, all that remains of the Ardrossan Canal on which the horse and Mr. Houston and Scott Russell made their discovery?

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station was about 4 or 5 feet on an average; it was really 5½ feet in the middle, but a proper average depth must have been about 4½ feet, because Scott Russell found by experiment that the natural speed of the long wave was about 8 British statute miles an hour or 12 feet per second. Here then are some of the results. The "Raith," a boat weighing 10,239 lbs. (nearly 5 tons), took the following forces to drag it along at different speeds:—at 4·72 miles an hour 112 lbs.; at 5·92 miles an hour 261 lbs.; and at 6·19 miles an hour 275 lbs. There is no observation at the critical velocity of about 8 miles an hour. The next is at 9·04 miles an hour, and the force is 250 lbs., as compared with 275 lbs. at 6·19 miles an hour. Then at a higher speed, 10·48 miles an hour, the force required to drag it increases to 268½ lbs. This illustrates that water is not a perfect fluid. It also illustrates the theoretical result in a beautiful and interesting way. If water were a perfect fluid, the forces at the lower speeds would be somewhat less than he has given, perhaps not very much less: at all speeds above 8 miles the force would be nothing; the boat once started, the motion would go on for ever. On the same canal another boat, weighing 12,579 lbs. (nearly 6 tons), gave these still more remarkable results:—at 6·19 miles an hour 250 lbs.; at 7·57 miles an hour 500 lbs.; at 8·52 miles an hour 400 lbs.; and at 9·04 miles an hour only 280 lbs. That is a striking confirmation of the result of the previous observations. Scott Russell says also: "I have seen a vessel in 5 feet water, and drawing only 2 feet, take the ground in the hollow of a wave having a velocity of about 8 miles an hour, whereas at 9 miles an hour the keel was not within 4 feet of the bottom." Again he says: "Two or three years ago, it happened that a large canal in England was closed against general trade by want of water, drought having reduced the depth from 12 to 5 feet. It was now found that the motion of the light boats was rendered more easy than before; the cause is obvious. The velocity of the wave was so much reduced by the diminished depth, that, instead of remaining behind the wave, the vessels rode on its summit." He also makes this interesting statement: "I am also informed by Mr. Smith of Philadelphia, that he distinctly recollects the circumstance of having

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travelled on the Pennsylvania canal in 1833, when one of the levels was not fully supplied with water, the works having been recently executed, and not being yet perfectly finished. This canal was intended for 5 feet of water, but near Silversford the depth did not exceed 2 feet; and Mr. Smith distinctly recollects having observed to his astonishment, that, on entering this portion, the vessel ceased to ground at the stern, and was drawn along with much greater apparent ease than on the deeper portions of the canal."

Even if one regretted the introduction of railways, do not imagine that it can be set forth on mechanical grounds that traction in a canal can compete for any considerable speeds with traction on a railway. Taking again some of the figures already given, a boat weighing 10,239 lbs. required 112 lbs., or about 1–100th of its weight, to drag it at $4\frac{3}{4}$ miles an hour. So that to drag a boat at that moderate speed took the same force as would be required to drag it on wheels up an incline of 1 in 100, supposing there to be no friction in the wheels on a railway. But at the higher speed of 9 miles an hour, taking advantage of the comparatively smaller force due to having passed the velocity corresponding with the long wave, we have 250 lbs., which divided by 10,239 is about 1 in 40; so that the force required to drag the boat along at the rate of 9 miles an hour was what would be required to drag it on wheels up an incline of 1 in 40. Sad to say, I am afraid the wheels have it in an economical point of view.

Ship Waves at Sea.—I must now call your attention to the most beautiful, the most difficult, and in some respects the most interesting part of my subject, that is, the pattern of waves formed in the rear of a ship at sea, not confined by the two banks of a canal. The whole subject of naval dynamics, including valuable observations and suggestions regarding ship waves, was worked out with wonderful power by William Froude; and the investigations of the father were continued by his son, Edmund Froude, in the Government Experimental Works at Haslar, Gun Creek, Gosport. William Froude commenced his system of nautical experiments in a tank made by

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himself at Torquay, in Devonshire; first wholly at his own expense for several years, and afterwards with the assistance of the Government he continued those experiments till his death. The Admiralty have taken up the work, and have made for it an experimental establishment in connection with the dockyard of Portsmouth; and now, after the death of William Froude, his son Edmund continues to carry out there his father's ideas, working with a large measure of his father's genius, and, with his father's perseverance and mechanical skill, obtaining results, the practical value of which it is impossible to over-estimate. It is certainly of very great importance indeed to this country, which depends so much on shipbuilding, and the prosperity of which is so much influenced by the success of its shipbuilders, to find the shapes of ships best suited for different kinds of work—ships of war, swift ships for carrying mails and passengers, and goods carriers. I may mention also that one of our great shipbuilding firms on the Clyde, the Dennys, feeling the importance of experiments of this kind, have themselves made a tank for experimental purposes on the same plan as Mr. Froude's tank at Torquay; and Mr. Purvis, who, when a young man, was one of Mr. Froude's assistants, is taking charge of that work. The Dennys are going through, with their own ships, the series of experiments which Mr. Froude found so useful, and which the Admiralty now find so useful, in regard to the design of ships; and as the outcome of all this work a ship can now be confidently designed to go at a certain speed, to carry a certain weight, and to require a certain amount of horse-power from the engine.

The full mathematical theory of ship waves has been exceedingly attractive in one sense, and in another sense it has been somewhat repulsive, because of its great difficulty, for mathematicians who have been engaged in hydrodynamical problems. Following out that principle of Stokes, which was further developed and generalised by Lord Rayleigh, we can see how to work out this theory in a thorough manner. In fact I can now put before you a model, Figs. 10 and 11, Plate 82, constructed from calculations which I have actually made, by following out the lines of theory that I have indicated. I find that the whole pattern of waves is comprised between two straight

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lines drawn from the bow of the ship and inclined to the wake on its two sides at equal angles of 19° 28′. It is seen in Figs. 9 and 10 that two such lines, drawn from the bow or front shoulders of the ship, include the whole wave-pattern. There is some disturbance in the water abreast of the ship, before coming to these two lines. Theoretically there is a disturbance to an infinite distance ahead and in every direction; but the amount of that disturbance practically is exceedingly small—imperceptible indeed—until you come to these two definite lines. You see the oblique wave-pattern—waves in echelon pattern. The law of that echelon is illustrated by the curves shown in Fig. 9, Plate 82. The algebraical equations of these curves are $x = \sqrt{\frac{1 \pm w}{(3 \pm w)^3}}$ and $\frac{y}{x} = \sqrt{\frac{1}{8}(1 - w^2)}$; where x and y, according to ordinary usage, are measured along, and perpendicular to, the direction of motion from E towards A, and w is an arbitrary variable; by assuming a series of arbitrary values for w, a corresponding series of values for x are found from the first equation, and thence the corresponding values of y from the second. I trace a complete curve thus—ABC and ADC; there is a perfect cusp in each curve at B and D respectively, although it cannot be shown perfectly in the drawing. Another formula, which need not be reproduced here, gives a wave-height for every point of those curves. Take alternate curves for hollows and for crests; and now in clay or plaster of Paris mould a form corresponding with the elevation due to the curve AB, plus the elevation due to the curve BC, adding the two together; thus you get for every point of your curves a certain wave-height. With the assistance of Mr. Maclean and Mr. Niblett the beautiful clay model which is before you (illustrated in Figs. 10 and 11, Plate 82) has been made, and it shows the results of the theory constructed from actual calculation. I will tell you how to construct the angle of 19° 28′ made by each of those two straight lines AB and AD with the direction of motion CA. Draw a circle; produce the diameter from one end to a length equal to the diameter; and from the outer extremity of this projecting line draw two tangents to the circle. Each of those tangent lines makes an angle of 19° 28′ with the

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produced diameter, that is, with the wake of the ship or with the line of progression of the ship.

A little more as to the law of this diagram, Fig. 9, Plate 82. The echelon waves consist chiefly of the very steep waves at a cusp. The theoretical formula gives infinite height at the cusp; but that is only a theoretical supposition, though it gives an interesting illustration of mathematical "infinity." Blur it, or smooth it down, precisely as an artist does when he designedly blurs a portion of his picture to produce an artistic effect; blur it artistically, correctly, and mathematically, and you get the pattern. It will be impossible to realise that perfectly; but I have endeavoured to do it in the model illustrated in Figs. 10 and 11, necessarily with an enormous exaggeration however, as you will remark. While every other dimension is unchanged, you must suppose each wave to be reduced to about a fifth part of its height shown in this model; thus you will get the steep "steamboat waves," so much enjoyed by the little boys who, regardless of danger, row out their boats to them every day at the Clyde watering places. Theoretically these waves are infinitely steep; practically they are so steep that the boat generally takes in a little water, and is sometimes capsized. There is a distance of perhaps a couple of feet from crest to crest, and the wave is so steep and "lumpy" on the outer border of the echelon that there is frequently broken water there fifty or a hundred yards from the ship. One point of importance in the geometry of this pattern is that each echelon cusp, represented in Fig. 9 at B or D, bisects the angle between the flank line AB or AD and the thwart-ship line BD: the angle in question being $70° 32'$ ($90° - 19° 28'$). An observation of this angle was actually made for me by Mr. Purvis. He observed, from the towing of a sphere instead of a boat (so as to get a more definite point), the angle between the flank line AB and the direction of motion CA, and found it to be $19\frac{1}{4}°$. The theoretical angle is $19° 28'$, and we have therefore in this observation a very admirable and interesting verification of the theory.

The doctrine embodied in the wave-model illustrated in Figs. 10 and 11, Plate 82, may be described in a very general way thus. Think

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of a ship travelling over water. How is it that it makes the wave? Where was the ship when it gave rise to the wave BCD in Fig. 9? Answer: the portion BCD of the wave-pattern is due to what the ship did to the water when the ship was at E, the point E being at the same distance behind C that the point A is in front of C; when it was at E it was urging the water aside, and the effect of the ship pushing the water aside was to leave a depression. Now suppose the ship to be suddenly annihilated or annulled, what would be the result? The waves would travel out from it, as in the case of a stone thrown into the water. Again suppose the ship to move ten yards forward and then stop, what would be the result? A set of waves travelling forward while the disturbance that the ship made by travelling ten yards remains. Now instead of stopping, let the ship go on its course: the wave disturbance is going *its* course freed from the ship, and travels forward. When the disturbance originated which has now reached any point C, the ship was as far behind that point C as it now is before it. Calculate out the result from the law that the group-velocity is half the wave-velocity—the velocity of a group of waves at sea is half the velocity of the individual waves. Follow the crest of a wave, and you see the wave travelling through the group, if it forms one of a group or procession of waves. Look, quite independently of the ship, at a vast procession of waves, or imagine say fifty waves; look at one of those waves, follow its crest; in imagination fly as a bird over it, keeping above the crest as a bird in soaring does sometimes, and, beginning over the rear of the procession, a hundred yards on either side of the ship's wake, you will find the waves get larger and larger as you go forwards. Then go backwards through the procession, and you will see the waves get smaller and smaller and finally disappear. You have now gone back to the rear of the procession; a small wave increases and travels uniformly forward, and, while the crest of each wave always goes on with the velocity corresponding to the length of the wave, the rear of the procession travels forward at half the speed of the wave: so that every wave is travelling forward through the procession from its rear at a speed which is the same relatively to the rear of the procession as the speed of the rear of the

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procession relatively to the water. Thus each separate wave is travelling at the ship's speed, which is twice as fast relatively to the water as the rear of the procession of waves is travelling. The wave is the progression of a form; the velocity of a wave is clearly intelligible; the velocity of a procession of waves is still another thing. The penetrating genius of Stokes originated the principle, admirably worked out by Osborne Reynolds and Lord Rayleigh, who have given us this in the shape in which we now have it.

Now I must call your attention to some exceedingly interesting diagrams that I am enabled to show you through the kindness of Mr. W. H. White, director of Naval Construction for the Admiralty, and Mr. Edmund Froude, to whose work I have already referred. Fig. 12, Plate 82, shows a perspective view of echelon waves taken from Mr. William Froude's paper, "Experiments upon the Effect Produced on the Wave-making Resistance of Ships by Length of Parallel Middle Body" (Institution of Naval Architects, vol. xviii 1877, page 77).

The three diagrams from Mr. White, Figs. 6, 7, and 8, Plate 81, show profiles of the thwart-ship waves of various ships at different speeds. Look first at Fig. 6, showing the wave profile for H.M.S. "Curlew" at a speed of nearly 15 knots an hour. Note how the water, after the first elevation, dips down below the still-water line; rises up to a ridge at a distance back from the first nearly but not exactly equal to the wave-length corresponding with the speed; and then falls down again, experiencing various disturbances. From the appearance of the waves raised by ships going at high speeds, we may learn to tell how quickly they are going. The other day, at the departure of the fleet from Spithead after the great naval review, a ship was said to be going at 18 knots, while it was obvious from the waves it made that it was not going more than 12. In Fig. 7 we have wave profiles for another ship at two different speeds. The upper line corresponds to a speed of 18·4 knots; the lower line to a speed of 17 knots. In the first case the water shoots up to its first maximum height close to the bow, sinks to a minimum

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towards midships, and flows away past the stern slightly above still-water level. In the second case the character of the wave is somewhat similar, but smaller in height; and there is a marked difference at the stern, due to other disturbing causes. In Fig. 8 we have three different speeds for H.M.S. "Orlando" similarly represented.

There is still another very interesting series of diagrams, Figs. 13 to 19, Plates 83 and 84, taken from Mr. Edmund Froude's paper "On the Leading Phenomena of the Wave-making Resistance of Ships," read before the Institution of Naval Architects, 8th April 1881. In Figs. 13 to 17 are shown the waves produced by a torpedo launch at speeds of 9, 12, 15, 18, and 21 knots per hour. We need not here go into the law of wave-length, but I may tell you that it is as the square of the velocity: the wave-length is four times as great for 18 as for 9 knots. Look now at the pattern of the waves in Figs. 9 and 10, Plate 82. Look at the echelon waves and the thwart-ship waves. Mr. Froude had not worked out the theory that has given the curvature of the transverse ridge exactly; but he drew the waves from general observation, and it is wonderful to see how nearly they agree with the theoretical curves, Fig. 9, and the model, Fig. 10.

Velocity and Length of Waves.

Velocity of Wave. Knots per hour.	Length of Wave. Feet.	Velocity of Wave. Knots per hour.	Length of Wave. Feet.
6	19·513	17	156·646
7	26·559	18	175·618
8	34·690	19	195·672
9	43·904	20	216·812
10	54·203	22	262·343
11	65·585	24	312·209
12	78·052	26	366·412
13	91·602	28	424·952
14	106·238	30	487·827
15	121·956	35	663·987
16	138·760	40	867·248

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That is a most interesting series of diagrams in Plates 83 and 84, and as a lesson it conveys more than any words of mine.

Here is a table (page 428) giving the length of a free wave; and remember, when once the waves are made and are left by the ship, they are then and thereafter free waves. At 6 knots per hour the wave-length is 19½ feet; at 12 knots it is four times as great. At 10 knots it is 54 feet; at 20 it is four times as much. The greatest speeds in Froude's diagrams give about 240 feet length of wave. Now that is a very critical point with respect to the length of the wave and the speed of the ship. I may tell you that Froude the elder and his son Edmund have made most admirable researches in this subject, and have poured a flood of light on some of the most difficult questions of naval architecture.

Parallel Middle Body.—I should like to say something about the practical question of parallel middle body. When I first remember shipbuilding on the Clyde, and its progress towards its present condition, a very frequent incident was that when a ship was floated it was found to draw too much water forward, in other words to be down by the head. When this happened, the ship was taken out of the water again, and a parallel piece, 10 or 20 or 30 feet long, was put into the middle: a parallel middle body, curved transversely, but with straight lines in the direction of its length. Many a ship was also lengthened with a view to add to its speed. William Froude took up the question of parallel middle body, and the effect of the entrance and run. The entrance is that part of the ship forward, where it enters the water and swells out to the full breadth of the ship; the run is the after part, extending from where the ship begins to narrow to the stern. A ship may consist of entrance, parallel middle body, and run. Froude investigated the question, Is the parallel middle body inserted in a ship an advantage or a disadvantage, in some cases or in all cases? He found it a very complex question. According to the relation of the wave-length to the length of the ship, it produces a good or a bad effect. A ship with a considerable length of parallel middle body shows very curious phenomena regarding the resistance at different speeds. As

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the speed is raised, the resistance increases; but on a further increase of speed, it seems as if it was beginning to diminish; the resistance never quite diminishes however with increase of speed, but only increases much less rapidly. The curve indicating the relation of the speed to the velocity has a succession of humps or rises, each showing a rapid increase of resistance; between these it becomes almost flat, showing scarcely any increased resistance. Froude has explained that thoroughly by the application of this doctrine of ship waves which I have endeavoured to put before you. When the effect of the entrance or bow, and the effect of the run or stern, are such as to annul or partially to annul each other's influence in the production of waves, then we have a favourable speed for that particular size and shape of ship. On the other hand, when the crest of a wave astern due to the action of the bow agrees with the crest of a wave astern due to that of the stern, then we have an unfavourable speed for that particular size of ship. Thus Froude worked out a splendid theory, according to which, for the speed at which a ship is to go, a certain length of parallel middle body may, if otherwise desired, be an advantage. But on the whole the conclusion was that—if the ship is equally convenient, if it is not too expensive, if it can pass through the lock gates &c., and if all the other practical conditions can be fulfilled, without a parallel body—it is better that the ship should be all entrance and run, according to Newton's form of least resistance: fine lines forward, swelling out to greatest breadth amidships, and tapering finely towards the stern. In other words, the more ship-shape a ship is, the better.

I wish to conclude by offering one suggestion. I must premise that, when I was asked by the Council to give this lecture, I made it a condition that no practical results were to be expected from it. I explained that I could not say one word to enlighten you on practical subjects, and that I could not add one jot or tittle to what had been done by Scott Russell, by Rankine, and by the Froudes, father and son, and by practical men like the Dennys, W. H. White, and others; who have taken up the science and worked it out in practice. But there is one suggestion founded on the doctrine of

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wave-making, which I venture to offer before I stop. I have not explained how much of the resistance encountered by a ship in motion is due to wave-making, and how much to what is called skin resistance. I can briefly give you a few figures on this point, which have been communicated to me by Mr. Edmund Froude. For a ship A, 300 feet long and 31½ feet beam and 2634 tons displacement, a ship of the ocean mail steamer type, going at 13 knots an hour, the skin resistance is 5·8 tons, and the wave resistance 3·2 tons, making a total of 9 tons. At 14 knots the skin resistance is but little increased, namely 6·6 tons; while the wave resistance is nearly double, namely 6·15 tons. Mark how great, relatively to the skin resistance, is the wave resistance at the moderate speed of 14 knots for a ship of this size and of 2634 tons weight or displacement. In the case of another ship B, 300 feet long and 46·3 feet beam and 3626 tons displacement—a broader and larger ship with no parallel middle body, but with fine lines swelling out gradually—the wave resistance is much more favourable. At 13 knots the skin resistance is rather more than in the case of the other ship, being 6·95 tons as against 5·8 tons; while the wave resistance is only 2·45 tons as against 3·2 tons. At 14 knots there is a very remarkable result in this broader ship with its fine lines, all entrance and run and no parallel middle body:—at 14 knots the skin resistance is 8 tons as against 6·6 tons in ship A, while the wave resistance is only 3·15 tons as compared with 6·15 tons. Another case which I can give you is that of a torpedo boat 125 feet long, weighing 51 tons. At a speed of 20 knots an hour the skin resistance is 1·2 ton, and the wave resistance 1·1 ton; total resistance 2·3 tons. To calculate the horse-power you multiply the speed in knots per hour by 6⅔, and then multiply the resistance in tons by the product so obtained; and the result for the torpedo boat going at 20 knots an hour is 307 horse-power to overcome a resistance of 2·3 tons or 1–22nd of her weight (51 tons). Again the ship B of 300 feet length, going at 20 knots an hour with an expenditure of 4550 horse-power, experiences a resistance of 34 tons, or about 1–110th of her weight (3626 tons). Thus the energy actually expended in propelling these vessels at 20 knots an hour at sea would be sufficient, if they were supported

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on frictionless wheels, to drag them at the same speed up railway inclines, of 1 in 22 for the torpedo boat, and 1 in 110 for the ship B.

My suggestion is this, and I offer it with exceedingly little confidence, indeed with much diffidence; but I think it is possibly worth considering. Inasmuch as wave resistance depends almost entirely on action at the surface of the water, and inasmuch as a fish swimming very close to but below the surface makes very little wave disturbance, it seems to me that by giving a great deal of body below the water line we may relatively diminish the wave disturbance very much. To get high speeds of 18 and 20 knots an hour, it is probable that, by swelling out the ship below like the old French ships, instead of having vertical sides—making the breadth of beam say five feet more below the water than at the water line—there may be obtained a large addition to the displacement or carrying-power of the ship, with very little addition to the wave disturbance, and therefore with very little addition to the wave resistance, which is most important at high speeds. I think it may be worth while to consider this in regard to the designs of ships.

In conclusion, I should like to urge you to look at these phenomena for yourselves. Look at the beautiful wave-pattern of capillary waves, which you will find produced by a fishing line hanging vertically from a rod, or from an oar, or from anything carried by a vessel moving slowly through smooth water at speeds of from about ½ knot to 2 knots an hour. Again look at the equally beautiful wave-pattern produced by ships and boats, as illustrated in Plate 82. But you can scarcely see the phenomena more beautifully manifested than by a duck and ducklings. A full-sized duck has a splendidly shaped body for developing a wave-pattern, and going at good speed it produces on the surface of a pond very nearly the exact pattern of ocean waves. A little duckling going as fast as it can, perhaps about a knot an hour, shows very admirably the capillary waves,* differing manifestly from the ocean waves formed in

* For information regarding capillary waves, see Scott Russell's Report on Waves (British Association, York, 1844, pages 311–390); also parts III,

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the front and at the rear of a larger body moving more rapidly through the open water. I call attention to this, because, having given you perhaps a rather dry statement of scientific facts, if I can say a word that will lead you each to use your eyes in looking at ships, boats, ducks, and ducklings, moving on water at different speeds, and to observe these beautiful phenomena of waves, I think, even were you to remember nothing of this lecture, you would have something to keep in your minds for the rest of your lives.

Sir WILLIAM MUIR, K.C.S.I., proposed a hearty vote of thanks to Sir William Thomson for his most interesting lecture. The test of a lecture of this kind was that it made itself clear to the understanding of the unlearned; and he thought what they had this evening been listening to had opened up a whole vista of remarkable phenomena, and had furnished reasons whereby more could now be understood about waves than had ever been the case before.

The PRESIDENT had great pleasure in seconding the vote of thanks to Sir William Thomson. It was always said that "Britannia rules the waves"; and when it was considered how Great Britain did three-fourths of the carrying trade of the world, he thought it absolutely necessary that she should have ships as perfect as they could be made. All who had enjoyed the privilege of listening to Sir William Thomson's most interesting lecture felt, he was sure, very greatly obliged to him for having devoted so much time to it. Not only had he added to the information that had been acquired on this subject, but he had presented in a condensed form

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IV, and V of Sir William Thomson's paper, "Hydro-Kinetic Solutions and Observations" (Philosophical Magazine, November 1871).

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the results of the long labours of Mr. Scott Russell, Mr. Froude; Lord Rayleigh, and others. On behalf of the Institution of Mechanical Engineers he desired to say that they should be delighted if he would do them the favour of allowing them to publish in the Institution Proceedings the lecture which he had just delivered. All who had listened to the lecture, or who read it on publication, would learn something on the subject.

The vote of thanks was unanimously agreed to.

The President proposed a hearty vote of thanks to the Marquess of Tweeddale for his kindness in remaining a second day in Edinburgh with the Institution, in order to take the chair on the occasion of this evening's lecture.

The vote of thanks was passed unanimously.

The Marquess of Tweeddale thanked the President and Members very warmly for the kind way in which they had welcomed whatever services he had been able to render on this occasion in connection with the Meeting of the Institution in Edinburgh.

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EXCURSIONS.*

On Tuesday Afternoon, the 2nd of August, after luncheon in the University by invitation of the Local Committee, an Excursion was made by special free train to visit the Forth Bridge Works, on the invitation of the engineers, Sir John Fowler, K.C.M.G., and Mr. Benjamin Baker, and under the guidance of Mr. Frederick E. Cooper, the resident engineer, Mr. William Arrol and Mr. Joseph Phillips, the contractors, and Mr. E. Malcolm Wood and Mr. Andrew S. Biggart.

The following Works in Edinburgh were opened to the visit of the Members on the afternoons of both Tuesday and Wednesday. Descriptions of these Works are appended (pages 439–443).

Messrs. George and William Bertram, St. Katherine's Paper Machinery Works, Sciennes.

Messrs. Thomas Nelson and Sons, Parkside Printing Works, Dalkeith Road.

Messrs. W. and A. K. Johnston, Edina Map Printing Works, Easter Road.

Edinburgh Northern Cable Tramway, Hanover Street.

Edinburgh Gas Works, South Back of Canongate.

In the evening the Institution Dinner was held in the Masonic Hall, George Street, Edinburgh, the President occupying the chair, and was largely attended by the Members and their friends. The following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present. The Most Honourable the Marquess of Tweeddale, Chairman of the Edinburgh Reception Committee; the Right Honourable John B. Balfour, M.P., late Lord Advocate; the Right Honourable Sir James King, Lord Provost of Glasgow; Sir William Muir, K.C.S.I., Principal of Edinburgh University; Sir William Thomson, Kt.; the Honourable Adye Douglas, Q.C., Agent-General for Tasmania; Colonel Malcolm, C.B., R.E.; Mr. James W. Barclay, M.P.; Provost Hugh Ballingall, Dundee; Bailie Anderson; Bailie Walcot; Bailie Russell; Bailie Cranston; Councillor Clapperton; Professor

* The notices appended of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

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G. F. Armstrong; Professor Crum Brown; Professor Ewing, Honorary Local Secretary, Dundee; Professor Steggall; Mr. T. N. Armit; Mr. William Arrol; Mr. Benjamin Baker, Engineer of the Forth Bridge; Mr. John Barry; Mr. Robert Bell; Mr. James R. Bertram; Mr. William Bertram; Mr. Andrew S. Biggart; Mr. Benjamin Hall Blyth; Mr. Alan Brebner; Mr. Andrew Betts Brown; Mr. George Carmichael; Mr. W. Allan Carter; Mr. W. Dyce Cay; Mr. W. N. Colam; Mr. Frederick E. Cooper; Mr. John Cooper, Burgh Engineer, Edinburgh; Mr. David Cowan; Mr. John Cran; Mr. David Cunningham, Harbour Engineer, Dundee; Mr. G. Miller Cunningham; Mr. Thomas Dale; Mr. St. John V. Day, Honorary Local Secretary, Edinburgh; Mr. Robert Douglas; Mr. Oswald W. Ellis; Mr. William Geipel; Mr. James Gibson, Superintending Engineer, Edinburgh Post Office; Mr. Charles G. Gourlay; Mr. Gershom Gourlay; Mr. H. G. Gourlay; Mr. William N. Grainger; Mr. Lewis Grant; Mr. N. M. Henderson; Mr. Matthew Holmes; Mr. T. B. Johnston; Mr. Fletcher F. S. Kelsey; Mr. William Kennedy; Mr. A. E. Keydell; Mr. W. Falconer King; Mr. J. M. Kinghorn; Mr. Alexander Leslie and Mr. Robert C. Reid, Engineers of the Edinburgh Water Works; Mr. Joseph Lindsay; Mr. Frederick T. C. Linton; Mr. James F. Low; Mr. Thomas McDougal; Mr. William Mackison, Burgh Engineer, Dundee; Mr. James M'Laren; Mr. W. J. Millar, Secretary of the Institution of Engineers and Shipbuilders in Scotland; Mr. Thomas Miller; Mr. James Milne; Mr. Richard A. Pearce; Mr. Joseph Phillips; Mr. Stewart Robertson; Mr. Frederick J. Rowan; Mr. William Skinner, City Clerk; Mr. Charles A. Stevenson; Mr. David A. Stevenson; Mr. James Taylor, Director of the Caledonian Railway; Mr. W. B. Thompson; Mr. William G. Thomson; Mr. William Umpherston; Mr. W. Walton Urquhart; Mr. John Waddell; Mr. James Watson, Water Engineer, Dundee; Mr. David M. Westland; Mr. John Whitelaw; Mr. Peter Whyte, Harbour Engineer, Leith; Mr. E. Malcolm Wood; Mr. W. A. Young.

The President was supported by the following Officers of the Institution:—Mr. Jeremiah Head, Past-President; Mr. Daniel Adamson, Mr. Charles Cochrane, Mr. David Greig, and Mr. Joseph

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Tomlinson, Vice-Presidents; Mr. Benjamin A. Dobson, Sir James N. Douglass, Mr. Edward B. Marten, Mr. R. Price-Williams, Mr. E. Windsor Richards, Mr. T. Hurry Riches, Mr. Benjamin Walker, and Mr. Thomas W. Worsdell, Members of Council.

After the usual loyal toasts, the President proposed "The Reception Committees," which was acknowledged by the Most Honourable the Marquess of Tweeddale. The toast of "The City of Edinburgh" was acknowledged by Bailie Anderson, in the absence of the Lord Provost. "The University of Edinburgh" was acknowledged by Sir William Muir. "The Institution of Mechanical Engineers" was proposed by the Most Honourable the Marquess of Tweeddale, and acknowledged by the President. The toast of "The Visitors" was acknowledged by the Right Honourable John B. Balfour, M.P.; "The Engineers of the Forth and Tay Bridges" by Mr. Benjamin Baker; "The Contractors of the Forth and Tay Bridges" by Mr. William Arrol; and "The Honorary Secretaries" by Mr. St. John V. Day and Professor Ewing.

On WEDNESDAY AFTERNOON, the 3rd of August, after luncheon in the University by invitation of the Local Committee, four alternative Excursions were made. By special train the Carron Iron Works were visited (pages 443–448), under the guidance of the secretary, Mr. T. D. Brodie, and the manager, Mr. David Cowan. The Broxburn Oil Works (pages 449–450) were visited by special train, under the guidance of the chairman, Mr. Robert Bell, the managing director, Mr. William Kennedy, and the works manager, Mr. N. M. Henderson. The Floor-Cloth and Linoleum Works of Messrs. John Barry, Ostlere and Co., were visited at Kirkcaldy (pages 451–453). The Burntisland Oil Works were visited (pages 450–451), under the guidance of the chairman, Mr. John Waddell, and the general manager and secretary, Mr. William N. Grainger. An excursion to Young's Paraffin Light and Mineral Oil Works at Addiewell (page 448), arranged on the invitation of the managing director, Mr. John Fyfe, had to be abandoned in consequence of a miners' strike causing a temporary stoppage of work.

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In the evening the Members were invited by the Right Honourable the Lord Provost, the Magistrates, and the Council of the City of Edinburgh, to a Conversazione in the Science and Art Museum, Edinburgh. They were also there favoured with a Lecture on "Ship Waves," by Sir William Thomson, Kt., F.R.SS. L. and E., LL.D., President R.S.E., in the large hall in the new west wing of the Museum (pages 409–434).

On THURSDAY, the 4th of August, an Excursion was made by special train, crossing the new Tay Viaduct, to Dundee, where the following Works &c. were opened to the visit of the Members, descriptions of which are appended (pages 453–459).

Messrs. Urquhart Lindsay and Co., Blackness Foundry.
Messrs. Gourlay Brothers and Co., Dundee Foundry.
Messrs. Gilroy Sons and Co., Tay Jute Works.
Messrs. Thomson Shepherd and Co., Seafield Jute Works.
Mr. F. S. Sandeman, Manhattan Jute Works.
Messrs. Thomas Bell and Sons, Belmont Jute Works.
Dundee Harbour and Harbour Works, by invitation of Mr. David Cunningham, Harbour Engineer.
University College; Chemical, Physical, and Electrical Engineering Laboratories; by invitation of Principal Peterson and the Professors.

After luncheon in the Albert Hall by invitation of the Dundee Reception Committee, a special free steamer, lent by the Harbour Trustees, conveyed the Members to view the Tay Viaduct from below (page 373), and to inspect the Piers, on the invitation of the engineers, Messrs. Barlow and Son. The Members were accompanied throughout the trip by the resident engineer, Mr. Fletcher F. S. Kelsey, and the contractor, Mr. William Arrol. The sail on the river commanded a fine view of the town and environs.

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On Friday, the 5th of August, an Excursion was made by one party of the Members in special brakes to visit the Edinburgh Water Works (pages 459–462), on the invitation of the engineers, Messrs. Alexander Leslie and Robert C. Reid. The route taken was by Alnwick Hill and Penicuik to Gladhouse Reservoir; returning thence by way of Rosebery and Edgelaw Reservoirs to Edinburgh. At Penicuik visits were made to Messrs. James Brown and Co.'s Esk Paper Mills (pages 462–463), and Messrs. Alexander Cowan and Sons' Valleyfield Paper Mills (pages 463–465).

Another party of the Members visited the Isle of May by special steamer from Leith, landing on the island by special permission of the Commissioners of Northern Lighthouses. The Electric Lighthouse described in Mr. David A. Stevenson's paper (page 347) was inspected under the guidance of Mr. Stevenson. In returning from the Isle of May the steamer went round the Bass Rock. On arrival at Leith the Harbour and Docks were visited, under the guidance of the engineer, Mr. Peter Whyte.

A third party of the Members proceeded by special train to Newcastle-on-Tyne, to visit the Royal Mining, Engineering, and Industrial Exhibition.

ST. KATHERINE'S PAPER MACHINERY WORKS.

These works, established in 1821 by Messrs. George and William Bertram for the manufacture of paper-making machinery, cover nearly two acres of ground, and comprise large turning and fitting shops, equipped with lathes, planing machines, drills, slot-drills, large wall planer, special machines for polishing and boring chilled rollers for glazing paper, overhead travelling cranes, &c. There are commodious pattern shops and stores, smithy with stea hammers, brass foundry, and a shop with special machinery of a fine description for the manufacture of brass strainer-pla straining paper-pulp. In addition to paper-making machin steam engines are also constructed here.

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PARKSIDE PRINTING WORKS.

These works, belonging to Messrs. Thomas Nelson and Sons, have been laid out with all the latest improvements, and cover an area of four acres, exclusive of six acres of recreation ground. The buildings are only one storey high throughout, and no drainage is allowed under the floors. The first room entered is the composing room; and next is the foundry, where for all classes of work a matrix in wax is obtained from the type or block set up in the composing room, papier mâché not being suitable for producing tints. Bees-wax mixed with black lead is run at a low temperature into a flat iron dish; and when the wax has set, the set up type or block is pressed upon it. The surface so obtained is next brightened with black lead and suspended in a bath of sulphate of copper, from which the copper is rapidly deposited on the matrix by means of a Weston dynamo-electric machine driven by an Otto gas engine. The resulting copper shells are backed with type metal, and set up to the proper height with wood blocks. The next rooms are those for the artists and the colour printing. The machines in use for colour printing include three Reliance Wharfedales for block printing, and six litho machines, of which four were constructed by Messrs. Newsum Wood and Dyson, one by Messrs. George Mann and Co., and one by Messrs. Faber and Schleigher. The machine rooms for letter-press printing contain thirty machines, ten by Messrs. Marinoni, twelve by Messrs. Fieldhouse Elliot and Co., and others by Messrs. Dawson and Harrild. The double-cylinder machines have since been fitted by Messrs. Nelson and Sons with a series of rollers of special composition, which pass over the printing surfaces of the cylinders and effectually prevent set-off. This room also contains a model of a web-printing machine designed by Mr. Thomas Nelson and exhibited in the ondon Exhibition in 1851, showing the essential principle of the printer on which all large newspapers are now printed, namely g on an endless web of paper from stereotyped plates buckled rotating cylinder, and cutting the paper into appropriate h a knife. The paper is supplied to the machine room

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direct from the warehouse, and is damped by an oscillating spray-rake, which swings over the sheet and distributes a copious shower of water. The sheets are then passed to a hydraulic press, and are afterwards slightly calendered by Heims German calenders. After being printed, the sheets are dried by passing over a series of steam-heated cylinders, and are finally subjected to hydraulic pressure. After being cut by an American Diamond self-cutting machine, the sheets pass on, through a series of stock rooms, to the folding room, where they are folded by hand or by means of Swiss and American folding machines. This room also contains machines for sewing on cord or tape and for stitching with thread or wire, and French card-cutting machines, &c. Finally in the binding shop the covers are made by hand labour; but the stamping and finishing are performed by machinery. The whole of the machinery is driven by three Otto gas engines, of 10 to 16 I.H.P.

EDINA MAP PRINTING WORKS.

This business, the property of Messrs. W. and A. K. Johnston, was established in 1825. The site of the works covers an area of 1·6 acre. The building is 320 feet long by 66 feet wide, having a southern wing 45 feet long; the floors and roofs are concrete. It is two storeys high, with a flat roof, on which other storeys can be erected. It is heated entirely by exhaust steam. The chief productions of the works are atlases and maps, which are constructed, drawn, engraved, printed, coloured, and bound or mounted. In the lithographic department the stones are ground and polished, ready for being drawn on or for receiving transfers from engraved plates. Many machines are constantly employed for printing maps in colours, in some cases as many as ten or twelve printings being required to produce one map. Several machines are constantly occupied in bank, commercial, and book work. Adjoining the engine room is the joiners' shop, in a section of which are manufactured globes. The other departments include the photographic room for reducing or enlarging work to be engraved or lithographed, the stock and packing rooms, the varnishing room, the mounting and binding rooms, etc.

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EDINBURGH NORTHERN CABLE TRAMWAY.

This is the first cable tramway introduced into Scotland. It consists of three miles of track commencing at the junction of Princes Street and Hanover Street, from which point it proceeds northwards along Dundas Street, Pitt Street, Brandon Street, and Inverleith Row, terminating at the junction of the last with Ferry Road. In passing into and out of Brandon Street there are two rather severe curves, one of which is round a corner of less than 90° and is 80 feet radius. The depôt is in Henderson Row, leading out of Pitt Street. In this building is placed the driving machinery, which consists of two 20-inch cylinder engines with automatic cut-off valve-gear. All the machinery is in duplicate, as it is intended to work from the same depôt a tramway from Princes Street through Frederic Street to Comely Bank in Stockbridge. The general principle upon which this tramway is constructed is similar to that of all the cable tramways that have been so successfully worked throughout the United States of America, Australia, New Zealand, and during the past three years at Highgate Hill, London. The details however differ very materially from those of other lines, several entirely new features being introduced to simplify the system, and to meet the more rigid requirements of British local authorities. The line has been constructed for the Cable Tramways Corporation of London by Messrs. Dick Kerr and Co., from the designs and under the superintendence of Mr. W. N. Colam.

EDINBURGH GAS WORKS.

These works occupy the site of the original works constructed in 1817 from plans by Mr. John Grafton, a pupil of Mr. William Murdock, of which however nothing remains but a fragment of a wall. The site has been gradually enlarged by the acquisition of neighbouring properties. Since 1880 the whole purifying plant has been reconstructed, and large additions have been made to the retort house, and to the condensing, exhausting, and washing apparatus, from the designs of the engineer, Mr. Robert Mitchell.

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The gasholders, with the exception of one small holder, are at a distance from the gas manufactory. The newest tank and gasholder were also designed by Mr. Mitchell, the former being constructed by Messrs. John Aird and Sons, and the latter by Messrs. C. and W. Walker. With the exception of a portion of the retort house and of the condensers, the present works are comparatively new. Upwards of five million cubic feet of 28-candle gas have been supplied in twenty-four hours. No material change has yet been made in the heating arrangements; but several regenerative furnaces are now at work.

CARRON IRON WORKS.*

The Carron Iron Works were founded by Dr. Roebuck of Sheffield in 1759, and the company was incorporated by royal charter in 1773. The works are situated on the banks of the river Carron, in Stirlingshire, about a mile from the Larbert Station of the Caledonian Railway, and the same distance from the Grahamstown Station of the North British Railway, and are connected with both systems and with the Forth and Clyde Canal by a branch railway; there is also a canal connecting with the port of Grangemouth on the Firth of Forth. The coalfields, which have a total area of about 3,500 acres, are in the vicinity of the works. The several seams belong to the lower portion of the upper series of coal measures. With the exception of the Main coal, all the seams differ very much in thickness in various parts of the field. The Craw coal, which is of excellent quality as a house coal, is chiefly used in the steamers belonging to the company. The Main and Coxrod seams are worked wholly for blast-furnace purposes, for which they are well suited. The ironstone supplies are drawn entirely from the Cadder estate, near Glasgow, having an area of about 5 miles in length by 1½ mile

* This description is abstracted by permission from a Paper recently contributed to the Institution of Civil Engineers by the manager, Mr. David Cowan (Proceedings, vol. lxxxvii, 1886, page 373).

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in breadth. There are six mineral seams, lying immediately below the carboniferous limestone, and locally known as the Possil strata. The most important seams are the blackband and clayband ironstones, which are worked on an extensive scale. The ore chiefly used in the blast-furnaces is blackband, with a slight admixture of clayband and hæmatite; the pig-iron produced is so soft that thin castings made from it can be punched and sheared.

The Carron Works, which occupy a space of 28 acres within the walls, are on two different levels. On the higher level are the blast-furnaces, heavy foundry, and stove-brick works; the lower level is occupied by the light foundry, together with the various fitting-shops, offices, &c. In Plate 85 is shown a general plan of the works.

The Blast-Furnaces F are four in number, about 50 feet in height by 16 feet diameter at the boshes, each supported on eight cast-iron columns and enclosed in plate-iron casings. Two of the furnaces have closed tops, and are fitted with Cowper's regenerative hot-blast stoves R, one to each furnace. Each stove is 54 feet high to the springing of the dome, and 24 feet diameter; these were the first regenerative fire-brick stoves erected in Scotland. The two furnaces with the regenerative stoves have each a weekly output of 220 tons, as against 180 tons from the two open-topped furnaces worked with pipe-stoves P. The blast is heated to a temperature of from 1,400° to 1,500° Fahr. As the furnaces work on raw coal, the large surplus of gas in excess of that required for heating the blast and raising steam for the blowing-engines is being utilised as fuel in other departments; and ultimately no raw coal will be used in the works except that put into the blast-furnaces. With this object it is proposed shortly to blow in another furnace; but before doing so certain improvements are being carried out, which it is hoped will still further reduce the cost of production, in addition to yielding a full supply of gas for all the departments of the works. These consist principally in increasing the total height of the furnaces to 68 feet, so as to give a working height of about 60 feet, which is the greatest height that a column of raw coal can stand without crushing; and also closing the top, and fitting an additional regenerative hot-

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blast stove and dust-catcher. At present, as gas is being collected from two furnaces only, the supply has to be supplemented from special gas-producers, consisting of plain plate-iron cylinders, charged by means of a bell and hopper, and provided with suitable tuyeres, into which air is forced by the blowing-engines at such a pressure as to balance that of the gases given off by the blast-furnaces. An independent supply of gas is thus available for the other departments of the works, in case the furnaces should be damped down at any time.

A gantry G is to be provided for storing minerals on the furnace bank. Wagons can neither be run direct on to the top of the gantry, nor even in a line parallel to it, but are delivered below at right angles, and raised at the western end by a hydraulic hoist H, which works in spiral guides making about a quarter turn during the ascent, so as to deliver the loaded wagon upon one or other of two roads running along the length of the gantry. Along these they are hauled by a hydraulic capstan, and descend empty at the eastern end by a spiral drop D similar to the hoist. On reaching the ground they run by gravity into sidings.

There are two vertical blowing-engines E with blowing cylinders 78 inches diameter by 48 inches stroke; and one beam-engine E with blowing-cylinder 102 inches diameter by 120 inches stroke. Steam is supplied from eleven double-flued Lancashire boilers B. Near the beam-engine are the pumping-engines for raising water for the blast-furnace tuyeres, &c.; and the hydraulic engines A, accumulators, &c., for supplying hydraulic power throughout the works.

The Heavy Foundry is one of the most modern of the structures of the old works, and is being worked in with the new in order chiefly to preserve it as a memorial of the past. Here many of the old "carronades" were cast; but latterly the work done has consisted chiefly of sugar pans, dyers' pans, stills, &c. When remodelled and completed, the building will be 154 feet long by 80 feet wide, and will be fitted with two overhead travellers capable of lifting from 25 to 30 tons, while the whole floor-space is commanded by light hydraulic cranes fixed either to the walls, or to the line of pillars running down the centre of the building. For the better class of

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castings reverberatory gas-furnaces will be used, but for ordinary purposes the iron will be melted in cupolas. Two of these cupolas are erected at present, and space has been provided for two more. They consist of wrought-iron shells lined with fire-brick, with an internal diameter of 4 feet throughout. The tuyeres, connected outside with an air-belt, are rectangular, each 6 inches high by 1 inch wide; and are so arranged that the direction of the blast is not towards the centre, but tangential to a circle of 12 inches diameter. On the top are a number of baffle-plates for catching the dust and preventing it from lodging on the roofs of the buildings. Similar cupolas are in use in the Light Foundry, where they have proved very successful. Each is capable of melting from 12 to 15 tons per hour, according to requirements. They are worked with a blast pressure of 2 lbs. per square inch, and the consumption of Scotch coke (Gartshore) is under 200 lbs. per ton of iron melted. There are two large moulding pits, one 30 feet diameter and 18 feet deep; the other elliptical, 50 feet by 30 feet, and 12 feet deep. As they are only 33 feet above mean sea-level, special precautions have to be taken to guard against water. An 18-inch tramway is being laid down, to be worked by locomotives. When complete, the foundry will be partially supplied with molten iron direct from the blast-furnaces.

The Stove-Brick Works are adjacent to the Heavy Foundry, and are specially designed for the manufacture of bricks required for the stoves, ranges, and register grates produced in the Light Foundry. Fire-clay of the finest quality is procured from the colliery adjoining, and is suitable for making the best fire-bricks, especially those used for the combustion chambers of regenerative hot-blast stoves, reverberatory furnaces, &c. The three kilns are small, as the demand for stove bricks is limited; they are not regenerative, but whenever they require to be rebuilt they will be made so. The only fuel used is blast-furnace gas. The drying shed has a floor-space of 90 feet by 66 feet, with a series of flues underneath, through which the waste products from the kilns circulate. There is an overhead tramway for distributing the ground clay to the several moulding tables.

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The Light Foundry occupies the whole of the low-level area of the works. The goods here manufactured consist of ships' and steamers' cooking apparatus and ship fittings, stable and cattle-house fittings, cooking ranges and stoves, register stoves, rain-water and sanitary goods, smithy and general workshop fittings, garden furnishings, cart bushes, and pots and pans. The peculiarly soft quality of the Carron iron enables it to be run into the finest moulds, and renders it specially suitable for castings in which lightness and strength and finish are required. The foundry forms a quadrangle round an open space, in which are the loading platforms L for the despatch of goods by rail, and a commodious basin for despatch by canal. The moulding shops have an area of 10,044 square yards, with ample provision for future extension; and are laid with tramways throughout, on which in many cases the molten metal, even for the finest castings, is conveyed to a distance of 200 yards before pouring. The blast-furnace gas is utilised for drying ladles, heating core-stoves, sand-kilns, &c., lighting up cupolas, and for almost every purpose for which coal is usually required in a foundry. The dressing shops are provided with the ordinary rumbling and emery-wheel appliances.

On the south side of the quadrangle are the Fitting shops C, with a floor area of 3,442 square yards. Here cooking apparatus of all kinds for sea and land, fittings for builders' use, or for stables and cattle houses, are put together. Every special piece of cooking apparatus is put to a practical test before being turned out. Adjoining the fitting shops is a grinding shop J containing fourteen stones, and the same number of sets of emery wheels, buffs, &c., arranged in two rows and driven from a central line of shafting. Over each line of machines is an overhead tramway for changing the stones when required. The shop is kept at a uniform temperature by the waste steam, which is also led into the grindstone troughs for tempering the water during cold weather. Another adjunct to the fitting shops is a sheet-iron workshop, and Berlin blacking shop K. For the best Berlin black work as many as four coats of enamel are required. The various articles are dried in kilns and stoves, and the several coats of enamel ground down with pumice stone, much in the

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same way as in coach painting. These kilns are fired during the night with blast-furnace gas, which is shut off during the day; but, owing to the mass of brickwork, a practically uniform temperature is maintained.

From 2,000 to 3,000 tons of castings are usually kept on hand in the extensive warehouses, which occupy a considerable part of the range of two-storey buildings forming the eastern boundary of the works. The central portion of the upper flat is taken up by the general offices, in which is conducted the whole of the business, comprising besides the ironworks the management of large hæmatite ore mines in Cumberland, and of other estates, and the independent business of public carriers.

YOUNG'S PARAFFIN LIGHT AND MINERAL OIL WORKS.

These works are situated less than halfway from Edinburgh to Glasgow, at Addiewell, Bathgate, and Uphall. At Addiewell is carried out the whole process of the manufacture of mineral oil from the shale containing it, until a pure clear oil is obtained and solid paraffin manufactured into candles. The retorts in use are the Henderson. The Pentland retort, in use at the Uphall works, is heated by gaseous fuel, admitting of the ammonia and tar contained in the coal being utilised as well as the heat; and it has a chamber at the top which partially purifies the crude oil, and thereby saves a subsequent distillation. The shale is first introduced into the iron top of the retort, where a gentle heat is applied for distilling certain of the products; and is afterwards dropped into the firebrick bottom chamber, where a high heat is applied and a large yield of ammonia liberated. The separation of the solid paraffin is aided by means of refrigerators worked with air, ether, or ammonia. The three works together turn out annually 6,500,000 gallons of burning oil, 800,000 gallons of naphtha, 10,000 tons of heavy oil, 6,500 tons of solid paraffin, and 3,000 tons of sulphate of ammonia; and they employ 3,000 people.

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BROXBURN OIL WORKS.

These works, established in 1878, cover 170 acres of ground, and are situated in the middle of their shale field of 4,000 acres. The raw material of their manufacture is bituminous shale, mined similarly to coal. The products are sulphate of ammonia; coke; naphtha; burning oils with specific gravities from 0·800 to 0·845 and flashing points from 100° Fahr. to 260° Fahr., Abel test; lubricating oils with specific gravities from 0·865 to 0·895; match paraffin; paraffin wax, refined and semi-refined; and paraffin candles. There are about 800 retorts, capable of distilling 1,000 tons of shale a day; and a refinery to refine all the oil and wax, about 10 million gallons of crude oil per annum. Over 1,600 men are employed at the works.

The shale on coming from the mines is dropped from the hutches or wagons into breaking machines; and after being broken is collected into a hopper below, whence it drops into the charging hutches. These are taken by endless rope to the top of the retort benches, and tipped direct into the retorts. The shale undergoes distillation in the retorts for sixteen hours, until it is exhausted of its oily and ammoniacal products. The spent shale is then allowed to drop from the retort while hot into the furnace beneath, where the carbonaceous matter still left serves as fuel for the next charge. The earthy residue left after burning is dropped into hutches beneath, and passed while red-hot into a pond and cooled; it there does further useful work in evaporating the dirty water of the works, and thus prevents river pollution. The hutches are then taken on by an endless chain, and the cooled residue is tipped on the waste heap. The transference of material is throughout done by gravitation, without shovelling; and manual labour is thus reduced as far as possible. The special features of the retorts are the use of the spent shale as fuel, and the automatic regulation of the temperature; they thus require no skilled labour, and on account of the equable heat the crude oil is of a particularly good quality, giving the best finished products. The products of distillation after condensing are passed through separators, where the oil readily parts from the water, the oil floating on the top. The ammonia

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water is passed through a column still, where it is converted into sulphate of ammonia; this kind of still is most efficient, and is very economical as to fuel. The crude oil is pumped to the refinery, where it is subjected to several distillations; these are continuous, and thereby a great saving is effected in plant, labour, and fuel, as well as the most thorough separation of the different products from one another. Between the distillations, the various oils are treated, in large stirring tanks of about 13,000 gallons capacity, with oil of vitriol and afterwards with caustic soda. Both chemicals separate a black tar, which, after recovery of the chemicals from it, is used for firing the stills. The heavy oil containing paraffin, obtained at the end of the distillations, is first cooled by the atmosphere and afterwards by freezing machines to a very low temperature, and is passed through filter presses. The final cooling is carried out in an apparatus of special construction, in which the refrigeration is effected slowly, in order to make the scale crystalline and easily separated from the oil. The oil is refined for lubricating purposes; and the solid paraffin scale is pressed and refined for candles, the softer scale going for match paraffin. The candle works are capable of turning out about 16 tons a day; but owing to the smaller demand in summer the make is then reduced to about half that quantity. The large quantity of sulphuric acid required in the purification of the oil is made at the works, platinum stills being used for the concentration.

BURNTISLAND OIL WORKS.

These works, standing prominently on the hill of Whinnyhall, on the south coast of Fife, were established in 1881. The extent of their shale fields is about 1,500 acres; and the chief characteristics of the shale are its richness in paraffin scales or wax, and its freedom from impurities. The process carried on is the distillation of shale, and the manufacture of sulphate of ammonia, paraffin scales, lubricating oils, and burning oils. The retorts, stills, and other appliances are of the newest and most improved kind, including the ammonia and ether refrigerator for cooling the paraffin scales. The

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works have lately been largely extended by the erection of a wax refinery and candle factory, with all the latest improvements; these are situated at a short distance from the oil works. Both works are connected by a branch line with the North British Railway at Kinghorn station; they give employment to about a thousand persons.

LINOLEUM AND FLOOR-CLOTH WORKS, KIRKCALDY.

In these works, the property of Messrs. John Barry, Ostlere and Co., the first process in the manufacture of linoleum is the production of oxidised linseed oil, which forms the agglutinating material. The oxidation is effected in a tall building kept at a high temperature by steam pipes; within it are hung large sheets of a coarse cotton fabric, over the surface of which the oil is exposed; a thin stream of oil is made to flow at intervals over the surface of each sheet, and as this film hardens under the influence of the hot air, another coating is applied, and so on until in about twelve weeks each sheet is covered to a thickness of about $\frac{3}{8}$ inch. As soon as the oxidised oil becomes thick enough to show signs of falling off the sheets, it is peeled off and is passed through rollers, which break up and mix the various layers. It is then mixed with gums and ochres, and melted up in steam-jacketed pans which are mounted on trunnions, so that when melted the contents can be readily poured into a large square mould. As soon as sufficiently set, the cake from the mould is divided into smaller portions, which are stacked ready for the next process.

The cork dust, which when mixed with the oxidised oil forms the basis of the linoleum, is obtained by grinding cork shavings between millstones, and sifting the powder so formed. The mixing of the cork dust and oxidised oil is effected in a pug mill, from which the stream issuing is cut into thin slices by a three-arm cutter revolving in front of the delivery opening. These slices are fed between heavy rollers, where each is rolled into a thin sheet in contact with a sheet of jute fabric which is to form the backing. The linoleum is produced in widths of 6 feet and 12 feet, and in thicknesses of from $\frac{1}{8}$ inch to nearly $\frac{1}{2}$ inch.

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For printing the linoleum, a ground colour when required is first applied by rollers. The printing in oil colours is done partly by hand, the 12-ft. widths being at present printed by hand only; and partly by a large multiple-colour printing machine designed by the manager, Mr. Wright, which has two drums, each nearly 30 feet diameter and over 6 feet wide, placed side by side with a short interval between them, and each driven independently by a Willans high-speed engine. The printing rollers, one to each colour, are mounted in a framing carried on a table, which traverses on a heavy bed parallel with the axis of the drums; the printing rollers are only 2 feet long, and thus print only one-third of the whole 6-ft. width of the piece of linoleum at each revolution of the drum. Each succeeding roller is adjusted at such a distance behind its predecessor that the colour it applies falls properly into its place in the pattern. The rollers are traversed laterally across the width of the piece when opposite the gap between the ends of the piece on the drum. One drum is being printed on whilst the other is being stripped. For hand printing, blocks are used about 2 feet square, which are made of wood with the brass printing surfaces mounted on them. The linoleum is passed up through the floor, over a table in front of the printer, and down again through the floor. The portion exposed on the table is surrounded by a frame furnished with suitable stops, by means of which the positions of the printing blocks are accurately fixed. Behind the printer are two short parallel lines of rails, each furnished with simple means for transferring from one line to the other a series of inking tables, which carry the different printing colours used. Each colour is in turn applied to the linoleum, the whole width being printed across with one colour before the next colour is applied. The pressure is given by hand for light patterns, and for heavier patterns by a cam worked by a lever.

The linoleum is then transferred to the drying stores, which are warmed by steam pipes, and are of such a height that 75 feet of linoleum can hang from the overhead floor in a single loop, while leaving ample head-room below. The linoleum hangs from one to three months, and is shifted from one store to another by means of

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overhead railways. The edges of the linoleum are trimmed by hand on long cutting tables.

In the manufacture of floor-cloth, the foundation is a jute fabric woven 24 feet wide, which is stretched on vertical frames in a lofty building, and the oil colour laid on with trowels from suitable stages; three coats are plastered on one side and two on the other. Each coat is allowed to harden, and its surface is scraped, before the application of the next; one side of the cloth is finished before the other is begun. The printing, storing, and cutting are effected in the same way as in the manufacture of linoleum.

The works are supplied with steam by Babcock and Wilcox boilers fitted with Juckes mechanical grates. They employ nearly 500 hands.

BLACKNESS FOUNDRY, DUNDEE.

These works were commenced in 1865 by the present firm, Messrs. Urquhart, Lindsay and Co., for the construction of machinery for weaving and finishing all heavy fabrics, such as linen and jute goods, canvas, &c., and of all the gearing and shafting necessary for such factories, and also for carrying on general engineering and ironfounding.

The main erecting shop is 167 feet by 74 feet, with a span-roofed shed annexed 84 feet by 38 feet, and beyond that a grinding-shop for stones and emery-wheels; the total floor area of these is 18,880 square feet, without any partition. Over the northern division and the western end of the erecting shop is a gallery, 32 feet wide, where light machines are erected, and all the lighter turning and tooling are done. Over the grinding-shop are four fire-proof flats, where patterns are stored. The two centre divisions of the erecting shop are served by three travelling cranes, so constructed that all the motions—travelling, traversing, and hoisting or lowering—are controlled from the floor, without the necessity of a man going aloft. These centre divisions have a clear head space of 27 feet. Over the two northern divisions a large flat for erecting small machines and for pattern-making is slung from strong roof tie-beams, so as not to interfere with the travelling cranes below. The floor space in this

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flat is 10,080 square feet, and that of the galleries is 6,384 square feet. The total floor area for tooling, pattern-making, and erecting is therefore 35,344 square feet.

The blacksmith's shop, which opens from the erecting shop, is provided with four steam-hammers, and has a floor space of 2,800 square feet. The moulding shop at its greatest length is 201 feet by 83 feet wide, and has a net floor-space of 14,450 square feet, exclusive of a recess of 2,300 square feet for the melting cupolas.

A tramway is laid throughout the whole works, and the wagons can pass under seven cranes, varying in capacity from 4 to 20 tons, thus rendering easy the transport of material.

DUNDEE FOUNDRY, DUNDEE.

These works, belonging to Messrs. Gourlay Brothers and Co., have been in existence for three or four generations, and have been added to from time to time so as to bring them up to the requirements of the present day for turning out the heaviest and best class of marine work both economically and rapidly. They are fitted with the latest improvements in machinery and hydraulic appliances. Among the larger cranes is a 50-ton traveller over the erecting shop, and two 30-ton travellers over the moulding shop, which has been recently erected, and is capable of turning out the heaviest castings very rapidly; over the boiler shop there are two travellers of 15 tons and 30 tons; while in the boiler yard there is in course of erection a 30-ton steam derrick-crane for the hydraulic riveter and the handling of heavy plates. The works are driven by a tandem compound engine, and the power is communicated by rope and friction gear.

A special feature of interest is a very old beam-engine, which has only recently been laid aside, and is the one that was originally experimented on by Mr. Stirling, who converted it into a hot-air engine; it ran for some time so altered, but was eventually re-converted to steam. Of his celebrated engine built here in 1843 no relics now remain; it had a cylinder 16 inches diameter and 4 feet stroke, making 28 revolutions per minute, and giving 45 horse-power, and did all the work of the Dundee Foundry for upwards of three

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years, during which period no other motive power was employed. It was laid aside however at the end of that time, owing to the failure of the heating vessels, which could not stand the heat they were exposed to.

TAY JUTE WORKS, DUNDEE.

These extensive works, belonging to Messrs. Gilroy Sons and Co., are entirely employed in the manufacture of jute cloth, spinning, weaving, and finishing. The jute is brought into the works as imported, in hard-pressed bales of 400 lbs. weight. These are cut open and passed through corrugated or toothed rolls for the purpose of softening. The material is then selected, and again put through another softening machine, where it is watered and oiled, which is called "batching." After this the jute is taken to the preparing, carding, drawing, and roving; then to the spinning, and then to the preparing for weaving into different fabrics. The cloth-finishing comes next; there is a very fine set of finishing mangles and calenders. There are also very large and powerful hydraulic presses for packing the finished fabric into bales. The motive power for driving the works is supplied by six separate steam engines of different types, made by Messrs. James Carmichael and Co. of Dundee, and Messrs. Hick Hargreaves and Co. of Bolton; in all indicating 2,240 horse-power. There are two large water-dripping refrigerators in the water reservoirs, for cooling the water used for condensing in the engines. The works employ about 2,000 hands.

SEAFIELD JUTE WORKS, DUNDEE.

These works, the property of Messrs. Thomson Shepherd and Co., situated at the west end of Dundee near the river, are devoted to the preparing, spinning, and dyeing of jute yarns, and the weaving of these into carpets of various kinds, as well as into sacking and horse-clothing. The number of hands employed is nearly eleven hundred; and the total power from four engines is over 1,000 I.H.P. One of these engines, a double-expansion tandem, built by Messrs. Carmichael and Co. of Dundee, and working at 300 H.P., is fitted up

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with Tate's electric stop-motion. Two others are beam engines, compounded to drive one fly-wheel, and working at 480 H.P.

MANHATTAN JUTE WORKS, DUNDEE.

These works, belonging to Mr. Frank Stewart Sandeman of the Stanley Cotton Mills, Perthshire, are constructed on the shed plan; the jute passes continuously through the various machines in the batching, preparing, spinning, weaving, finishing, and packing departments, whereby the cost of handling it is reduced to a minimum. The number of workers employed is about 700, while the whole range of qualities of jute yarns and cloth are produced. The prevailing custom of applying oil to the jute batch before it is carded is in these works superseded by a different process, and the products are therefore free from the smell and other objectionable characteristics of mineral and fish oils. The engines are a pair of horizontal compound tandem, designed by Messrs. Hick Hargreaves and Co., Bolton, and fitted with Corliss valves on each of the high and low-pressure cylinders, and with electric stop-motions throughout the mill; and they develop 1,000 I.H.P. The power is transmitted through a mortice wheel and pinion; the wheel is keyed separately from the fly-wheel, and the breadth of the teeth is 24 inches. The boilers are Lancashire or duplex-flue, and Babcock and Wilcox tubular, the former fitted with Vicars and the latter with mechanical chain stokers. Green's economiser and other appliances for preventing the production of smoke and for saving fuel have been adopted, with the result that there is practically a total absence of smoke from the top of the chimney, which is 175 feet high with a diameter of 8 feet inside at top. The coal used is Scotch dross, of which the consumption is 2 lbs. per I.H.P. per hour, and 9 lbs. of water are evaporated per pound of coal. The friction throughout the mill, including all shafting, gearing, and pulleys, does not exceed 14·75 per cent. of the whole power given out by the engines; and this favourable result is attributed in a great measure to the exclusive use of solid woven cotton belting as made at the Stanley Cotton Mills, where cotton driving ropes of a superior kind are also manufactured, as largely used at the Forth Bridge Works.

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BELMONT WORKS, DUNDEE.

These works, the property of Messrs. Thomas Bell and Sons, were established in 1832, and are chiefly employed in the manufacture of wide canvas for the foundation of floorcloth and linoleum. The great breadth of the looms, which were designed by the late senior partner and are 8 yards wide and driven by steam power, forms a striking feature of the works. Other classes of jute goods are also manufactured here.

DUNDEE HARBOUR.

The whole works of the Harbour have been constructed within the last seventy years. There are four wet docks, two old and two new; the older or western docks were completed upwards of fifty years ago; and the last new dock was completed about twelve years ago. There are two commodious graving docks, and a Morton slipway. During the last twelve or fifteen years great improvements have also been made in furnishing the docks with all the necessary appliances for rapid discharge. Vessels frequenting the harbour having lately increased greatly in size and draught of water, river wharves of timber have been built outside the stone river walls, and the berths at these wharves have a depth of 20 feet at ordinary low water. Vessels drawing more water than is to be had over the cills of the new docks, where there is about 22 feet depth at ordinary spring tides, come alongside the new river wharves and discharge part of their cargo, whereby generally they are so lightened as to be able to enter the docks during the next tides. Hydraulic machinery has been introduced, and the pressure pipes are carried around the quays of the new docks generally, and to the river wharves. Cargoes are discharged by the aid of small portable hydraulic jiggers, which are put in position to suit the hatchways of vessels, and usually make 250 lifts per hour from each hatchway. The principal manufacture of Dundee being jute fabrics, the principal importation to the harbour consists of jute bales, which arrive in large vessels, chiefly from Calcutta and Chittagong. The average cargo is 12,000 or 13,000 bales, each bale being about 400 lbs. in

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weight. They are discharged at the rate of 250 bales in an hour from each hatchway, and when the vessel is a steamer having four hatchways, the cargo can be put on shore in twelve working hours. If there is the usual amount of discharge proceeding however, it is found that the cargo cannot be classified and carted away at a greater rate than from 250 to 300 bales per hour. The quays generally possess ample shed accommodation, and there is a fine warehouse with hydraulic appliances.

Within the last twelve years the trustees have acquired the lighting and buoying of the River Tay between the harbour and the sea. One of the improvements effected has been to establish at the entrance to the river a lightship with a powerful siren. It was also found necessary to alter the direction of the leading lights, which define the channel over the bar of the river; and for this purpose the seaward lighthouse, 65 feet in height, built of brick and stone work, and weighing 450 tons, was moved bodily without interfering with its exhibited light, a distance of 160 feet, and reset in its new position on its old foundations.

The working of the ferries between Dundee and the opposite shore of Fife has also been lately acquired; and has been greatly improved by the addition of a new steamer, the erection of new offices, and the adoption of the electric light on the steamers, as well as in other ways.

The entrance to the harbour has been much improved within the last seventeen years, $1\frac{3}{4}$ million tons of deposit having been dredged from opposite the entrances, whereby the bed of the river has been deepened on an average about ten feet, and some fifty acres of land have been reclaimed from the river on the east side of the docks, about half of which has already been occupied by shipbuilders and timber merchants.

UNIVERSITY COLLEGE, DUNDEE.

This College was opened in 1883, under an endowment of £150,000, of which nearly the whole was given by the late Miss Baxter of Balgavies. There are now six professorships:—of classics and ancient history, mathematics and natural philosophy, chemistry,

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engineering, English literature, and biology. An effort now in progress for the extension of the college, by the addition of a medical school, has already led to the endowment of a chair of anatomy and a lectureship in botany. A new Technical Institute, founded and endowed by the late Sir David Baxter, is now being built within the college grounds, and will be worked in close connection with the scientific department of the college.

The greater part of the present structure consists of dwelling houses converted into class-rooms and laboratories; but new buildings have been erected for the accommodation of the chemical department, in which there is a very fully equipped laboratory, and also for the electrical engineering laboratory, for the physical lecture-room, and for a small workshop which is used for the construction of laboratory apparatus, for experimental work in engineering, and for the electric lighting of the drawing office and other rooms. Besides these laboratories there are others for the subjects of natural philosophy and biology. It is arranged that the Technical Institute now in process of construction shall provide accommodation for the whole engineering department of the college. An important feature in it will be an engineering laboratory containing a 50-ton testing machine, an experimental steam-engine, etc.

The chemical department affords an interesting example of the system of ventilation by pressure. It is about to be extended by the addition of an establishment for dyeing and bleaching.

EDINBURGH WATER WORKS.

The city of Edinburgh and the adjacent district derive their present supply of water from two main sources, namely the Pentland Hills and the Moorfoot Hills, as shown in the plans, Plates 86 and 87.

Pentland Supply.—Plate 86. The Pentland supply consists chiefly of spring water, most of which is conveyed direct to the city in pipes; and the yield of the springs being subject to very little fluctuation in quantity, a comparatively small amount of storage is all that is

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required to equalise the available discharge throughout the year. There are however several small reservoirs, which are used for this purpose; and they also serve to store the water of the adjacent district naturally draining into them. In connection with the supply of spring water, several compensation reservoirs have been constructed, the water of which being of a peaty nature is not suitable for drinking, but is now used to afford compensation in water power to the mills on the streams into which the spring water appropriated for Edinburgh naturally flowed.

Moorfoot Supply.—Plate 87. The Moorfoot supply differs from the Pentland in being entirely a surface-water supply. Two reservoirs have been constructed, namely the Portmore and Gladhouse reservoirs, for impounding the water naturally draining into them, for the purpose of affording a supply for domestic purposes; and two compensation reservoirs, Edgelaw and Rosebery, have been constructed for the purpose of affording compensation to the streams on account of the water abstracted. The capacity of the reservoirs is fixed as equal to six months' yield of the district draining into them, which experience has proved to be sufficient for equalising the yield of three dry years consecutively.

All the embankments of these reservoirs are constructed upon much the same principle, and consist of earthwork formed in thin horizontal layers, with a puddle wall in the centre of the bank, which is continued down through a trench till a water-tight foundation is reached. These embankments are formed with slopes of 3 to 1 inside and 2½ to 1 outside, while the level of the bank is generally 5 or 6 feet above the level of the waste-weir crest.

The waste weirs are formed of masonry, and the channels leading from them consist of alternate flat gradients and flights of altar steps.

Gladhouse and Portmore reservoirs have upstand shafts standing free of the embankment, so that the water may be drawn off at different levels, with the view of securing the purest water nearest the surface; while the compensation reservoirs have the sluice shaft in the centre of the embankment, where the water is always drawn off at the bottom level, as its quality is of no importance.

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Edinburgh Waterworks Reservoirs.

Works.	Name of Reservoir. *See* Plates 86 and 87.	Distance from Edinburgh.* By Road.	Distance from Edinburgh.* By Pipe.	Size of Reservoir. Surface Area.	Size of Reservoir. Greatest Depth.	Size of Reservoir. Storage Capacity.	Embankment. Greatest Height.	Embankment. Total Content.	Drainage Area.	Cost. Approximate Total.	Cost. Per Million Cubic Feet of Storage.
		Miles.	Miles.	Acres.	Feet.	Gallons.	Feet.	Cub. yards.	Acres.	£	£
PENTLAND.	Castlehill	0·30	..	..	30	1,715,625	30	..	..	10,153	..
	Torduff	5·60	4·90	11¾	80	112,500,000	85	177,600	758	13,467	748
	Clubbiedean	6·20	5·50	12¾	44	65,625,000	55	69,052	250	6,021	573
	Bonally	6·60	..	14½	25	53,125,000	32	37,074	110	3,500	411
	Harlaw	8·00	..	30½	64	168,750,000	67	72,968	3,934	7,778	288
	Threipmuir	8·50	..	112	23	206,250,000	29	34,552	3,613	10,000	303
	Glencorse	8·30	9·50	52	62	359,373,000	77	86,335	3,964	43,000	747
	Loganlea	10·30	..	18½	55	121,875,000	59	102,000	1,426	11,364	582
	Harper Rig	12·20	..	173½	38	562,500,000	36	54,587	4,217	11,548	128
	Crosswood	16·00	..	62	40	175,000,000	48	88,061	2,113	20,686	738
MOORFOOT.	Alnwick Hill	3·60	3·30	5	24	19,904,263	33	107,521	..	18,800	..
	Edgelaw	13·16	..	37	80	275,000,000	93	93,050	6,363	35,000	795
	Rosebery	13·68	..	52⅓	75	381,250,000	84	175,403	7,751	33,000	541
	Gladhouse	15·86	13·42	399	68½	1,713,356,000	79	152,349	6,131	63,400	231
	Portmore	17·37	16·95	102½	12½	250,000,000	16	16,068	610	12,500	312

* The distance by road is from the Mound in Princes Street; that by pipe is from Castlehill Reservoir.

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The water is conveyed towards Edinburgh partly by a built aqueduct and partly by a pipe; of the latter a portion is 24 inches diameter and the rest 22 inches. The water is subjected to a process of filtration at Alnwick Hill, where the works consist of a service reservoir, four filter-beds, and a clear-water reservoir, from which last the water is led to Edinburgh and the adjacent district of supply. There are seven separate pipes leading the water into Edinburgh, and at present the district of supply is being divided up, so that it may be arranged for each pipe to serve its proper district.

In Plates 86 and 87 are shown the drainage areas and the positions of the various reservoirs; and the accompanying Table (page 461) gives details as to their capacity and cost, &c.*

ESK PAPER MILLS, PENICUIK.

These mills, belonging to Messrs. James Brown and Co., are situated in the valley of the North Esk within 8 miles of Edinburgh, and close to the Eskbridge station of the North British Railway. When established in 1790, they turned out probably not more than one ton of paper per week. About 1815 new buildings were erected and new machinery was introduced, including a Fourdrinier machine and powerful steam-engines. New machinery has since been gradually introduced to the present time, and the mills now produce 100 tons of paper per week. The raw materials consist chiefly of esparto grass and rags; and the processes through which they pass before becoming finished paper are dusting, boiling, bathing, bleaching, pressing, beating, making, calendering, cutting, sorting, and baling. The raw material, run by a siding from the railway direct into the mills, is first thrown into the dusting machine, where it is shaken about, and the dust extracted by a powerful exhaust fan. It is then conveyed by a series of endless felts to the boiler, where it is at once violently beaten down by a

* A full description of the Edinburgh Water Works was contributed by Mr. Alexander Leslie to the Institution of Civil Engineers (Proceedings, vol. lxxiv, 1883, page 91), from which the Table here given has been abridged.

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continuous shower of boiling alkali. After the boiling, which occupies about eight hours, the grass is forked loosely into open vats, and is bathed with tepid water and drained of alkali. In the bleaching cisterns, which have semicircular ends and are fitted with revolving knives, the grass is then pulped, partially opened out, and slightly rinsed with pure water, and then bleached; after which the pulp is treated in the "presse pâte" machine, to remove all remaining sand or grit, and knots, roots, heather, etc., and is delivered in rolls into boxes, having thus been thoroughly prepared without any hand labour. In the beating engine the fibres of the pulp are drawn out into a finely divided condition, and the colouring and sizing materials are added. The beating engines are driven by a compound engine working up to nearly 600 I.H.P. There are four paper-making machines, one of which is 120 feet long and delivers paper 76 inches wide at any speed from 20 feet to 150 feet per minute, according to the thickness or quality required. The calendering machines are fitted with cotton and chilled-iron rolls, and by means of compound levers great pressure is exerted upon the paper sheet. In the cutting machines, six or eight sheets can be cut at a time. The plant and general machinery are of the newest and most approved kind; while the arrangements for using waste liquors over again and for preventing pollution of the river are very complete. At night the works are lighted up mainly with the electric light, which is useful for matching colours. The number of workpeople employed is about 300.

VALLEYFIELD PAPER MILLS, PENICUIK.

These works were established in 1708, and since 1770 have been the property of Messrs. Cowan. The paper here manufactured is used for a great variety of purposes. It includes ledger papers, similar to the well-known American papers, tub-sized by hand and loft-dried; also animal-sized writing, book, and drawing papers, from the highest quality downwards; printing paper of the ordinary character for book-work, and super-calendered for illustrated books and serials; and tough cartridge and ammunition papers for the government offices. The principal processes in the manufacture are

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selecting and preparing the fibres, boiling with caustic soda, washing, bleaching, sizing, treating with antichlor, colouring, beating to pulp, and running upon a machine to form paper. The treatment of esparto grass is by the boiling processes of Roeckner and Sinclair with a caustic solution; this while still hot is floated into an evaporator, and incinerated to recover the soda, which is obtained chiefly in the form of the carbonate mixed with silicate and other salts. The offensive odorous gases evolved during the process of incineration are carried, according to MM. Porion and L'Espermont's plan, into a smoke-consuming chamber, where they are allowed to expand and burn, and their unpleasant smell is thereby got rid of. In Porion's evaporating plant the caustic solution is beaten into froth by revolving fans working in a tunnel of hot air; the froth bubbles expose a large surface and evaporate quickly, making the liquor thicker and more ready for the furnace. Amongst the machines is a very large Forbes rag engine for beating the stuff, capable of making sixteen tons of paper per week; one 78-inch, two 71-inch, and two 68-inch paper-making machines; three long air-driers composed of about eighty drums each; an automatic paper-winding machine, the axle of which revolves upon an inclined way; cutting machines; and many glazing and calendering rolls. A 71-inch paper-making machine makes the paper entirely from esparto. In order to avoid polluting the river, the floor washings and machine waters are conducted separately down tortuous channels where suspended matter is deposited, and are then led by a single channel to a filter bed, and thence finally to the river. The channels are cleaned periodically; the pulp deposited in the machine-water channel is flushed into a tank through sluices at the bottom of every two lengths of channel, and is dried and sold to packing-paper makers. The boiler waters are purified in a similar manner, assisted however by chemical precipitation. The deposit on the filter beds is cut out and wheeled away. The process of preparing gelatine size from hide pieces and cuttings is also carried on at these works. The mills are supplied with the finest spring water, conducted in pipes from about three miles distance. On the top of a hill there is a chimney shaft communicating with the boilers through a bricked

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archway running up the steep hill side. The seventeen steam boilers are fed with dross coal by self-acting feeders; economisers raise the feed-water to a temperature of 220° Fahr. The motive power is supplied by numerous steam engines, ranging from 6 to 200 I.H.P., and amounting to about 1,200 H.P. in all.

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MEMOIRS.

William Barber Buddicom was born in Liverpool on 1st July 1816, being the second son of Rev. Robert Pedder Buddicom of Everton, afterwards principal of St. Bees College. After serving a five years' apprenticeship from 1831 to 1836 with the old-established firm of Mather Dixon and Co. in Liverpool, he was engaged in his twentieth year as resident engineer on the Newton Bridge section of the Liverpool and Manchester Railway under Mr. Edward Woods, which position he occupied for two years, and during the time carried out many important works on the line. In 1838 he became resident engineer on the Glasgow Paisley and Greenock Railway under Messrs. Locke and Errington, where he remained until 1840, when he was appointed locomotive superintendent of the Grand Junction Railway, and prepared the plans and estimates and laid the foundation of the original Crewe Works. Here he introduced the system of premiums to engine drivers for economy in consumption of fuel and oil, with such good results in reducing the working expenses of the line that the plan has since become almost universally adopted. In conjunction with Mr. Locke he designed the original Crewe outside-cylinder engines. In 1841 he went to France, on the invitation of Mr. Locke, the engineer of the Paris and Rouen Railway, to erect works near Rouen for constructing the rolling stock for that line. Under the firm of Allcard Buddicom and Co. he started an old millwright's shop at Les Chartreux, a suburb of Rouen, pending the building of extensive works at Sotteville, on the line of the railway; and he worked the line from its opening in 1842 till 1860. In 1848, when all the other railways were in the hands of the "Clubists," it was mainly through his exertions that the Paris and Rouen line was not handed over to them. In 1851 Mr. Allcard retired, and the firm became Buddicom and Co., by whom the additional sections of the line were also worked

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as they were successively opened. All the rolling stock for these lines was made to Mr. Buddicom's designs, as was also a great portion of that for the Amiens and Boulogne, the Orleans and Tours, the Southern of France, and other railways. The Sotteville Works employed from 1500 to 2000 men. In 1847 he received the dignity of Chevalier of the Legion of Honour for his distinguished services. After 1860 he was associated with Messrs. Brassey, Parent, Scharcken and Co. in making the Bellegarde Tunnel on the Lyons and Geneva Railway, the Maremma Railways, and the Southern Railways of Italy; and was also interested in the Mont Cenis mountain railway on Fell's system. In 1864 he retired from professional work, and settled in Flintshire, of which county he was a magistrate, and filled the office of high sheriff in 1864. He became a Member of this Institution in 1874; and was also a Member of the Institution of Civil Engineers, and of the Société des Ingénieurs Civils of France. His death took place on 4th August 1887 at the age of seventy-one, at his residence, Penbedw Hall, Mold, Flintshire.

Edward Fletcher was born in Manchester on 9th September 1840, and was the third son of the late Mr. James Fletcher, of Messrs. William Collier and Co., engineers and machine-tool makers, Salford, who was a Member of this Institution till his death in 1881. At the age of fourteen he was placed in the drawing office of these works, of which his father was then the sole proprietor; and in 1876 he was made a partner in the firm, along with his two younger brothers, Joseph Fletcher and David Hardman Fletcher. From 1866 to 1876 he had entire management of the foundry belonging to the firm; and since the death of his brother, David Hardman Fletcher, in 1884, he had the entire control and management of the business until his death. He was thoroughly acquainted both practically and theoretically with the manufacture of machine tools. He died on 27th June 1887 at the age of forty-six, after a short illness. He became a Member of this Institution in 1885.

Major-General Henry Hyde, Inspector-General of railway stores at the India Office, and formerly of the Bengal Engineers, was

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born at Camberwell, London, on 8th November 1824. He entered the service in 1844, and after remaining at the Chatham depôt for two years proceeded to India, arriving at Calcutta in June 1846. His active service commenced in the following year, when, in the execution of his duty in connection with the frontier roads in the Cis-Sutlej states, he was attacked and wounded. In 1849 and 1850 he was engaged in the campaign that commenced with the siege of Moultan, at which he was present and for which he received the medal and clasp; the campaign ended with the battle of Goozerat, in which he also took part. After performing various services as a military engineer, including the charge of the frontier forts in Peshawur, and the expeditions against the Momaunds and the Sitana Fanatics, under General Sir Sydney Cotton, he was selected for various appointments of a civil nature. He was deputy consulting engineer in the railway departments of the North-West Provinces and of Bengal respectively in 1859 and 1860: inspector-general of Public Works accounts and officiating secretary to the government of Bengal in 1861. In the same year he was appointed to officiate as master of the Calcutta Mint, and in the following year, on the death of Colonel Baird Smith, was confirmed in the appointment. He also organised and superintended the paper currency department from 1862 to 1870, for which he received the thanks of the Governor-General in Council. During his time the Mint was raised to a state of high efficiency, and was considered in some respects to be in advance of that in London. He was president of the committee for the defence of the River Hooghly by torpedoes, and government director of the Bank of Bengal from 1870 to 1876. He was a fellow of the University of Calcutta and a member of the senate; also President of the Asiatic Society there. He continued to be master of the Mint till 1876, when he left India. On his return to England he was selected, on account of his peculiar qualifications, to be Inspector-General of railway stores at the India Office, and held that appointment at the time of his death, which took place on 23rd September 1887, in the sixty-third year of his age. He became a Member of this Institution in 1865.

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Thomas Routledge, of Claxheugh, near Sunderland, was born in London on 22nd September 1819, and was educated by Rev. Dr. Lord, of Tooting. His father had intended him to follow his own business of a wine merchant; but finding that his heart was set upon chemical and scientific pursuits, he wisely allowed him to follow the bent of his inclinations. Accordingly when quite a young man he became connected with Coad's works at Lambeth, and afterwards with copper smelting works in South Wales. He was thus impelled to give attention to the study of mineralogy and practical mechanics. Possessing a quick and discerning mind, he invented many new appliances whereby the cost of labour might be reduced, and the manufacture of useful articles from mineral products be effectively and profitably carried out. Having become acquainted with the Marquess of Besano, who had been devoting his attention to the use of fibrous substances in the manufacture of paper, he took up the idea at once, and spent much of his time at Kew Gardens in order to find out what fibrous materials could be best employed for the purpose. In the result he rented an old paper mill at Eynsham, near Oxford, and there began to manufacture paper from esparto grass, being in fact the very first manufacturer who did so. Having visited Spain to see the grass growers themselves, he entered into contracts with them for their produce, and thus introduced Spanish grasses into the English market. He very soon found however that, if he wished to make his enterprise a profitable one, it must be carried on upon the sea-coast, where the esparto could be imported direct to the works, and a corresponding reduction be effected in working expenses in other respects also. He therefore established the Ford Paper Mills at South Hylton, on the Wear, near Sunderland, as a centre from which this new trade could be carried on. Here his sound practical mechanical experience and scientific attainments found ample scope for application, in replacing old appliances and devising new processes; and he carried out his designs in a manner that secured for himself and for his paper a high place in public estimation. Eventually indeed he became the chief English authority upon all questions affecting the paper industry; and references made to him in the reports of the Kew Gardens, as an

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expert upon fibrous substances, sufficiently show the value attached to his opinions by those who were best qualified to judge of them. His death took place in London on 17th September 1887, in the sixty-eighth year of his age. He became a Member of this Institution in 1880, and was also connected with many other scientific and learned societies.

Eli Spencer, son of Edmund Spencer, was born at Ashton-under-Lyne on 23rd October 1823. After receiving his education at Mr. Sunderland's school, he entered in 1837 the workshops of Mr. John Stanley, Jun., Dukinfield, where he passed through the preliminary stages of turning, fitting, &c. Two years later he was articled to serve the remainder of a seven years' apprenticeship with Messrs. Hibbert, Platt and Sons, Hartford Works, Oldham, and was placed under the supervision of Mr. William Richardson, at that time a leading workman of the firm. During this period he was fitting and setting up machinery in the works and in the mills of the immediate neighbourhood, and studying mechanical drawing after working hours. In 1845–6 he was associated with Mr. Richardson in the first drawing office started by Messrs. Hibbert, Platt and Sons, where he remained until the Hartford New Works were built, when he was sent there to take charge of the drawing office and to assist in the management generally. In 1848 he was engaged in erecting machinery in a mill at Magdeburg; and in 1851 was appointed to represent the firm of Messrs. Platt Brothers and to superintend their exhibit at the International Exhibition in London. In 1858, after the death of Mr. James Platt, he became general assistant to Mr. John Platt; and in 1859 was given an interest in the business, becoming a partner in 1864, and a managing director in 1868, which position he filled until his retirement through ill-health in 1880. He shortly afterwards went to reside at Fulshaw Park, Wilmslow, where his death took place after a short illness on 5th September 1887, in the sixty-fourth year of his age. In 1863 and 1864 he was associated with Mr. John Platt and Mr. John Dodd in improvements in mules for spinning cotton, wool, &c. In connection with most of the international exhibitions he took a

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leading part; and in association with Mr. John Platt and Mr. John Robinson assisted Mr. Cobden in his enquiry respecting the treaty of commerce with France, for which service he afterwards received on 23rd January 1860 a diploma and medal from the late Emperor of the French. His thorough technical experience of machine making was combined with a knowledge of the economical questions bearing upon cotton spinning, and with excellent commercial abilities. He became a Member of this Institution in 1866, and in 1880 he contributed a paper on recent improvements in the machinery for preparing and spinning cotton (Proceedings, page 492), having previously aided in the preparation of Mr. John Platt's paper on the same subject in 1866 (Proceedings, page 199).

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Institution of Mechanical Engineers.

PROCEEDINGS.

September 1887.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Friday, the 30th of September 1887, at Half-past Seven o'clock p.m.; Edward H. Carbutt, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council and that the following thirty-three candidates were found to be duly elected:—

MEMBERS.

Colonel Ahmed, Bey,	Constantinople.
William Arrol,	Glasgow.
William Beardmore,	Glasgow.
Alexander Richardson Binnie,	Bradford.
Henry Brier,	London.
Edward Kynaston Burstal,	Oxford.
Emery John Caiger,	London.
Thomas Carlyle,	Woolwich.
Joseph Crawhall Chapman,	London.
John Coulman,	Hull.
Alexander Crabbe,	Serampore.
George Benjamin Cutler,	London.
James Deas,	Glasgow.
Alexander Gordon,	Hamilton, U.S.

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THOMAS HENRY HARRISON, . . .	London.
ROWLAND WATKIN LEWIS, . . .	Wolverhampton.
DAVID MICHAEL LITSTER, . . .	P.W.D., India.
KENNETH LUPTON, ...	Leeds.
FREDERICK BLUMENTHAL MILES, . .	Philadelphia, U.S.
WILLIAM MILNE, ...	Natal.
JOHN PLACE, ...	London.
JOHN RIEKIE, ...	Rawal Pindi.
ALEXANDER SPENCER, ...	London.
JOHN PETER SUVERKROP, . . .	Edinburgh.
EDWARD HIRST THWAITES, . . .	Bradford.
ALEXANDER TURNBULL, . . .	Glasgow.
GEORGE WINMILL, ...	N. W. Ry., India.

ASSOCIATES.

ENOCH HIND, ...	Nottingham.
EDWARD HERMANN NEVILLE, . .	Liverpool.

GRADUATES.

BRUCE LAING BREMNER, . . .	Preston.
JOHN EDWARD PATERSON, . . .	Sydney.
JOHN MORGAN PRICE-WILLIAMS, . .	London.
WILLIAM WADE FITZHERBERT PULLEN, .	Cardiff.

The PRESIDENT announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and that the list of those retiring was as follows:—

PRESIDENT.

EDWARD H. CARBUTT, . . .	London.

VICE-PRESIDENTS.

DANIEL ADAMSON, ...	Manchester.
JOSEPH TOMLINSON, ...	London.

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MEMBERS OF COUNCIL.

SIR JAMES N. DOUGLASS, F.R.S., .	London.
ALEXANDER B. W. KENNEDY, F.R.S., .	London.
R. PRICE-WILLIAMS, . . .	London.
E. WINDSOR RICHARDS, . . .	Middlesbrough.
T. HURRY RICHES, ...	Cardiff.

All the above had been nominated by the Council for re-election; and in addition the following nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Member.	MEMBERS OF COUNCIL.	
1862.	SIR DOUGLAS GALTON, F.R.S., .	London.
1869.	ARTHUR KEEN, . . .	Birmingham.
1873.	JOHN G. MAIR, ...	London.
1882.	ALBERT E. SEATON, . .	Hull.
1884.	JOSEPH W. SWAN, . . .	London.

The PRESIDENT reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

No other names were added.

The PRESIDENT announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The following letter from the Association of Engineers from Liége University was read by direction of the President:—

Monsieur Alfred Bache, Le 25 septembre 1887.

Secrétaire de l'Institution of Mechanical Engineers,

L'Association des Ingénieurs sortis de l'Ecole de Liége m'a chargé de vous envoyer, ainsi qu'à Monsieur Chapman, Secrétaire honoraire du meeting de Londres (1886), un faible souvenir de sa reconnaissance pour les soins que l'un et l'autre vous avez apportés à l'organisation de ce meeting. C'est grâce à vous que les Ingénieurs de Liége ont pu visiter en peu de jours les usines les plus intéressantes de l'Angleterre, et y ont été reçus avec une cordialité qui restera longtemps dans leur souvenir.

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Ils espèrent que les relations entre les Ingénieurs anglais et belges ne seront point interrompues, et se mettent à votre disposition pour le cas où il vous serait agréable de tenir de nouveau un meeting sur le sol belge.

Veuillez recevoir, Monsieur le Secrétaire, l'assurance de mes sentiments de cordialité et de confraternité.

A. HABETS,

Secrétaire général de l'Association des Ingénieurs sortis de l'Ecole de Liége.

The letter was accompanied by two bronze statuettes of Belgian make, one representing David's victory over Goliath, and the other an Improvisatore with his mandolin.

The PRESIDENT was very glad that the Belgian engineers who visited England last year appreciated what the Institution had done for them. He need scarcely say that the Honorary Secretary, Mr. Henry Chapman, had worked very hard on their behalf, and had looked very well after them; and it was therefore highly gratifying to the Institution that they had acknowledged in this handsome manner the services which he had rendered to them and to the Institution. Every one who knew Mr. Chapman, and the indefatigable zeal with which he attended to everything he took in hand, would feel sure that he had done all that possibly could be done to render the visit of the Belgian engineers agreeable and profitable to them; and whenever he looked at the presentation now made to him, he hoped it would remind him not only of that visit but also of the Institution of Mechanical Engineers. They were also much pleased that the services of their friend Mr. Bache, as Secretary, had similarly been acknowledged in the handsome present which had been made to him. He had done his very best for the Institution, and those who had the means of seeing the amount of work he did could thoroughly appreciate it. They were therefore glad that the Belgian engineers recognised how hard Mr. Bache had worked for them as well as for the Institution, and that his services had thus been so fully and kindly acknowledged.

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The Adjourned Discussion upon the following Paper read at the Spring Meeting was then resumed:—

Experiments on the Distribution of Heat in a Stationary Steam-Engine; by Major THOMAS ENGLISH, R.E., of the War Office.

The following supplementary Paper was also read:—

Supplementary Experiments on the Initial Condensation in a Steam Cylinder; by Major THOMAS ENGLISH, R.E., of the War Office.

The following Paper was read and partly discussed:—

On Irrigating Machinery on the Pacific Coast; by Mr. JOHN RICHARDS, of San Francisco.

At Ten o'clock the Discussion was adjourned; the publication of the Paper is accordingly deferred for the completion of the Discussion.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 71 Members and 32 Visitors.

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EXPERIMENTS ON THE DISTRIBUTION OF HEAT IN A STATIONARY STEAM-ENGINE.

BY MAJOR THOMAS ENGLISH, R.E., WAR OFFICE.

Read at the Meeting on 17 *May* 1887.

It recently became desirable to ascertain the most economical method of working some direct-acting high-pressure pumping engines, supplied for the late Egyptian expedition, and intended for use under the conditions of a very hot climate, great scarcity of water, high price of fuel, and difficulties of transport almost prohibitory for heavy weights. The scope of the trials was originally intended to embrace only the coal consumption, and whether it was advisable to use a surface condenser; but in carrying them out it became apparent that by somewhat extending the series, and by providing means for measuring the condensed water, some results of more general interest might be brought out; and the object of this paper is to detail these, and the methods adopted to obtain them.

The engines were constructed by Messrs. Tannett Walker and Co., Leeds, from their own designs, modified in some respects in consultation with the author. As indicated in Plate 108, which shows a general plan of the arrangement of the experimental apparatus, each engine consists of a pair of horizontal cylinders, lagged but not jacketed, 16 inches diameter by 18 inches stroke; and each cylinder drives a differential pump on the prolongation of the piston-rod, with rams of 4 inches and $5\frac{3}{4}$ inches diameter, working up to 700 lbs. pressure per square inch. The piston-rods, $2\frac{1}{2}$ inches diameter, pass through both ends of the cylinders, and are connected by a crank-shaft, which has cranks at right angles and a flywheel on each end, and is carried on a single framing, to which the cylinders are bolted. The strains are sufficiently self-contained for enabling the engines to be worked without any other foundation than three longitudinal timbers bolted together with distance blocks. Both cylinders are in one casting, weighing about 33 cwts., and this is the heaviest single piece. The

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slide-valves are on the outside, as shown in Plate 109, and are of the ordinary flat-faced pattern; the steam ports measure 10 inches by $1\frac{1}{4}$ inch, and the exhaust port 10 inches by $2\frac{1}{2}$ inches. The outside lap is $\frac{5}{8}$ inch, the inside lap nil, the travel $3\frac{1}{2}$ inches, and the angular advance of the main eccentric 23°. On the back of the main valve work flat expansion-plates without lap, over ports in the main valve which measure 10 inches by $1\frac{1}{4}$ inch; and the travel of the expansion plates on the main valve is $3\frac{3}{4}$ inches. As shown in Fig. 38, the expansion eccentric E can be clamped to the main eccentric M in any required position; and by shifting the expansion eccentric round the shaft, the cut-off can be varied by hand to any point of the stroke, the same relative movement of one valve on the other being still preserved by means of a system of levers of the author's design. Beyond this there is nothing special in the arrangement of the engines, which are well made, and drive the pumps very steadily and quietly at 40 revolutions or 120 feet speed of plunger per minute.

The engine with which the trials were made was set up at Woolwich Arsenal in connection with a portable surface-condenser on wheels, Plate 108, made by Messrs. J. and E. Hall, Dartford, for the same service as the engines. It consists of a horizontal wrought-iron barrel, 2 ft. $3\frac{1}{2}$ ins. diameter and 9 ft. 9 ins. long, enclosing 379 brass tubes of $\frac{5}{8}$ inch diameter; inside these the steam is condensed on a cooling surface of about 604 square feet. The air-pump and circulating pump are formed by the two ends of a single cylinder of 12 inches diameter and 14 inches stroke, which is fixed horizontally underneath the condenser, and they are driven direct by the prolongation of the piston-rod of a steam cylinder of 10 inches diameter; this cylinder works on a crank-axle connecting with two of the road wheels to act as flywheels, the whole machine being blocked up for working.

In actual use it was intended to work the pumping engines in pairs, each pair being supplied with steam of 80 to 90 lbs. pressure by a set of twelve multitubular boilers on wheels, each of 8 horse-power nominal. For the trials at Woolwich however it was more convenient to substitute three multitubular boilers, Plate 108, each of 40 horse-power nominal, made by Messrs. John Fowler and Co., Leeds. The

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barrels of these boilers are 4 ft. 1 in. diameter and 9 ft. 6 ins. long; they have copper fire-boxes, 3 ft. 5 ins. wide by 4 ft. 6 ins. long and 5 ft. deep to the bars; and contain 58 brass tubes, 3 ins. diameter and 10 ft. long. The grate area in each boiler is about 15 square feet, and the heating surface 548 square feet. Two of these boilers were used together in the trials, for supplying steam to one main engine, air-pump engine, and feed-pump; from the domes, which are 2 ft. diameter and 3 ft. high, the steam was led through pipes 3 ins. diameter and 21½ ft. long, into a steam main 6 ins. diameter and 19 ft. long, from which a branch 4 ins. diameter for 68½ ft. length and 2½ ins. diameter for 9¼ ft. length led to the engine, as shown in Plate 108; the surface of the steam-pipe was therefore about 141 square feet.

A jacket by which the boiler steam could be partially dried, or possibly superheated slightly, was fitted on the steam branch, Plate 108. It consisted of a 6-inch pipe enclosing a length of 51½ ft. or a surface of 54 square feet of the branch; the space between the two pipes could be filled at pleasure with steam supplied from the boiler of a small locomotive, which was kept blowing off at 140 lbs. pressure. The water condensed in the space between the pipes passed off by a drain-cock from the lowest point.

The boilers were lagged with wood and sheet iron, except at the sides of the fire-boxes; the steam-pipes were clothed throughout their lengths with strips of roofing felt. The feed-pump is of the Worthington pattern, with four rams of 3½ inches diameter and 6 inches maximum stroke. The exhaust pipe from the main engine is 4 inches diameter and 8¾ feet long, and was arranged either to exhaust direct into the air, or to be connected at pleasure with the condenser by a pipe 6 inches diameter and 13½ feet long. The air-pump and circulating pump were driven at speeds varying from 42 to 54 revolutions per minute, and a vacuum of from 26 to 28 inches of mercury was readily maintained. From 210 to 270 gallons of circulating water passed through the condenser per minute, and the rise of temperature in the water averaged about 15° Fahr. The exhaust steam from the engine driving the air and circulating pumps was condensed in a pipe 1½ inch diameter and 92 feet long, with a surface of about 36 square feet, which was immersed in cold water,

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Plate 108; the resulting condensed water was collected and measured, and the quantity was found to range from 0·09 to 0·13 lb. per revolution. The exhaust from the feed-pump was similarly condensed in a pipe 1 inch diameter and 37 feet long, with about 10 square feet of surface; and it was found that the weight of steam required to drive the feed-pump averaged 0·025 lb. per pound of feed water pumped. The water of condensation from the main engine passed from the air-pump through a pipe 4 inches diameter and 54½ feet long, at the end of which it was collected, and was transferred to a rectangular measuring tank holding 47·19 gallons, which when full was emptied into the feed-tank.

The total weight of water from the main engines is thus obtained during a trial; and when divided by the number of strokes ascertained from a counter it gives the weight of water and steam passing through the engine per stroke. It was attempted at first to ascertain the quantity of water used in the non-condensing trials, and also to check the quantity condensed in the other trials, by measuring the total feed-water supplied to the boilers during a trial, after they had been pumped up to the original level in the gauge-glasses. There proved however to be so much difficulty in ascertaining accurately the amount of water in the boilers when steam was up, and so many minor discrepancies appeared in the condensing trials, in reconciling the amount thus obtained with the quantity condensed, that this method was abandoned. The exhaust steam was therefore passed through the condenser for all the trials, the air-pump suction-pipe being disconnected when it was not desired to make use of the vacuum.

The non-condensing trials were therefore really condensing at atmospheric pressure; but the indicator diagrams so taken cannot practically be distinguished from ordinary non-condensing diagrams, while in the author's opinion the weights of water used are much more accurately obtained than by measuring the feed-water.

Hartley coal, of about three-quarters the evaporative value of best Welsh steam coal, was used throughout the trials. The average evaporation was about 7·9 lbs. of water per lb. of coal; and the rate of combustion varied from about 6·5 lbs. to 12·4 lbs. per square foot of grate per hour. No priming worth notice appeared at any time.

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The series of trials extended altogether over fifty hours' working of the engine; but out of this total, various results, representing in the aggregate twenty-eight hours' working, were rejected on account of doubtful measurements as to some point or other. The results of the remaining twenty-two hours' working are believed to be accurate, so far as the measurements and indicator diagrams are concerned, and are given without further selection. These trials are sixteen in number, in two sets, one condensing and one non-condensing, each with and without the steam-pipe jacketed, and each with a cut-off at approximately one-quarter and one-eighth and one-sixteenth of the stroke successively, thus making twelve different combinations. The remaining four of the sixteen trials are repetitions of some one or other of these twelve, and were made in order to check the results, and to ascertain the probable limits of difference under varying conditions of weather and slightly varying pressures and speeds. Indicator diagrams were taken at frequent and tolerably regular intervals with a Richards indicator having a spring of 30 lbs. to the inch; the spring was tested by the makers at the conclusion of the trials, and was found to be correct. Six of the trials lasted two hours each, and the remaining ten were one hour each. The number of indicator diagrams taken in any one trial varied from eight to twenty-four; and it was found that, including the shifting of the indicator from either end of the cylinder to the other, one diagram could be taken about every five minutes. The calculated mean of the measured ordinates in each indicator diagram, at every tenth of the stroke including clearance, was taken as the basis of calculation for determining the distribution of heat. The clearance is seven per cent. of the volume described by the piston; and the real number of expansions corresponding with the nominal cut-off at 1-4th and 1-8th and 1-16th of the stroke averaged 3·4 and 5·8 and 6·7 respectively.

The method of calculation is based on one described by Professor Cotterill.* It consists in ascertaining, from the weight of water used per stroke, and from the pressure given in the calculated mean

* See "The Steam Engine considered as a Heat Engine," by James H. Cotterill, 1878, pages 281–2.

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diagram at the end of the stroke or at any point after the cut-off, the volume occupied by one pound of the working mixture of steam and water in the cylinder, excluding the cushion steam. Dividing the volume thus found by the volume which would be occupied by one pound of saturated steam at the same pressure, the quotient will be the proportion of steam in the working mixture in the cylinder. The number of thermal units in this weight of steam can then be ascertained from tables of the properties of steam. The number of thermal units contained in the water making up the remainder of the working mixture can be similarly ascertained from tables. The number of thermal units converted into work from the commencement up to any point in the stroke will be that corresponding with the mean pressure from the commencement up to that point of the stroke, multiplied by the volume of one pound of the working mixture at that point. These three numbers of thermal units being added together, and their sum subtracted from the total heat in an equal weight of saturated steam at the initial pressure, the difference will be the amount of heat abstracted from the steam by the metal of the cylinder and piston, less re-evaporation, and by other sources of loss up to this point in the stroke. The amount of heat corresponding with the work done in overcoming the back pressure is approximately ascertained by multiplying the average back pressure, as determined from the diagram, by the volume of one pound of the working mixture at the point of the stroke under consideration; and the amount corresponding with the effective work is obtained by deducting the heat corresponding with the back pressure from the total heat converted into work. The amount of heat which would be required per pound of steam for performing the same work in a perfect engine, working between the same limits of temperature, can be readily calculated; and if this is subtracted from the total amount of heat actually received in a pound of initial steam, the difference will give the heat wasted from all causes.

These results are shown graphically in the accompanying diagrams, Plates 88 to 103. In the indicator diagrams the lengths of the average ordinates, measured between the zero line and the

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small circles in the upper curves and also marked in figures, show the pressures taken for calculation; and some of the original indicator diagrams are drawn in, from which these average ordinates were obtained. To avoid confusion, only the two extreme indicator diagrams are shown, with a few of the intermediate ones. The abscissæ represent the volumes, including clearance, from the beginning to the end of the stroke, in both the upper and the lower diagrams on each Plate.

In the lower diagram on each Plate, the total height represents the number of thermal units which are contained in one pound of steam at the initial pressure, in excess of the number contained in one pound of water at the temperature corresponding with the back pressure: this latter being the final state in which it may be conceived that each pound of the working mixture is recovered after use, and is returned to the boiler.

The number of thermal units which have been converted into effective work at any point in the stroke, being plotted as ordinates from the base line, give the lowest curved line EE in the diagram. Adding to these the number of thermal units corresponding with the back pressure gives the curve TT of total work performed by one pound of steam.

The number of thermal units contained in the weights of steam and condensed water respectively, which together make up one pound of the working mixture, in excess of the number of units contained in the same weights of water at a temperature corresponding with the back pressure, are then successively plotted as ordinates upwards from the curve TT of total work. By joining the summits of these ordinates, the two highest lines SS and WW on the diagram are formed; and at any point of the stroke the remaining height from the uppermost of these lines WW, up to the top horizontal line which represents the number of thermal units supplied in one pound of steam, will show the amount of heat abstracted by condensation on the surfaces of the cylinder and piston, and by other sources of loss. This amount is gradually diminished by re-evaporation between the cut-off and the end of the stroke, the diminution being nearly in proportion to the increase of volume.

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The dotted curve PP on the diagram * represents the amount of heat theoretically necessary, or that which would be required per pound of steam in a perfect engine, to perform the total work shown by the curve TT; and therefore the vertical distance between any point in this curve PP, and the top horizontal line representing the number of thermal units supplied at the commencement of the stroke, will give the heat wasted from all causes.

The ratio of efficiency, given in figures on each indicator diagram, is obtained by dividing the number of thermal units corresponding with the effective work by the number supplied at the commencement of the stroke. If the steam supplied is mixed with water carried over by priming, or condensed in the steam-pipes, there will be no alteration in the curves representing the distribution of heat, so far as the author can see; for these depend solely on the amount of water mixed with the steam at the end of the admission; and whether this water is derived from condensation during admission, or originally enters the cylinder in the liquid state, will not affect the result. If priming or condensation in the steam-pipes exists in a perceptible degree however, the heat-supply per pound of steam and water passing through the engine will be proportionately reduced; and therefore the loss by condensation during admission will be actually less than appears from the diagram. This condensation cannot however in any case be less than the subsequent re-evaporation during the remainder of the stroke. It appears to the author to be impracticable to determine, with any approach to accuracy, what the amount of priming or condensation in a steam-pipe may be; the ratio of efficiency in each case is therefore calculated on the assumption that the steam supplied is practically dry. It will be seen from the diagrams that the effects of jacketing the steam-pipes are small and variable; and in the author's opinion they do not in any case extend beyond the re-evaporation of water condensed in the steam-pipes, or possibly a diminution of priming.

The absolute efficiency, or ratio of the effective work performed to the heat supplied, is approximately, but not by any means exactly, in inverse proportion to the weight of water consumed per indicated

* See foot-note on page 492.

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horse-power per hour; the difference depends principally on the varying limits of temperature between which the engine is worked, and the consequently varying amount of heat supplied per pound of steam.

In the appendix, pages 490–3, are shown the detailed figures worked out for determining in one of the trials the heat distribution at 80 per cent. of the stroke. The calculations required at any other point are precisely similar to these. In Table 2, pages 494–9, are collected the results of the whole series of trials, worked out for the termination of the stroke. In the somewhat laborious calculations involved in obtaining these results, the author has received much valuable assistance from Capt. Willock, R.E.

A comparison of the whole of the observed results is shown in the diagram, Plate 104, in which the abscissæ represent square feet of surface exposed to the steam throughout the stroke by the steam passages, cylinder, and piston; the clearance surface measures 5·24 square feet at the commencement, and the total surface 11·98 square feet at the end of the stroke. Ordinates measured downwards from the top of the diagram represent the number of thermal units abstracted from the enclosed steam at any point; and the curves shown are plotted from such ordinates, obtained for each point of the stroke by multiplying the observed weight of steam and water in the cylinder in each case by the number of thermal units already ascertained to have been abstracted from one pound weight of steam. The palpable convergence of all these curves to the zero of exposed surface at about 150 thermal units agrees closely with the hypothesis that there is a sudden initial condensation of the entering steam, equivalent, in all the trials with this engine, to the transference of about 150 thermal units, or 28·6 thermal units per square foot of exposed clearance surface, to the surface metal of the steam passages, cylinder, and piston; and that this heat is gradually given back again to the steam during the stroke, by the excess of re-evaporation over further condensation in the cylinder. The heat thus regained by the steam increases approximately in direct proportion to the surface exposed; but still leaves in the metal, at the end of the stroke in this engine, an amount of heat equivalent to 0·4 thermal unit for

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each degree of difference between the temperatures corresponding with the initial and back pressures.

The adoption of this hypothesis renders it possible to calculate the weight of water required per stroke, and also at any point of the stroke the quantity of heat abstracted by the metal per pound weight of steam supplied. This calculated quantity of heat abstracted is shown by the dotted line AA on the lower diagram for each of the sixteen trials, Plates 88 to 103, in comparison with the observed amount shown by the uppermost full line W W. It also becomes possible, by a reversal of the process detailed in the appendix, to calculate approximately the indicator diagrams resulting from the assumed distribution of heat; and these are shown in each case by the dotted lines DD, Plates 88 to 103, for comparison with the actual diagrams drawn by the engine. The corresponding calculated horse-power, weight of water per stroke, weight of water per horse-power per hour at the observed number of revolutions, and the calculated ratio of efficiency, are marked in figures on the indicator diagrams. The dotted curve HH on each diagram shows the hyperbolic expansion curve corresponding with the observed weight of saturated steam per stroke.

The conclusions drawn by the author are:—that, in order to obtain the best results for any given range of temperature, there should be a definite relation between the surface of the steam passages, the diameter of the cylinder, and the length of stroke; and that in the design of a steam engine the adjustment of these proportions is perhaps the most important point to be considered as regards economy. The following Table 1 (page 488) shows, for two different points of cut-off, the calculated results of varying the length of stroke of the engine which was experimented on, while the diameter of the cylinder, the absolute clearance volume, and the clearance surface exposed, remain unaltered; and it will be seen that the same number of expansions may give widely different results as regards the ratio of efficiency and the water consumed per indicated horse-power per hour; and also that, with the same length of stroke, these results are but slightly affected by doubling the number of expansions.

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TABLE 1.

Calculated Efficiency of Engine and Consumption of Water with two different points of Cut-Off and with varying Lengths of Stroke.

Diameter of Cylinder 16 inches. Clearance 0·143 cubic foot. Clearance Surface 5·24 square feet.	Point of Cut-Off 1·4 inch. Absolute Pressures per sq. inch:— Initial 87·4 lbs.; Back 2·7 lbs.			Point of Cut-Off 4·25 inches. Absolute Pressures per square inch:— Initial 71·3 lbs.; Back 2·9 lbs.				
Length of Stroke . . . . Inches	8·0	18·0	21·8	8·0	18·0	21·8	38·6	46·3
Number of Expansions	3·47	7·24	8·67	1·68	3·47	4·20	7·24	8·67
Percentage of Efficiency . . . Per cent.	4·8	7·3	8·1	5·3	7·9	8·6	10·3	11·1
Water consumed per I.H.P. per hour . . Lbs.	56·0	34·6	31·3	54·8	32·5	30·0	23·0	21·0

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The results above detailed can be compared directly with those from the extensive series of marine-engine trials made by a board of U.S. naval engineers in 1874. From a copy of the official report of those trials * the author has constructed the diagrams, Plates 105 and 106, in which the difference of length between the two ordinates at the extremities of each oblique line shows the number of thermal units regained by a cylinderful of steam, between the point of cut-off and the end of the stroke. These oblique lines correspond with the curves in Plate 104; while the horizontal dotted and full lines show approximately the square feet of clearance surface and of stroke surface respectively, for the cylinder of each of the steamers named. The vertical distances between these horizontal lines and the extremities of their corresponding oblique lines show in each case the amount of heat abstracted from the enclosed steam, at the point of cut-off and at the end of the stroke. As the clearance surface is not given in the report, and can only be estimated, and as the indicator diagrams accompanying the report are single ones, it is not prudent to attach much weight to any individual result in Plates 105 and 106. But the general direction of the oblique lines in Plate 105 appears to the author to correspond closely with the hypothesis of an initial condensation equivalent to about 28·6 thermal units per square foot of exposed clearance surface in unjacketed cylinders, whether single or forming parts of a compound engine; and the horizontal lines are severally placed at such heights as to agree with this supposition. It further appears that no marked effect, either on initial condensation or on the subsequent excess of re-evaporation, is produced by variations in piston-speed ranging between 150 and 437 feet per minute. In the jacketed-cylinder trials, the results of which are shown in Plate 106, the initial condensation is considerably less than appears in Plate 105. The diagram for jacketed cylinders in Plate 106 is drawn to correspond with an initial condensation of 20·6 thermal units per square foot of exposed clearance surface; but further experiments are necessary before this amount can be stated with certainty.

* See "Engineering," 1875, vol. xix, pages 14 and 129 and 139; and 1876, vol. xxi, page 121.

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APPENDIX.

The following are the details of the calculation for determining the distribution of heat at 80 per cent. of the stroke including clearance, in the trial of 18 November 1886, condensing, cutting-off at one-sixteenth of the stroke, and with the steam-pipe jacketed, Plate 99.

Total water used during trial, 1623 lbs.

Number of revolutions during trial, 2455.

W = water per stroke $= \frac{1623}{4 \times 2455} = 0 \cdot 1653$ lb.

Clearance, 7 per cent. of stroke.

Average point of compression, 96·68 per cent. of return stroke.

Mean absolute pressure at commencement of compression = 2·32 lbs. per square inch.

p_c = mean absolute cushion-pressure at commencement of stroke $= 2 \cdot 32 \times \frac{3 \cdot 32 + 7}{7} = 3 \cdot 4$ lbs. per square inch.

p_1 = initial pressure = 87·4 lbs. per square inch.

p_b = back pressure = 2·7 lbs. per square inch.

p_2 = terminal pressure at 80 per cent. of stroke including clearance = 19·3 lbs. per square inch.

p^m = mean pressure from commencement to 80 per cent. of stroke including clearance = 39·5 lbs. per square inch.

Total volume to end of stroke including clearance = 2·183 cubic feet.

Total volume swept through from commencement to end of stroke = 2·040 cubic feet.

Total clearance volume = 2·183 − 2·040 = 0·143 cubic foot.

X = volume swept through from commencement to 80 per cent. of stroke including clearance = 2·040 − 0·2 × 2·183 = 1·603 cubic foot.

c = ratio of clearance volume to $X = \frac{0 \cdot 143}{1 \cdot 603} = 0 \cdot 089$.

Total volume to 80 per cent. of stroke including clearance $= (1 + c) X = 1 \cdot 089 \times 1 \cdot 603 = 1 \cdot 746$ cubic foot.

Ratio of clearance to total volume at 80 per cent. of stroke including clearance $= \frac{c}{1 + c} = \frac{0 \cdot 089}{1 \cdot 089} = 0 \cdot 082$.

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n = volume of cushion steam at terminal pressure, in decimals of total volume $= \frac{c}{1+c} \times \frac{p_c}{p_2} = 0 \cdot 082 \times \frac{3 \cdot 4}{19 \cdot 3} = 0 \cdot 0144$.

Volume of working steam at terminal pressure, in decimals of total volume $= 1 - n = 0 \cdot 9856$.

Volume of working steam at terminal pressure, in decimals of space swept through $= (1 - n)(1 + c) = 0 \cdot 9856 \times 1 \cdot 089 = 1 \cdot 073$.

Volume of working steam in cubic feet $= (1 - n)(1 + c) X = 1 \cdot 073 \times 1 \cdot 603 = 1 \cdot 72$ cubic foot.

V = volume of one pound of working mixture $= \frac{(1 - n)(1 + c) X}{W} = \frac{1 \cdot 72}{0 \cdot 1653} = 10 \cdot 41$ cubic feet.

v = volume of one pound of saturated steam, at terminal pressure p_2 of $19 \cdot 3$ lbs. $= 20 \cdot 4$ cubic feet.

s = volume of one pound of water $= 0 \cdot 016$ cubic foot.

If x is the fraction by weight of saturated steam in the working mixture of steam and water, then $x\,v + (1 - x)\,s = V$; therefore $x = \frac{V - s}{v - s} = \frac{10 \cdot 41 - 0 \cdot 016}{20 \cdot 4 - 0 \cdot 016} = \frac{10 \cdot 394}{20 \cdot 384} = 0 \cdot 51$.

Fraction by weight of water in working mixture $= 1 - x = 0 \cdot 49$.

p'_m = mean pressure reduced to correspond with working volume, by deducting pressure due to clearance steam $= \frac{p_m}{(1 + c)(1 - n)} = \frac{39 \cdot 5}{1 \cdot 073} = 37$ lbs. per square inch.

E_2 = total work in thermal units $= \frac{p'_m \times V \times 144}{772} = \frac{37 \times 10 \cdot 41 \times 144}{772} = 72$ thermal units.

E_b = back-pressure work in thermal units $= \frac{p_b \times V \times 144}{772} = \frac{2 \cdot 7 \times 10 \cdot 41 \times 144}{772} = 5$ thermal units.

Effective work in thermal units $= E_2 - E_b = 72 - 5 = 67$ thermal units.

I_2 = thermal units in raising one pound of water from freezing point and evaporating it at the terminal pressure p_2 of $19 \cdot 3$ lbs. per sq. inch, or temperature t_2 of 226° Fahr. = 1077 thermal units.

h_b = thermal units in raising one pound of water from freezing point to temperature t_b of 137°, corresponding with back pressure p_b of $2 \cdot 7$ lbs. per square inch = 106 thermal units.

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Thermal units in raising the weight of steam in one pound of the working mixture from temperature t_b of 137°, and evaporating it at pressure p_2 of 19·3 lbs. per square inch $= (I_2 - h_b)\ x$ $= (1077 - 106) \times 0{\cdot}51 = 495$ thermal units.

h_2 = thermal units in raising one pound of water from freezing point to temperature t_2 of 226°, corresponding with terminal pressure p_2 of 19·3 lbs. per square inch = 195 thermal units.

Thermal units in raising the weight of water contained in one pound of the working mixture from temperature t_b of 137° of back pressure to temperature t_2 of 226° of terminal pressure $= (h_2 - h_b)\,(1 - x) = (195 - 106) \times 0{\cdot}49 = 44$ thermal units.

Q_1 = thermal units supplied per pound weight of steam at temperature t_1 of 318° and initial pressure p_1 of 87·4 lbs. per square inch $= 1178{\cdot}5 - 106 = 1072{\cdot}5$ thermal units.

Thermal units abstracted by cylinder, per pound weight of steam $= Q_1 - E_2 - (I_2 - h_b)\,x - (h_2 - h_b)\,(1 - x) = 1072{\cdot}5 - 72 - 495 - 44$ $= 461{\cdot}5$ thermal units.

Ratio of efficiency of a perfect engine $= \dfrac{t_1 - t_b}{t_1 + 461^\circ} = \dfrac{318^\circ - 137^\circ}{318^\circ + 461^\circ}$ $= 0{\cdot}2324$.

E_1 = thermal units convertible into work in a perfect engine per pound weight of steam $= Q_1 \times \dfrac{t_1 - t_b}{t_1 + 461^\circ} = 1072{\cdot}5 \times 0{\cdot}2324$ $= 249$ thermal units.

Ratio of necessarily rejected heat to actual work $= \dfrac{Q_1 - E_1}{E_1} = \dfrac{t_b + 461^\circ}{t_1 - t_b}$ $= \dfrac{598}{181} = 3{\cdot}3$.

Total necessary heat * in actual engine per pound weight of steam $= \left(1 + \dfrac{Q_1 - E_1}{E_1}\right) E_2 = 4{\cdot}3 \times 72 = 310$ thermal units.

Heat wasted * per pound weight of steam $= 1072{\cdot}5 - 310 = 762{\cdot}5$ thermal units.

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* It should be borne in mind that the dotted curve PP in the diagrams, Plates 88 to 103, and the calculations here given for obtaining the total necessary heat and the heat wasted, have reference to the forward stroke only. For the complete cycle of the double stroke or one revolution, the total necessary heat would be $\dfrac{Q_1}{E_1}(E_2 - E_b)$; and the heat wasted would be $\dfrac{Q_1}{E_1}(E_1 - E_2 + E_b)$.

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Absolute ratio of efficiency of actual engine at 80 per cent. of stroke including clearance $= \frac{E_2 - E_b}{Q_1} = \frac{67}{1072 \cdot 5} = 0 \cdot 0625$.

Relative efficiency of actual engine compared with perfect engine at 80 per cent. of stroke including clearance $= \frac{E_2 - E_b}{E_1} = \frac{67}{249} = 0 \cdot 269$.

The results of the precisely similar calculations worked out for the termination of the stroke, and for the whole series of the trials, are collected in the accompanying Table 2, pages 494–9.

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TABLE 2 (*continued to page* 499).—RESULTS OF TRIALS.

Horse-Power, Speed, and Water Consumption.

1886. November and December. *Diagrams shown in Plates* 88 *to* 103.		1 Indicated Horse-Power.			2 Revolutions per minute.			3 Consumption of Water. Lbs. per I.H.P. per hour.			4 Consumption of Water. Lb. per stroke.		
See Diagrams in Plates . .		88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103
Nominal Cut-Off . . .		1–4	1–8	1–16	1–4	1–8	1–16	1–4	1–8	1–16	1–4	1–8	1–16
Number of Expansions . .		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
		I.H.P.	I.H.P.	I.H.P.	Revs.	Revs.	Revs.	Lbs.	Lbs.	Lbs.	Lb.	Lb.	Lb.
Condensing	Steam-pipe jacketed	57·8	50·3 46·6 49·4	46·9	40·2	39·5 39·7 40·4	40·9	34·2	34·0 36·1 38·2	34·6	0·205	0·182 0·176 0·194	0·165
	Not jacketed	62·0	51·0 47·2	45·7	42·2	40·3 40·4	41·2	35·4	34·7 38·9	38·8	0·217	0·183 0·190	0·179
Non-condensing	Steam-pipe jacketed	52·4	36·2	29·6 29·6	40·4	40·1	40·1 39·3	39·6	41·2	42·9 51·0	0·214	0·155	0·132 0·160
	Not jacketed	51·0	36·0	29·7	39·8	40·3	39·5	41·1	42·6	50·5	0·220	0·158	0·158

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TABLE 2 (*continued from preceding page*).—RESULTS OF TRIALS.
Cylinder Pressures: Initial, Terminal, Mean Forward, and Mean Back.

1886. November and December. *Diagrams shown in Plates 88 to 103.*		5 Initial. Lbs. per sq. inch.			6 Terminal. Lbs. per. sq. inch.			7 Mean Forward. Lbs. per sq. inch.			8 Mean Back. Lbs. per sq. inch.		
See Diagrams in Plates . . .		88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103
Nominal Cut-Off		1–4	1–8	1–16	1–4	1–8	1–16	1–4	1–8	1–16	1–4	1–8	1–16
Number of Expansions . . .		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
Condensing	Steam-pipe jacketed	Lbs. 71·3	Lbs. 89·0 82·6 83·3	Lbs. 87·4	Lbs. 22·8	Lbs. 18·9 17·6 19·3	Lbs. 17·0	Lbs. 43·1	Lbs. 39·4 36·1 38·0	Lbs. 35·0	Lbs. 2·9	Lbs. 3·2 3·2 4·2	Lbs. 2·7
	Not jacketed	72·6	86·5 83·3	86·8	23·5	18·7 17·7	16·0	44·1	38·0 36·1	33·5	2·6	2·5 3·3	2·4
Non-condensing	Steam-pipe jacketed	83·7	90·9	88·1 87·8	28·8	22·3	20·0 20·2	51·8	41·7	36·8 36·6	15·4	16·5	16·2 15·5
	Not jacketed	87·6	91·6	89·3	28·1	21·9	20·0	52·6	41·8	36·7	16·6	16·7	15·6

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TABLE 2 (*continued from preceding page*).—RESULTS OF TRIALS.

Work Done per pound of Steam supplied: Total, Effective, and Back-Pressure.

1886. November and December. *Diagrams shown in Plates* 88 *to* 103.		9 Total Work.* Thermal Units per pound of steam supplied.			10 Effective Work. Thermal Units per pound of steam supplied.			11 Back-Pressure Work. Thermal Units per pound of steam supplied.		
See Diagrams in Plates		88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103
Nominal Cut-Off . .		1-4	1-8	1-16	1-4	1-8	1-16	1-4	1-8	1-16
Number of Expansions		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
		Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.
Condensing	Steam-pipe jacketed	80	82 78 75	80	75	75 71 66	74	5	7 7 9	6
	Not jacketed	77	79 72	71	72	72 65	65	5	7 7	5
Non-condensing	Steam-pipe jacketed	92	103	107 87	65	63	61 51	27	40	46 36
	Not jacketed	91	100	88	62	61	51	29	39	37

* The figures in group 9 are severally the sum of the corresponding figures given in the two succeeding groups 10 and 11.

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TABLE 2 (*continued from preceding page*).—RESULTS OF TRIALS.

Heat Lost and Heat Supplied per pound of Steam.

1886. November and December. *Diagrams shown in Plates 88 to 103.*		12 Thermal Units of Heat Lost at end of stroke. Exhaust Steam.			13 Water in Cylinder.			14 Abstracted by Cylinder.			15 Thermal Units of Heat Supplied.*		
See Diagrams in Plates . . .		88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103	88–91	92–98	99–103
Nominal Cut-Off		1-4	1-8	1-16	1-4	1-8	1-16	1-4	1-8	1-16	1-4	1-8	1-16
Number of Expansions . . .		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
		Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.	Units.
Condensing	Steam-pipe jacketed	590	543 526 521	550	38	36 35 32	35	359	407 427 427	407	1067	1068 1066 1055	1072
	Not jacketed	567	544 489	482	43	40 37	42	384	412 467	482	1071	1075 1065	1077
Non-condensing	Steam-pipe jacketed	613	650	684 571	11	5	3 5	279	235	199 332	995	993	993 995
	Not jacketed	581	621	573	10	4	5	310	269	330	992	994	996

* The figures in group 15 are severally the sum of the corresponding figures given in the four preceding groups 9, 12, 13, 14.

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TABLE 2 (*continued from preceding page*).—RESULTS OF TRIALS.
Volumes of Steam. Condensation in Cylinder.

1886. November and December. *Diagrams shown in Plates 88 to 103.*		16 Volume of one pound of Steam and Water in cylinder at end of stroke.			17 Volume of one pound of Saturated Steam at terminal pressure.			18 Condensation * in Cylinder at end of stroke.		
See Diagrams in Plates .		88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103
Nominal Cut-Off. . .		1-4	1-8	1-16	1-4	1-8	1-16	1-4	1-8	1-16
Number of Expansions .		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
		Cub. Feet.	Cub. Feet.	Cub. Feet.	Cub. Feet.	Cub. Feet.	Cub. Feet.	Per cent.	Per cent.	Per cent.
Condensing	Steam-pipe jacketed	10·55	11·73 12·13 10·98	13·00	17·40	20·83 22·25 19·81	22·94	39·3	43·7 45·5 45·5	43·3
	Not jacketed	9·87	11·81 11·27	12·03	16·95	21·13 22·13	24·32	41·9	44·1 49·2	50·5
Non-condensing	Steam-pipe jacketed	9·54	12·96	15·12 12·50	13·99	17·80	19·72 19·54	31·8	27·2	23·3 36 1
	Not jacketed	9·29	12·00	12·64	14·32	18·15	19·72	35·1	33·9	35·9

* The figures in group 18 are severally the percentage of difference between the corresponding figures given in the two preceding groups 16 and 17.

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TABLE 2 (*concluded from page* 494).—RESULTS OF TRIALS.

Efficiency of Actual Engine: Absolute and Relative.

1886. November and December. *Diagrams shown in Plates* 88 *to* 103.		19 Total Work of Perfect engine. Thermal Units per pound of steam supplied.			20 Absolute Efficiency* of Actual engine at end of stroke in percentage of Heat supplied.			21 Relative Efficiency† of Actual engine in percentage of Efficiency of Perfect engine.		
See Diagrams in Plates .		88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103	88 *to* 91	92 *to* 98	99 *to* 103
Nominal Cut-Off . .		1–4	1–8	1–16	1–4	1–8	1–16	1–4	1–8	1–16
Number of Expansions		3·4	5·8	6·7	3·4	5·8	6·7	3·4	5·8	6·7
		Units.	Units.	Units.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Condensing	Steam-pipe jacketed	244	240 233 217	249	7·0	7·0 6·7 6·3	6·8	30·8	31·3 30·5 30·5	29·3
	Not jacketed	237	252 233	254	6·7	6·6 6·1	6·1	30·3	28·2 28·0	25·6
Non-condensing	Steam-pipe jacketed	129	131	129 131	6·5	6·4	6·1 5·1	49·6	48·1	47·2 39·0
	Not jacketed	127	131	134	6·2	6·1	5·1	48·8	45·8	38·1

* The figures in group 20 are severally the quotient resulting from the division of those in group 10 by those in group 15.

† The figures in group 21 are severally the quotient resulting from the division of those in group 10 by those in group 19.

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Discussion, 17 *May* 1887.

Major ENGLISH mentioned that, in order to see whether he could ascertain by direct experiment the amount of initial condensation in a steam cylinder, he had since the paper was written made some preliminary trials on this subject with an ordinary portable engine in good order, having a cylinder 10 inches in diameter and 14 inches stroke. The piston-rod was disconnected, and the piston blocked at the end of the stroke furthest from the crank, and the cylinder and steam port nearest the crank were filled up solid, leaving the engine in other respects exactly as it was. The fly-wheel and therefore the valve were driven from another engine. The effect was that at each revolution of the fly-wheel the steam from the boiler could alternately enter and be exhausted from the clearance at the further end of the cylinder. The exhaust pipe was connected with the surface condenser in the same manner as in the trials described in the paper, and the resulting water was measured. A series of half a dozen trials of an hour each was made, and the result in each case was that the water collected was found to be between four and five times the amount which could be accounted for by the steam required for merely filling the clearance. This result corroborated strongly the statements in the paper. The experiment was one that could be easily tried by anyone having an engine available. The engine with which the experiments were made might be seen by any of the Members who desired to inspect it; and he purposed carrying out with it a full series of trials, both condensing and non-condensing, with various steam-pressures and piston-speeds.

Mr. BENJAMIN WALKER, Member of Council, complimented the author upon the admirable set of diagrams by which his paper was so elaborately illustrated. When he first had any communication with him in reference to working engines economically, the author was of opinion that a sharp cut-off like that given by the Corliss gear was what was wanted, and had set himself to design a valve-motion which would accomplish that object and do it quietly and without

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much wear and tear. In this effort the author had admirably succeeded; and the valve-motion shown in Plate 109, and of which a full-size specimen was exhibited, had given the greatest satisfaction to the several users for whom his own firm had had the pleasure of making it. He had been informed by Mr. Butter, the mechanical manager of the gun-carriage department in Woolwich Arsenal, that a pair of engines fitted with this valve-motion were in that respect the most economical engines in the arsenal. Although the author seemed subsequently to have gone back to the old notion that a sharp cut-off was not an advantage, there could be no doubt that the valve-motion he had designed was very effective. As would be seen from the drawing and from the indicator diagrams, there was a rapid introduction of steam and a rapid cut-off, an easy motion, and no rattle. If that sort of valve-gear were applied to the compound or the triple-expansion engine, the result would be a very perfect engine. The more rapidly the steam was admitted, and the more rapidly it was cut off at the point suitable for the rate of expansion corresponding with the varying circumstances of the work to be done, the more economical was the engine. The valve-motion designed by the author he considered was one that met the special requirements of the ordinary engine, and that would last; it was not expensive, and it would make no noise.

Mr. DAVID GREIG, Vice-President, considered the excellent indicator diagrams obtained by the author were sufficient to show the very economical working of the engines described in the paper. The reverse calculation of the theoretical indicator diagram resulting from the assumed distribution of heat struck him as a point of particular interest, to which he was not aware that the attention of engineers had previously been so pointedly directed. Notwithstanding the economical character of the indicator diagrams, it nevertheless appeared from the concluding portions of Table 2 (page 499, group 20), that only from 5 to 7 per cent. of the heat supplied into the cylinder was utilised in the engine. Such a result was enough to show engineers that they were a long way from realising the economy which ought to be attained. He had himself become convinced by the author's

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(Mr. David Greig.)
arguments, not only in the present paper but previously, that an amount of alteration in engines still remained necessary, of which he had not before been aware. Boilers too were not evaporating water enough for the quantity of fuel consumed. With regard to the re-evaporation which took place in the cylinder during the latter part of the stroke, he should be glad to understand fully whether the additional power resulting therefrom was gained for nothing, or whether it had to be paid for in the shape of additional steam originally admitted into the cylinder. With all the rest of the paper he fully concurred; and he considered the Members were greatly indebted to the author for the very large amount of trouble he had taken in the laborious calculations he had gone through, and for the admirable way in which he had brought the subject before the Institution.

The discussion was then adjourned.

(*For continuation of Discussion see page* 510.)

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SUPPLEMENTARY EXPERIMENTS ON THE INITIAL CONDENSATION IN A STEAM CYLINDER.

BY MAJOR THOMAS ENGLISH, R.E., WAR OFFICE.

Read at the Meeting on 30 *September* 1887.

As was briefly mentioned at the commencement of the short discussion at the previous meeting, it appeared to the author to be desirable to make a series of experiments designed to ascertain, as directly as possible, the net amount of Initial Condensation in a Steam Cylinder; and he has now the pleasure of laying the results before the present meeting.

The experiments were carried out in a portable engine of ordinary type, made by Messrs. Clayton and Shuttleworth. The cylinder, 10 inches diameter and 14 inches stroke, is jacketed on the sides, but not at the ends; and as steam is admitted directly from the boiler into the steam-chest, and as the total quantity of steam required for an experiment is very small compared with the capacity of the boiler, no question of priming, or of condensation before admission, can arise. The connecting-rod was disconnected, and the piston was rigidly blocked at the end of the stroke furthest from the crank, the interior of the cylinder surrounding the piston-rod being entirely filled up with wood and iron packing. The steam passage between the valve seat and the end of the cylinder next the crank was also solidly filled up; and the port itself was closed by a brass plate scraped down to the level of the valve seat. The port admitting steam to the end of the cylinder furthest from the crank was left open; and the crank shaft, eccentric, and valve were driven by another engine. The steam pressure in the boiler was maintained at a uniform amount, and the regulator was kept open during a trial. The result of these arrangements was that steam at boiler pressure was alternately admitted to and exhausted from the clearance space in the steam passage and end of the cylinder furthest from the crank, once in each revolution, the time of admission corresponding with a cut-off at about seven-tenths of the stroke.

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Each experiment lasted for about an hour, the revolutions during this time being noted by a counter; and indicator diagrams, usually three in number, were taken at intervals. The steam passing through the engine under these conditions was measured, as in the trials detailed in the original paper, by connecting the exhaust port with a surface condenser, and collecting the resulting water: which, after deducting that derived from the steam required to fill the clearance volume of about 0·035 cubic foot, should give a direct measure of the difference between the amount condensed by the clearance surface of 2 square feet on entering the cylinder, and the amount re-evaporated from the same surface. Sixty-four separate experiments, of which thirty-five were condensing and twenty-nine non-condensing, were satisfactorily made, besides five rejected for manifest errors. The steam pressures employed were about 45, 30, 20, and 10 lbs. above the atmosphere, and the numbers of revolutions were approximately 130, 100, 70, and 50 per minute.

The results are obtained from the following calculations, using similar notation to that employed in the original paper (pages 490–3).

Let ρ_1 be the density, or weight in lbs. per cubic foot, of the steam on admission and up to the point of cut-off; and let t_1 be the corresponding temperature. Also let ρ_b and t_b be similar quantities for the steam in the cylinder when the exhaust port closes.

Let W be the weight in lbs. of the water collected per revolution from the condenser. Then this is made up of— (1) the difference of weights of the steam filling the clearance volume $c\,X$ at the temperature t_1 and t_b respectively, or $(\rho_1 - \rho_b)\ c\,X$; and (2) the weight of steam condensed and not re-evaporated between admission and cut-off, on the constant clearance surface S_c of 2 square feet. Hence the weight of steam per revolution, condensed and not re-evaporated between admission and cut-off, is $W - (\rho_1 - \rho_b)\ c\,X$.

If Q_1 be the number of thermal units in each pound of steam entering at temperature t_1, and h_1 the number of thermal units in a pound of water at this temperature, then the number of thermal units abstracted from each pound of steam condensed between admission and cut-off is $Q_1 - h_1$.

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And if C be the number of thermal units abstracted per revolution from the steam contained in the clearance, between admission and cut-off, then $C = (Q_1 - h_1)\left\{W - (\rho_1 - \rho_b)\, c\, X\right\}$.

These quantities for each experiment are given in the accompanying Tables 3 and 4 (pages 506–9).

The results of the experiments appear to indicate that the net initial condensation, or excess of condensation over re-evaporation, by the clearance surface varies directly as the initial density, and inversely as the square root of the number N of revolutions per unit of time. Assuming that it varies also directly as the clearance surface S_c, the last column of the tables will give the amount in thermal units corresponding with one square foot and one revolution per second. The thermal units per square foot of clearance surface are also shown for each experiment by the ordinates in the diagram, Plate 107, the initial density divided by the square root of the number of revolutions per second being denoted in each case by the corresponding abscissæ.

The average of the results of the whole series corresponds with an excess of initial condensation over re-evaporation during admission, equivalent to 8·2 thermal units per square foot of clearance surface for steam at 0·146 density or 60 lbs. per square inch total pressure, and at one revolution per second, in a jacketed cylinder. This and the previous results obtained by the author, as well as those of the U. S experiments in 1874–5 (page 489), can be fairly represented by the following formulæ for the excess of condensation over re-evaporation of the enclosed steam at any point of the stroke of an engine, where Q represents the sum of the thermal units existing in one pound of the mixed steam and water, and of those accounted for by the work done, and S is the surface of the sides of the cylinder up to the point in question in square feet :—

$$(Q_1 - Q)\ W = \frac{60\,\rho_1\, S_c}{\sqrt{N}}\left(1 - \frac{\rho_b + 0{\cdot}06}{\rho_1} \times \frac{S}{S_c}\right) \text{ for jacketed cylinders.}$$

$$(Q_1 - Q)\ W = \frac{80\,\rho_1\, S_c}{\sqrt{N}}\left(1 - \frac{\rho_b + 0{\cdot}06}{\rho_1} \times \frac{S}{S_c}\right) \text{ for unjacketed cylinders.}$$

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TABLE 3.

Net Initial Condensation in jacketed Cylinder of Non-condensing Engine.

1887.	Clearance Volume.	Revolutions per second.	Density of Steam. Lb. per cubic foot.		Thermal Units in one pound of		Water collected per revolution.	Net Initial Condensation by clearance surface. Thermal Units.	
			Initial.	Exhaust.	Steam.	Water.		Total per revolution.	Per sq. ft. of surface at one rev. per second.
	cX	N	ρ_1	ρ_b	Q_1	h_1	W	C	$\frac{C\sqrt{N}}{S_c}$
	Cubic Foot.	Revs.	Lb.	Lb.	Units.	Units.	Lb.	Units.	Units.
May 16	0·035	1·73	0·156	0·043	1173	269	0·0213	15·7	10·3
May 25	0·035	2·19	0·149	0·042	1172	265	0·0135	8·9	6·6
May 28	0·035	1·70	0·148	0·043	1172	265	0·0160	11·2	7·3
May 13	0·035	1·23	0·148	0·043	1172	265	0·0240	18·4	10·2
June 1	0·035	1·21	0·146	0·043	1171	263	0·0237	18·3	10·1
May 16	0·035	1·64	0·146	0·040	1171	263	0·0161	11·3	7·2
June 2	0·035	0·92	0·144	0·042	1171	262	0·0251	19·6	9·4
May 13	0·035	1·69	0·140	0·043	1170	260	0·0170	12·4	8·1
May 16	0·035	1·54	0·126	0·040	1168	254	0·0147	10·7	6·1
May 14	0·035	1·32	0·118	0·041	1167	248	0·0150	11·3	6·5
May 25	0·035	2·09	0·117	0·040	1166	247	0·0098	6·5	4·7

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May 28	0·035	1·65	0·116	0·039	1166	247	0·0154	11·7	7·5
May 17	0·035	1·62	0·115	0·042	1166	247	0·0150	11·5	7·3
June 2	0·035	0·85	0·115	0·039	1166	247	0·0225	18·2	8·4
June 1	0·035	1·25	0·113	0·040	1166	246	0·0128	9·4	5·3
May 14	0·035	1·30	0·104	0·041	1165	241	0·0120	9·0	5·2
May 17	0·035	1·66	0·103	0·043	1164	240	0·0149	11·8	7·6
May 25	0·035	2·05	0·095	0·039	1163	234	0·0069	4·6	3·3
May 14	0·035	1·25	0·092	0·040	1163	233	0·0110	8·6	4·8
May 31	0·035	1·69	0·091	0·041	1162	232	0·0124	9·9	6·4
June 1	0·035	1·19	0·090	0·040	1162	231	0·0101	7·7	4·2
June 2	0·035	0·80	0·089	0·040	1161	230	0·0151	12·5	5·6
May 17	0·035	1·71	0·089	0·041	1161	230	0·0102	7·9	5·2
May 25	0·035	2·12	0·071	0·039	1157	216	0·0044	3·1	2·3
May 31	0·035	1·65	0·071	0·040	1157	216	0·0074	5·9	3·8
May 31	0·035	1·19	0·070	0·039	1156	214	0·0080	6·4	3·5
May 14	0·035	1·36	0·068	0·039	1156	213	0·0065	5·1	3·0
May 17	0·035	1·64	0·067	0·040	1156	212	0·0060	4·7	3·0
June 2	0·035	0·85	0·066	0·039	1156	212	0·0081	6·7	3·1

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TABLE 4.

Net Initial Condensation in jacketed Cylinder of Condensing Engine.

1887.	Clearance Volume.	Revolutions per second.	Density of Steam. Lb. per cubic foot.		Thermal Units in one pound of		Water collected per revolution.	Net Initial Condensation by clearance surface. Thermal Units.	
			Initial.	Exhaust.	Steam.	Water.		Total per revolution.	Per sq. ft. of surface at one rev. per second.
	cX	N	ρ_1	ρ_b	Q_1	h_1	W	C	$\frac{C\sqrt{N}}{S_c}$
	Cubic Foot.	Revs.	Lb.	Lb.	Units.	Units.	Lb.	Units.	Units.
June 13	0·035	1·69	0·146	0·020	1171	263	0·0173	11·7	7·6
June 15	0·035	1·21	0·145	0·020	1171	263	0·0227	16 6	9·1
June 10	0·035	1·80	0·143	0·024	1171	262	0·0163	11·0	7·4
June 16	0·035	0·83	0·143	0·015	1171	262	0 0257	19·3	8·8
Aug. 4	0·035	1·95	0·143	0·019	1171	262	0·0203	14 5	10·2
Aug. 3	0·035	0·87	0·143	0·012	1171	262	0·0181	12·3	5·7
July 28	0·038	1·09	0·142	0·028	1171	262	0·0233	17·3	9·0
July 13	0·038	1·60	0·140	0·023	1170	261	0·0154	10·0	6·3
Aug. 11	0·038	1·59	0·140	0·018	1170	260	0·0160	10·6	6·6
Aug. 13	0·038	2·17	0·138	0·025	1170	259	0·0136	8·5	6·3
June 15	0·035	1·13	0·118	0·017	1167	249	0·0193	14·5	7·7
June 13	0·035	1·65	0·117	0·019	1166	247	0·0168	12·3	7·9

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June 16	0·035	0·89	0·116	0·015	1166	246	0·0199	15·1	7·1
Aug. 3	0·035	0·85	0·114	0·012	1166	246	0·0142	9·8	4·5
June 10	0·035	1·90	0·113	0·019	1166	246	0·0107	6·8	4·7
July 13	0·038	1·61	0·112	0·021	1166	246	0·0115	7·4	4·7
Aug. 11	0·038	2·13	0·111	0·015	1165	244	0·0093	5·2	3·8
July 28	0·038	1·15	0·111	0·025	1165	244	0·0137	9·6	5·2
Aug. 11	0·038	1·65	0·111	0·015	1165	244	0·0115	7·3	4·7
June 13	0·035	2·09	0·091	0·016	1161	231	0·0084	5·4	3·9
June 13	0·035	1·70	0·091	0·016	1161	231	0·0109	7·7	5·0
June 16	0·035	0·86	0 091	0·014	1161	231	0·0144	10·9	5·1
July 26	0·038	1·15	0·090	0·020	1161	231	0·0149	11·3	6·1
July 28	0·038	1·13	0·089	0·017	1161	230	0·0125	9·1	4·8
Aug. 3	0·035	0·81	0·088	0·012	1161	250	0 0142	10·7	4·8
Aug. 12	0·038	2·17	0·087	0·015	1161	230	0·0087	5·6	4·1
Aug. 12	0·038	1·65	0·083	0·018	1160	225	0·0122	9·1	5·8
June 13	0·035	2·19	0·071	0·015	1157	216	0·0066	4·3	3·2
June 13	0·035	1·72	0·070	0·014	1156	215	0·0094	7·0	4·6
July 26	0·038	1·16	0·070	0·015	1156	215	0·0114	8·8	4·7
July 26	0·038	0·83	0·070	0·015	1156	215	0·0134	10·6	4·8
Aug. 4	0·035	0·88	0·066	0·012	1156	213	0·0130	10·5	5·0
Aug. 12	0·038	2·13	0·066	0·014	1156	212	0·0060	3·8	2·8
Aug. 4	0·035	1·13	0·065	0·012	1155	210	0·0103	7·9	4·2
Aug. 11	0·038	1·70	0·063	0·013	1155	209	0·0103	7·9	5·2

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Adjourned Discussion, 30 *September* 1887.

The PRESIDENT considered they were greatly indebted to the author, not only for his original valuable paper, read at the previous meeting in May, but also for the supplementary paper he had now given, describing the further experiments made subsequently. At the present time, when the eyes of the whole country were fixed upon government officials, it could not but be gratifying to find that some at any rate were anxious to help the spread of knowledge; and from the information which they gained in the public departments to assist the Institution in the study of economy in steam-engine management.

Mr. MICHAEL LONGRIDGE said the paper gave evidence of a great deal of thought, care, and trouble, which he was only sorry should have been expended on an engine so far from economical as to require from 34 to 39 lbs. of water per indicated horse-power per hour when condensing, besides half as much more to drive its own air and circulating pumps, and from 40 to 51 lbs. when non-condensing. Such an engine he considered very unsuitable for sending out to a country where the price of both fuel and water was high, and where therefore engines were wanted that would work on a consumption more like the record arrived at in other cases. For single-cylinder condensing engines that record was about 17 lbs. of water per I.H.P. per hour, and for non-condensing from 22 to 24 lbs.

In page 480 the pressure in the steam-pipe jacket was given as 140 lbs.; but as the amount of condensation from the jacket was not given, no idea could be formed as to how much the steam used in the cylinders was superheated.

In page 482 it was mentioned that the spring of the indicator was tested; and no doubt other precautions had been taken. But he should like to know whether the engine pistons and slide-valves had been tested, because from his own experience the amount of condensation at the end of the stroke was greater than it ought to be, and he could only account for this by supposing that there must have been a considerable leakage past the valves and pistons of the engines.

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In page 483 the statement that the number of thermal units in the weight of steam could be ascertained from tables of the properties of steam seemed to him likely to mislead; and the same remark applied also to page 491, where I_2 was said to represent the thermal units expended in raising one pound of water from freezing point and evaporating it. What this symbol did represent, he considered, was the internal heat in the steam, which was less than the heat required to evaporate the steam by the equivalent of the external work due to the increase of volume on evaporation.

With regard to the mode of presenting the experiments in the paper, he thought it was hardly quite as clear and concise as it might be for enabling the greatest benefit to be derived from them. Unless the figures were given in such a form that they could be grasped at once, he was afraid they would never be looked at or read. In preference to reducing the steam in the clearance spaces to the terminal pressure, and calculating the volume of the working steam apart from the cushion steam, and reckoning the temperatures from the exhaust line of the indicator diagram, he thought it was far better to take the actual volumes and pressures direct from the diagram, and to calculate the heat from a fixed zero of temperature, either the freezing point of water or the zero of Fahrenheit's thermometer; the former method introduced a variable standard of efficiency, which he thought was undesirable. In the accompanying Tables 5 and 6 (pages 512–13), and in the diagrams Figs. 41 to 44, Plate 110, was shown the way in which he had himself worked out similar experiments with a pair of horizontal compound tandem engines. The indicator diagram in Fig. 45, Plate 111, was taken from one of the high-pressure or non-condensing cylinders, not jacketed; and would exemplify the method as well as the diagrams accompanying the paper. Here the compression was seen to begin at H in the return stroke, at which point the cylinder contained a certain volume HM of steam at a certain pressure HK; this steam, for reasons which it would take too long to give, he assumed to be free from water. The weight of this steam, calculated as had been done by Major English, amounted to 0·486 lb., and was put down in the first line of Table 5. As the

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TABLE 5.

Weight of Steam and Water in Non-condensing Cylinder.

Line or Ordinate.	Weight in pounds, and Percentage, at successive stages of the stroke. *See* Figs. 41 and 42, Plate 110.	Steam.		Water.		Total.
		Lbs.	Per cent.	Lb.	Per cent.	Lbs.
1	Steam left from previous stroke	0·486	100	..	..	0·486
3	Steam and Water at end of compression	0·373	77	0·113	23	0·486
4	Supplied from boiler (feed-water 3·583 lbs. per stroke) . . .	3·476	97	0·107	3	3·583
5	Total steam and water supplied	3·849	95	0·220	5	4·069
6	Present at end of admission	2·708	67	1·361	33	4·069
7	„ „ one-third of expansion	2·688	66	1·381	34	4·069
8	„ „ end of stroke	3·088	76	0·981	24	4·069
9	Deduct steam in line 1	0·486	..	..	..	0·486
10	Steam and Water discharged from cylinder during exhaust . .	2·602	73	0·981	27	3·583

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TABLE 6.

Distribution of Heat in Non-condensing Cylinder.

Line or Ordinate.	Thermal Units in Work, Steam, Water, and Metal, at successive stages of the stroke. *See* Figs. 43 and 44, Plate 110.	Work. Units.	Steam. Units.	Water. Units.	Metal. Units.	Total. Units.
1	Heat left from previous stroke	..	539	..	..	539
2	Heat in work of compression	37	..	..	..	37
3	Distribution of heat at end of compression	..	420	33	123	576
4	Heat supplied from boiler (feed-water 3·583 lbs. per stroke)	..	4221	36	..	4257
5	Total heat supplied	..	4641	69	123	4833
6	Distribution of heat at end of admission	180	3067	441	1145	4833
7	" " " " one-third of expansion	307	3017	385	1124	4833
8	" " " " end of stroke	447	3443	242	701	4833
9	Deduct heat in line 1 and in absolute work	447	539	..	..	986
10	Heat discharged from cylinder during exhaust	..	2904	242	701	3847
11	Add heat in work of expulsion	154	..	..	..	154
12	Total heat discharged	..	..	..	..	4001
13	Add heat in effective work, as measured from diagrams	256	..	..	..	256
14	Total heat received and accounted for	..	..	..	..	4257

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(Mr. Michael Longridge.)
piston went on to the end of the return stroke, the steam was compressed according to the curve HL. At the end of the return stroke the pressure was again measured, and from the volume LN and pressure LB the weight of the steam was again calculated. In this as in most cases it was found to be less than the weight given before. The difference, 0·113 lb., as shown in line 3 of Table 5 and in Fig. 42, was water, which was formed by condensation of the steam compressed. Then a certain quantity of steam and water was supplied to the cylinder from the boiler, as given in line 4, namely 3·476 lbs. of steam and 0·107 lb. of priming water. Adding these together, line 5 gave 3·849 lbs. as the total quantity of steam in the cylinder, and 4·069 lbs. as the total quantity of steam and water. Proceeding to the end D of the admission, line 6, the weight of steam calculated from the volume and pressure was then 2·708 lbs., leaving a balance of 1·361 lb. which was water. The same was done for several points in the expansion curve, for one of which X, corresponding with one-third of that period, the weights of steam and water were given in line 7; and again at the end E of the stroke, as given in line 8. The whole of this final quantity of steam was discharged from the cylinder, except what was left in the clearance: deducting this, the net amount of steam and water discharged from the cylinder was 3·583 lbs., as shown in line 10. From this table the diagram, Figs. 41 and 42, Plate 110, was plotted by ordinates 1–3–6–7–8, which were drawn proportional to the figures given in lines 1–3–6–7–8 of the table. The diagram therefore represented the varying condensation and re-evaporation throughout the double stroke. In the return stroke, Fig. 42, it was seen that the steam and water were assumed to retain throughout the period of discharge nearly the same proportion to each other as at the end of the forward stroke; this assumption however did not exactly correspond with the actual state of the case.

Similarly in Table 6, and in Figs. 43 and 44 plotted therefrom in Plate 110, was shown the distribution of the heat at corresponding points of the stroke, as calculated from the weights of steam and water in Table 5. The 0·486 lb. weight of steam left from the previous stroke, multiplied by the internal heat of steam at that

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pressure, gave the 539 thermal units shown in line 1; to which must be added the work of compression, measured from the indicator diagram and amounting to 37 units, as shown in line 2; the sum was 576 units, which were distributed as shown in line 3. The distribution there given was arrived at by taking from line 3 of Table 5 the weights of steam and of water—namely 0·373 lb. and 0·113 lb. respectively—and multiplying these by the respective internal heats of steam and of water, whereby 420 units were accounted for in the steam and 33 units in the water; the balance, or 123 units, was therefore the heat that had gone into the metal. Going on to the end D of the admission, the heat equivalent of the total work up to that point was added to the heat in the steam and water, calculated as before; and their sum being deducted from the total heat of 4833 units left 1145 units as the quantity of heat then in the cylinder metal. A similar calculation gave the distribution of the heat at X when one-third of the expansion had been accomplished, and at the end E of the stroke; and lines 7 and 8 showed the results of the calculation. Then deducting in line 9 the heat left in the cylinder at the commencement of the compression, and the equivalent of the total or absolute work performed, the remainder in line 10 showed the heat discharged into the atmosphere or condenser, as the case might be:—namely 2904 units in the exhaust steam, 242 units in the water escaping with that steam, and 701 units from the cylinder metal. If the engine had a condenser, all this heat would be found there, and in addition the heat equivalent to the work done upon the steam during the expulsion; the latter was calculated, as were the other quantities of work, from the indicator diagram, and was given in line 11. The sum in line 12 was therefore the quantity of heat which would be found in the condenser, or the heat rejected by the engine; and this sum, together with the heat utilised in the effective work (line 13), would be equal to the heat supplied from the boiler (lines 14 and 4). By proceeding in this way, the results could be calculated by regularly progressive steps, directly from the volumes and pressures shown by the indicator diagrams, and could be tabulated in a concise form capable of graphical representation. The calculations might at first sight seem complicated, but really they

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(Mr. Michael Longridge.)
were not so. The key to them was the following simple equation:—

$$Q = W + U + M$$

which expressed the fact that at any point in the stroke the quantity of heat Q supplied to the cylinder was equal to the sum of the absolute work W done up to that point, and of the internal heat U in the steam and water present, and of the heat M abstracted by the metal: as might be seen by reference to lines 6, 7, and 8, in Table 6. This of course was only another form of expressing the truth stated on page 492 of the paper, that the "Thermal units abstracted by the cylinder per pound weight of steam $= Q_1 - E_2 - (I_2 - h_b)\,x - (h_2 - h_b)\,(1 - x)$;" but he thought the simpler equation given above, being more general, showed the same truth in a shape more easily grasped.

The supplementary paper on initial condensation appeared to him to be far more valuable than the original; and he was very glad the subject of condensation during the admission had here at last been tackled. In his own diagram, Fig. 41, Plate 110, it was seen that the period of the admission was left blank, the reason being that he knew nothing about it beyond the fact that in some way a large absorption of heat occurred there; and the author he believed was the first to make a start in investigating what took place there. Something more might be done; and he would suggest that the compression curves of engines should be studied. To do this properly, the indicator diagram ought to be taken, not from the piston-rod, but either from the valve-spindle or from a crank set at such an angle that the indicator barrel would be rotating at its greatest speed during the period of the compression, so that the compression curve would be lengthened to extend throughout a great part of the diagram, instead of being as short as it was when the motion of the barrel was derived from the piston-rod, as was usually the case. If the diagram were taken from a crank in a proper position, the run of the compression curve would be extended much more, and in that way the curve could be studied better; and it would be useful for this to be done, because the area of the condensing surface in the cylinder did not vary very materially

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during the compression. It would also be well to calculate the distribution of the heat at equal intervals of time, instead of at equal divisions of the piston travel. If the author could manage this, it would be a very great help to engineers engaged in every-day work, who had neither the opportunity nor the time for doing it themselves.

Turning to the economical aspect of the matter, the author's figures showed what of course was well known, that the clearance surface, and in fact the whole cylinder surface, had a remarkable effect upon the economy of the engine by absorbing and giving out heat. That effect he thought might be partly met by using some other material for the cylinder instead of cast-iron. Supposing for instance the cylinder cover and the piston face were to be lined with a sheet of lead. The specific heat of lead (0·03) was less than one-quarter that of cast-iron (0·13); and its conducting power being also less than one-half, there ought with lead to be only one-eighth of the condensation. That was an experiment he should like to see tried, but in a more suitable engine than the portable engine used in the author's second series of experiments, in which the surfaces of the cylinder cover and piston face were together only about half the total clearance surface; for it would be difficult to line the inside of the steam passages. If such an experiment was found to answer, a further step might be taken by searching for some material of low specific heat and low conducting power, of which to make the whole cylinder. If that were done, he was certain it would be found that the economy of the steam engine was far from having yet reached its maximum. There would of course be a good deal of trouble and expense in such an investigation; but the prize would be a great one, both for the engineer who should win it and also for the nation.

Professor ALEXANDER B. W. KENNEDY, Member of Council, mentioned that twelve months ago, in criticising statements about steam-engine economy (Proceedings 1886, pages 505–7), he had pointed out that an indicator diagram always showed considerably less than the whole amount of steam which had been evaporated in

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(Professor Kennedy.)
the boiler to give that particular diagram. This he thought was known practically to all engineers; and if anything had been wanting to make it more clear, the present paper made it clear with a vengeance. In fact he had heard it jocularly suggested that the engine experimented upon ought to be called a hydraulic engine rather than a steam engine, because the amount of water passing through it was considerably larger than the amount of steam. Nevertheless he was really very glad that it was not an extremely economical engine, because such an engine would not have brought out so clearly as this particular engine had done the point to which he desired to draw attention; and he would confine himself to this matter, and make no further criticism whatever of the engine itself. Both the experiments and the paper he considered were most interesting, and so far as he could judge most trustworthy; he certainly had been very much interested in studying them. What steam-engine designers and users had to look at in these experiments might be said to be the difference between the hyperbolic expansion curve marked HH in the indicator diagrams, Plates 88 to 103, and the actual expansion curve indicated by the series of small circles. While the latter was the actual average curve, the line HH represented fairly closely the curve which ought to be got from the same amount of steam in the same engine; in other words the amount of work paid for was nearly represented by the area under HH, while the amount actually got was the intolerably smaller amount represented by the area that was comprised under the lines marked with the small circles. Drawing a horizontal line NCB across any one of the author's diagrams, as in Fig. 46, Plate 111, the ratio of the portion NC to the whole length NB represented the ratio of the steam utilised to the steam paid for; while the ratio of the other portion CB to the whole NB represented the ratio of the steam wasted to the steam paid for. On looking into these ratios it would be seen that the matter was sufficiently appalling. Having measured some of the author's diagrams in this way, he had found (Table 7, page 520), as the average of three diagrams when the engine was condensing, that the ratio of the steam utilised to the steam paid for was nearly 42 per cent., and in three non-condensing diagrams the

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average was about 47 per cent., measured just after cut-off in each case. The reason why non-condensing diagrams were better than condensing was no doubt because there was a smaller range of temperature and smaller proportional initial condensation in a non-condensing engine. These percentages simply meant that the present indicator diagrams ought to be got with somewhere about half the amount of steam that was actually put into the cylinder in that particular engine. More than all improvements in valves or valve-gear or governors &c., which did not go to the root of the matter, what was really wanted was some mode of obviating the serious loss which was at present incurred because of iron being such a very good conductor of heat. The very simple and straightforward engine described in the paper, if it had no initial condensation, would give results pretty nearly as good as those which had been obtained from Mr. Mair's large pumping engines;* what the latter would give, if they had no initial condensation, he should hardly like to say; but it was not for engineers to despair of some such result being reached.

It was interesting to find out at what particular point re-evaporation did commence; and this might be ascertained from the author's indicator diagrams in a somewhat different way from that represented in Plate 104. If re-evaporation commenced where the expansion curve was rather steep, not very far from the beginning of the stroke, it did not show so well in the author's indicator diagrams as it would do further on where the curve became flatter. But by following out the method embodied in Fig. 46, Plate 111, it could be found out with tolerable ease. Taking the same six diagrams as before, he had found that in the three condensing experiments the re-evaporation † did not begin until the pressure had fallen to an average of about 38 lbs. per square inch absolute, and in the three non-condensing experiments to about 50 lbs. These figures showed that during the first part of the stroke there was no re-evaporation,

* Proceedings of the Institution of Civil Engineers 1882, vol. lxx, page 313.

† By re-evaporation is here meant re-evaporation of any of the steam which had been condensed on admission. Table 7 shows that frequently there is still some condensation after cut-off; and of course the steam so condensed begins to re-evaporate, as shown by the table, at higher pressures than those here cited.

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Professor Kennedy.)

TABLE 7.

Condensation and Re-evaporation of Steam in cylinders lagged but not jacketed.

1	2	3	4	5	6	7	8	9	10	11	12
Diagrams shown in Plates 89 to 102.	Mean Initial Pressure. *	Actual Ratio of Expansion.	Weight of Steam and Water passing thro' cyl. per I.H.P. per hour.	Weight of Steam at cut-off per I.H.P. per hour.	STEAM in percentage of column 4.						
					At Cut-off.	At 80 lbs. *	At 70 lbs. *	At 60 lbs. *	At 50 lbs. *	At 40 lbs. *	At 30 lbs. *
	Lbs.	Ratio.	Lbs.	Lbs.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Fig. 3. Condensing.	73	3·46	35·4	16·7	47·1	..	..	47·0	45·1	45·2	50·0
Fig. 5. Non-condensing.	84	3·37	39·6	21·5	54·4	..	53·5	53·5	53·5	56·5	64·0
Fig. 9. Condensing.	89	5·82	† 34·0 †	14·3	42·1	40·0	39·5	39·0	39·5	41·5	45·0
Fig. 19. Non-condensing.	91	5·75	41·2	19·7	47·8	47·5	47·5	48·5	48·8	51·5	59·0
Fig. 23. Condensing.	87	6·35	34·6	12·5	36·0	35·0	35·0	35·0	35·0	37·0	40·0
Fig. 29. Non-condensing.	87	6·86	51·0	19·9	39·0	34·0	34·5	35·0	37·0	39·5	48·5

* Absolute pressure per square inch. † Best average result shown in diagrams (Table 2, group 3).

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TABLE 8.—*Experiments at University College, London.*

Prevention of Initial Condensation by steam-jacketing.

1	2	3	4	5	6	7	8	9	10	11	12
Number of Experiment.	Without or With steam-jackets.	Mean Initial Pressure. *	Actual Ratio of Expansion.	Weight of Steam and Water per I.H.P. per hour.			Ratio of Total Steam without and with jackets.	Weight of Steam.			
								After cut-off in High-pressure cyl.		End of return stroke in Low-pressure cyl.	
				Passing through cylinders.	Used in jackets.	Total.		Total per I.H.P. per hour.	Per cent. of col. 5.	Total per I.H.P. per hour.	Per cent. of col. 5.
No.		Lbs.	Ratio.	Lbs.	Lb.	Lbs.	Ratio.	Lbs.	Per cent.	Lbs.	Per cent.
100	Without	39·4	3·23	40·00	—	40·00	1·35 to 1·00	20·6	51·5	34·0	85·0
83 } 102 }	With	48·3	3·56	27·85	1·67	29·52		19·2	68·9	25·1	90·1
73	Without	87·7	3·00	30·25	—	30·25	1·09 to 1·00	18·1	59·7	27·6	91·2
75	With	85·0	3·60	26·98	0·76	27·74		16·4	60·8	24·2	89·7
62	Without	89·3	6·64	35·37	—	35·37	1·37 to 1·00	15·8	44·7	29·5	83·4
39	With	88·3	6·41	24·24	1·52	25·76		14·3	59·0	23·4	96·5
80	Without	94·6	8·25	36·36	—	36·36	†1·76† to §1·00§	13·4	36·9	29·8	82·0
91	With	94·0	8·43	19·51	1·18	20·69		11·0	55·1	19·4	99·4

* Absolute pressure per square inch. † § Percentage of Steam in cylinders at release { † High 39·2, Low 57·7 per cent. § High 67·3, Low 93·3 per cent.

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(Professor Kennedy.)
and that it only began at a considerable distance along the expansion line. The working out of these results was shown in Table 7 (page 520), which was only putting in another form the author's figures plotted in the diagram in Plate 104. In Table 8 (page 521) were shown some similar figures from his own experiments, having a particular bearing on the prevention of initial condensation by steam-jacketing, which, though certainly not a total preventive, nevertheless went a long way in that direction. For instance, taking the two experiments Nos. 62 and 39 in Table 8, each made with the same engine, working with the same pressure within one pound, and with the same expansion, the ratio of steam used without the jacket to that used with the jacket (column 8) was 1·37, that is 37 per cent. more steam without the jacket than with it. In another case, Nos. 80 and 91, with a higher degree of expansion and a rather higher pressure, the ratio was 1·76; that is a difference as large as 76 per cent. was made by the mere discarding of the jacket.

By aid of the diagram plotted in Plate 104 for representing the initial condensation and re-evaporation, the result mentioned in page 486 was arrived at for the zero of exposed surface. His own impression however was that such a result was not one that could be trusted, because the zero of exposed surface was of course non-existent in fact. A zero of time might indeed be recognised, by saying that the process of initial condensation was instantaneous. But this instantaneous process took effect over a surface of finite extent; and he thought therefore not very much faith could be put in a method of calculation based on what would happen at the zero of exposed surface, particularly when reasoning from an engine which had a somewhat large clearance surface for producing the initial condensation. The dotted lines marked DD in Plates 88 to 103, which were calculated on the hypothesis deduced from the diagram in Plate 104, although they agreed tolerably with the actual indicator lines in some cases, did not agree with them so closely in others; but this was a small matter.

He had been most interested in the author's supplementary paper; and he hoped to be able to utilise it, because there were so very few experiments hitherto of that kind. Some experiments on

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initial condensation had been made by Herr Escher in Switzerland in 1871, in a box made to resemble the clearance space of a cylinder. Either those experiments were not entirely satisfactory, or else he had not quite understood their results; but they were at any rate in the same direction as those now described in the present paper. He would ask the author whether in working out the results it might not be better to take into account the temperature or the range of temperature of the steam, rather than its density; because, while the initial density of the steam was connected with the initial temperature, the effect of the condensation was connected with the range of temperature; that is to say, the high-pressure cylinder of a compound engine with a given initial density of steam would not give the same result as a simple engine starting with the same initial density of steam and expanding through a greater range of temperature in its single cylinder: so that he thought it would have been better to introduce the steam temperatures into the equations given in page 505, instead of basing these upon the densities only. These formulæ therefore he considered could be looked upon only as quite empirical; and he feared they would not be applicable to compound engines; nor even to simple condensing engines, so far as could be gathered from the figures he had already quoted.

In his own experimental compound engine he had lately been able to arrange so as to measure with reasonable accuracy the amount of water still left in the steam, not only at the end of the expansion at the point E in Fig. 45, Plate 111, but also at the beginning of the compression at the point H or somewhere thereabouts, where the steam had finally all gone away to the condenser. It was very striking to see how the re-evaporation went on during the whole of the return stroke. Of course that re-evaporation was harmful in so far as it raised the back-pressure; but it was good in so far as it got rid of water, which would otherwise be still remaining in the cylinder as water; it dried the cylinder walls. The set of figures from one trial (Table 8, No. 91) showed that in the jacketed high-pressure cylinder the amount of steam at the cut-off was 55 per cent. of the whole amount of steam supplied into the cylinder from the boiler, and at the release it had risen to 67 per cent. In the

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(Professor Kennedy.)
low-pressure cylinder at the release it was 93 per cent., and at the end of the low-pressure return-stroke it had got up to 99 per cent.

From the suggestion to use lead for diminishing the condensation in cylinders he was afraid no good would result. He had been trying some lead in cylinders for preventing condensation; and although the condensation was less than with cast-iron, it was not reduced anything like 50 per cent.

Mr. LONGRIDGE considered, if that was the case, the condensation was due to the water remaining in the cylinder, instead of to the metal. At the same time he thought a metal of lower specific heat must lessen condensation.

Professor KENNEDY admitted that the lead had lessened the condensation, but not to any large extent. He was now going to try vulcanite.

Professor W. CAWTHORNE UNWIN remarked that the curve HH in the author's diagrams, Plates 88 to 103, was a hyperbolic expansion curve. To bear the interpretation put upon it by Professor Kennedy, that is for the abscissæ to represent the quantity of steam paid for, it should be a saturation curve, as in some of the diagrams in Professor Cotterill's book.* The two curves were very nearly the same, unless they were carried to very extreme limits; but the abscissæ of the saturation curve and diagram curve gave the ratio of steam used to steam existing as steam in the cylinder. Professor Kennedy had said that the author had been dealing with a bad case; and the puzzle was how it came to be so bad a case, because apparently this was an engine constructed with a considerable amount of skill, with a good condenser, and with good valve arrangements and other details: so that it was not quite easy to see why it should be using something like 40 lbs. of water per I.H.P. per hour. Having lately been trying an engine of not very different size and

* The Steam Engine considered as a Heat Engine; by James H. Cotterill, 1878, page 146.

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working with about 21 lbs. of water, he confessed the magnitude of the consumption in the author's experiments seemed very surprising. His engine was a slide-valve engine, having a large clearance surface, and he had not got anything like so large a result. No doubt the point of the paper was the very large influence, much larger than had perhaps been realised, of the area of surface in the clearance space. Now that Major English had called attention to it so very prominently, it was easy to see that a large area of metal clearance surface must have a large effect upon the working of the steam. A doubt however had suggested itself to him with regard to the tightness of the condenser in these experiments. For when building an experimental engine he had wished to do as the author had done, namely to measure the condensed steam as well as measure the feed-water into the boiler, in order that one might be a check on the other; and he had had to consider how to construct a surface condenser so that the measurement should be a trustworthy one. He came to the conclusion that an ordinary surface condenser having a large number of tubes with packed joints and subject to variations in temperature could not be trusted to be absolutely tight. Several engine makers assured him that the joints were tight; and no doubt for ordinary purposes they were sufficiently tight. But the whole weight of the condensed steam was so small, that a leakage, which in the working of the condenser for practical purposes would be absolutely inappreciable, would produce a large effect on the measurement of the steam in experiments such as these. It would therefore add to the value of the paper if the author would state what kind of surface condenser it was that he had used, and whether he attached any importance at all to the doubt now suggested. In the surface condenser which he had had made, the joints were practically as tight as those of the tubes in a boiler, and there was not a single drop of leakage; but he had some doubt whether a large number of packed tubes could be trusted to be so tight as to have no effect on the amount of air-pump discharge. The figures of water consumption given in the paper were really so large that he should like to get at some explanation of them.

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Mr. DRUITT HALPIN observed that at the commencement of the paper it was mentioned that the chief conditions which had had to be considered in the design of the engines were a very hot climate, great scarcity of water, high price of fuel, and difficulties of transport almost prohibitory for heavy weights. The usual concomitants under such circumstances were in this case fortunately absent: there was apparently no limit to price; and he hoped the value of the machinery would be recouped in the information now furnished by the author's experiments. Also there would have been no limit in the skilled labour to work the machinery when doing the duty for which it was designed, as the rank and file of the corps of Royal Engineers was largely made up of trained mechanics. In regard to economy, the result was seen to be that in most careful trials the engine had not consumed less than 34 lbs. of water per I.H.P. per hour, and under some circumstances the consumption had gone up to 51 lbs. That certainly was hardly such a result as might have been expected under the condition of unlimited price. The cylinders were stated to be 16 inches diameter by 18 inches stroke, and not jacketed. If there ever was a case in which a jacket would pay, he certainly thought it would be this, where there were all the elements in its favour—very slow piston-speed, and a very low number of revolutions per minute, as well as a relatively high expansion. It might be argued that jackets would increase the weight of the engine; but they would more than proportionately decrease the weight of the boiler, so that the total weight of the whole apparatus would have been considerably less.

The expansion gear shown in Plate 109 was certainly a most elegant outcome of Zeuner's diagram. All variable expansion gears might be roughly classed as automatic and non-automatic: or those which were variable while the engine was running, and those which could be varied only while the engine was standing. The gear here shown was one of those that could be varied only while the engine was standing; and he certainly thought the present case was not a suitable one for its application. For he understood the duty of this engine was to pump water through a long length of delivery pipes, starting from nothing and gradually working up to a pressure of 700 lbs. per

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square inch when the far end of the pipe was reached. Under these circumstances he thought an ordinary Meyer gear, variable by hand while the engine was running, would have been more desirable than the very elegant modification which had been introduced by the author.

The efficiency of the boilers seemed, as far as he could make out, almost on a par with that of the engines. For it appeared from page 480 that in the trials made two of the boilers had together approximately 1100 square feet of heating surface; and taking the maximum consumption of steam and the maximum horse-power, and making very liberal allowance for the condenser and feed-pump, he found that the rate of evaporation came to only a little over 2 lbs. of water per square foot of surface per hour. It could not therefore be said that the boilers were overdriven, and gave a poor result on that account; and it was added on page 481 that the evaporative duty even at that very moderate rate was only about 7·9 lbs. of water per lb. of coal. Even taking the most favourable case for the boiler, of receiving the feed water at a temperature of 50° Fahr. and evaporating at a pressure of 80 or 90 lbs. per square inch, the efficiency would at the outside be only 60 per cent. of what it ought to be with Hartley coal: which certainly was a very poor result, considering that the chief object of the whole scheme ought to have been to get the maximum economy.

Mr. CHARLES E. COWPER asked why the cylinders were not jacketed. It really seemed strange at the present time that, in a case where high economy was desired, such an ordinary precaution against waste of steam by excessive condensation in the cylinder should not have been adopted, however unnecessary jacketing might have been considered twenty years ago.

Mr. W. W. BEAUMONT, referring to the very important question which had been raised by Professor Unwin, namely why was this engine so uneconomical, observed that the author had himself dwelt upon that which was probably the answer to the question; for in page 487 it had been suggested that there should be a definite

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(Mr. W. W. Beaumont.)
relation between the surface of the steam passages, the diameter of the cylinder, and the length of stroke, in order to obtain the best results for any given range of temperature. The figures given in Table 1 (page 488) tended to show that a much longer stroke in proportion to the diameter of the cylinder than was used in these experiments would give a better result. Whether that was so or not might be a question in this particular case: although he believed that well known constructors who had made a good many small engines had obtained better results when the stroke was greater in proportion to the diameter of the cylinder than it was in the engine with which the present experiments had been made, where the stroke was 18 inches and the diameter 16 inches. The conclusion drawn by the author indicated one at least of the reasons for the want of economy in the engine.

With regard to the supplementary experiments, although engineers must be glad that experiments of this kind had been undertaken in order to obtain information on the subject of initial condensation, he was afraid they must still wait for experiments that would repeat the actual conditions under which the steam was used and under which it was condensed in the steam engine while at work: instead of simply sending a puff of steam into a small space where it did not expand, and allowing it again to exhaust itself thence, as had been done in the experiments from which the author's results had been obtained.

Mr. DAVID GREIG, Vice-President, considered it a most serious thing that not more than half the full effect was got out of the steam used in an engine; and the paper had no doubt accomplished a great object in leading engineers to think over this subject, which was one of such great importance. Although these experiments had been conducted with engines which seemed to be excessively uneconomical, still it was clearly seen from the results that other engines also were not getting anything like what they ought to do from their steam. Since reading the paper, he had been working continuously at experiments for the purpose of solving some part of the problem; and he hoped at some future time he might be able to lay before the

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Institution something more on the subject. Thus far it was quite a puzzle to him; and he had never expected to see such results so accurately presented as had been done by the author. One thing clearly proved was that an excessively early cut-off was very uneconomical. Only last week he heard an engine complained of as very uneconomical, which was cutting off at one-seventeenth of the stroke: the consequence of course being that it was using more water and more coal than it should do. This was a subject that hitherto had not been quite solved. The fact was that the temperature of the steam must not be reduced in a single cylinder to the full extent necessary for the economy desired. More cylinders were wanted for reducing it; and the higher the initial pressure, the greater was the number of cylinders necessary for the purpose of reducing it. He should be glad to learn from the author whether it was possible to calculate the most effective cut-off; and what was the best proportion between the length and diameter of the cylinder. Something he was sure would be learnt from the present paper, as the author had taken a great deal of trouble with it, and had rendered it most valuable.

Mr. P. W. WILLANS observed that in Tables 3 and 4 there were one or two curious differences in the initial condensation in a non-condensing and a condensing engine. Thus in a trial on June 1 of a non-condensing engine (page 506), and a trial on June 15 of a condensing engine (page 508, line 2), the revolutions per second were the same (1·21), and the initial density of the steam was practically the same (0·146 and 0·145); but the water collected per revolution was greater in the non-condensing engine (0·0237) than in the condensing (0·0227), which was just the reverse of what he should have expected. Most engineers he supposed had come to the conclusion that it was the range of temperature in the cylinder which caused this initial condensation. If so, there must be nearly double the range in the condensing engine that there was in the non-condensing; and yet the two experiments he had just referred to seemed to show the reverse. He also remarked that the indicator diagram contributed by Mr. Longridge, Fig. 45, Plate 111, showed considerable

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(Mr. P. W. Willans.)
compression in the cylinder, and he presumed the temperature would follow the pressure during that compression. All good engines had some compression; and therefore the author's later experiments would hardly throw much light on the subject. If the compression reached pretty nearly the initial pressure, and if the temperature followed the pressure during compression, there would surely not be very much condensation due to the heating of the cylinder walls before the stroke began. On this point he was now making experiments which would cover a greater variation both in speed and in steam pressure than those which were the subject of the present paper, and as far as he could see he should not get more than about 10 per cent. initial condensation at high speeds; but he had not gone quite far enough to be able to say more at present.

Mr. G. R. BODMER pointed out that the condensation of water in the cylinder during the course of the stroke did not necessarily represent heat abstracted by the walls of the cylinder. As was well known, when steam in the presence of water expanded adiabatically, or without any communication of heat, either condensation or re-evaporation took place, according as the weight of steam present at the commencement of the expansion was greater or less than that of the water then present. It had been shown by Clausius that if the proportion of steam to water was to be kept constant during expansion, the expansion could not be adiabatic, but heat must be communicated to the steam. Hence if the steam were dry to start with, and continued dry during expansion, this would be a proof that heat had been transferred to it from the cylinder walls or otherwise; or if the proportion of steam to water continued constant during expansion, so that there was neither condensation nor re-evaporation, this also would prove the same. Taking for instance the indicator diagram shown in Fig. 25, Plate 100, he found from measurement that at the commencement of the expansion the proportion of steam to water in the cylinder was only 34 per cent. If that small proportion of steam had expanded adiabatically, without any communication of heat by way of either addition or subtraction, there would have been a slight re-evaporation from the large

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proportion of water present in the cylinder; and at the end of the stroke the re-evaporation would have amounted to about 3·5 per cent.; that is there would have been 3·5 per cent. less water in the cylinder as compared with the weight of steam at the end of the expansion than there was at the commencement. But at the end of the stroke the condensation as given in the third column of group 18 in Table 2 (page 498) was 50·5 per cent., leaving 49·5 as the percentage of steam, and thus showing a re-evaporation of 15·5 per cent. during the expansion, of which 3·5 per cent. was due to adiabatic expansion. Consequently only 12 per cent. was due to heat communicated from the cylinder walls; and thus neither did condensation necessarily imply a loss, nor did re-evaporation always denote transfer of heat from the cylinder walls. Hence the curve HH in Plates 88 to 103, referred to by Professor Kennedy in conjunction with the actual indicator diagram, for ascertaining the ratio between the work paid for and the work done, ought not, strictly speaking—if he might venture to differ from such eminent authorities as Professors Kennedy and Unwin—to be either the hyperbolic curve of dry steam or the curve of saturated steam, but the adiabatic curve; and if the steam was dry at the commencement of the expansion, and was expanded adiabatically, it would not be dry at the end. There was not much difference between the three curves; but as the paper was a scientific one, it was as well to be scientifically accurate, and the difference in the amount of condensation as deduced from the adiabatic curve was quite appreciable. For determining the total condensation at any point, it was of course quite right and necessary to employ the curve of saturated steam. Another point worth noting was that according to Major English's experiments the heat transferred from the metal to the steam in the cylinder was sufficient both to supply the whole of the work and to increase the internal heat of the steam besides, as compared with its value at the beginning of expansion. This was evident from an examination of the diagrams representing the number of thermal units expended in various ways; taking Fig. 26, Plate 100, as an example, it would be seen that, whereas the heat converted into effective work was 65 thermal units, as given in the

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(Mr. G. R. Bodmer.)
third column of group 10 in Table 2 (page 496), the heat returned to the steam from the metal, as measured from the line WW, was about 140 thermal units; whence as a necessary consequence the internal heat of the steam was greater at the end than at the commencement of the expansion.

Mr. JEREMIAH HEAD, Past-President, understood from Mr Longridge (page 510) that a consumption of 17 lbs. of water per I.H.P per hour was about the best result in ordinary practice from a single-cylinder condensing engine, and 24 lbs. from a non-condensing. It was somewhat disappointing to learn that from his extensive experience he could not report anything better. In compound marine engines his own impression was that the consumption of water had now been brought down at least as low as 14 or 15 lbs.; and judging by what had taken place at the recent trial of agricultural engines at Newcastle-on-Tyne, he supposed that non-condensing compound engines had got certainly below 20 lbs., he thought to 18 lbs. of water per I.H.P. per hour.

With regard to lining cylinders with some partially non-conducting substance, such as lead or vulcanite, he would refer to the plan of lining the cylinder with an exceedingly thin jacket of compressed steel, and packing with some better non-conducting substance the annular space between the liner and the cylinder casing. All who had seen, in the present Manchester Exhibition, the compressed-air reservoirs of steel made by the Whitworth Company for use in fish torpedoes, would have noticed how exceedingly thin such steel could now be made, and how at the same time it could be very sound and strong indeed. He believed the idea had been conceived of making cylinder linings of that extremely thin but tough steel, and surrounding them of course with an outer casing of sufficient thickness, and with a non-conducting substance packed in between. That plan would make the cylinder almost completely non-conducting.

Mr. HENRY DAVEY wished to ask the author if he could explain the variation in Table 4 (pages 508–9), of nearly 4 to 1 between the maximum and minimum amounts of net initial condensation.

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Major ENGLISH said he was not concerned to defend the economy of the engines; for the paper would never have been written if they had been economical. The results of the experiments served to call attention to the great want of economy which was apparent in a slow-speed direct-acting pumping engine as ordinarily constructed; and it was hardly necessary to go into the question of the reasons for the selection of these engines.

In reply to Mr. Longridge's question (page 510) as to the amount of water that was condensed in the jacket on the steam-pipe, it was found almost impossible to get any definite figures. Sometimes the result would be double what it was at others; and, as it was in no case large, it was thought undesirable to include it.

With regard to the tightness of the pistons and valves, they were carefully tested during the experiments, and he thought there was no doubt as to their being tight.

With regard to Professor Kennedy's remarks (page 519) respecting the particular point in the stroke at which re-evaporation commenced, it should be borne in mind that it was only the balance of re-evaporation over condensation or of condensation over re-evaporation that could be observed at all. It was quite possible that at one part of the surface re-evaporation might be going on, while at the very same time condensation might be going on at another part. The only result that could be got from observation was the balance of one over the other, so far as he could see.

As to the zero of exposed surface (page 522), he had introduced it simply as a working hypothesis by which it might be rendered easier to calculate the difference between initial condensation and re-evaporation for any point in the stroke.

As to taking the temperature of the steam instead of its density (page 523), the one followed almost from the other. It was simply a matter of convenience which of the two was taken; but it certainly appeared to him from these trials that the initial condensation varied directly with the density, while there did not seem to be any direct relation between the initial condensation and the varying temperature. Therefore in framing the formula which might account for the initial condensation he thought it more desirable to take the density than the temperature.

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(Major English.)

Respecting Professor Unwin's suggestion (page 525) as to leakage of the condenser, this point had also been carefully tested on every occasion on which the condenser was tried; and as it was a separate condenser worked by a separate steam engine (page 479) it was a very simple matter to test it. The only thing required was to run the condenser engine by itself, and see that no water came from the overflow, which proved necessarily that there was no leakage. In this way the condenser had been found to be perfectly tight. It was sufficient he thought if the condenser tubes were made as tight as those in a boiler.

In regard to Mr. Beaumont's remarks (page 528) as to the experiments on initial condensation not being made under the same conditions that would exist in an actual steam engine, he considered that in an actual steam engine at the beginning of the admission the conditions were almost identically those which prevailed in these experiments: the piston was scarcely moving, and it was to ascertain the amount of initial condensation in the clearance space at that point that these trials had been made. The only difference he could see was that in these trials the piston was absolutely blocked by solid packing, and therefore did not move at all; whereas in the working of the actual engine it was moving at a very slow speed indeed.

As to Mr. Greig's enquiry (page 529) whether it was possible to calculate the most effective point of cut-off, he considered the point of cut-off ought to depend upon the relative dimensions of the cylinder and steam passages, and upon the proportion between diameter and length of stroke. It was impossible in his opinion to say what was the best proportion between the length and diameter of the cylinder, without knowing the intended steam pressure and number of revolutions per minute.

The variation of the results given in the last column of Table 4, referred to by Mr. Davey (page 532), should be proportional he thought to the initial densities; and he was unable to explain the differences, amounting in some cases to thirty per cent. from the mean. He could only suppose that they were experimental errors; and the large number of trials were made on purpose if possible

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to counteract the effects of such errors. In experimenting on a large scale with an air-pump it was almost impracticable, as far as he could see, to prevent the water from coming over in gulps from the condenser; and it was very difficult indeed to determine the exact moment at which the water due to any one trial had all come over. The disturbance caused by the movement of the flange of the air-pump valve perhaps threw water up and out of the overflow, which would not necessarily have come over except under circumstances that might not arise in all cases.

The PRESIDENT was sure the Members would all agree with him that the best thanks of the Institution were due to Major English for the two very interesting papers which he had furnished for their benefit. He had himself had something to do with these engines at the time of the war in the Soudan. When it was intended to make the Suakim and Berber Railway, it was stated that the pumping engines were to be ordered from America for supplying the water along the line. Through his action in the House of Commons that order was altered, and the engines were given to English makers to construct; so that he felt he had done something in the way of getting work for English makers. He was very glad that the paper had been read, because it was clear that, even if the engines experimented upon were not the most economical that could have been built, the Institution would derive great benefit from the information obtained in these trials. When it was found that at present only a little more than 40 per cent. of the steam supplied was being utilised, it was clearly time that something more should be learnt on so important a matter. Every one who could find leisure to study these papers carefully would he was sure learn a great deal more from them than could be gained from the reading and discussion alone. He had great pleasure in asking the meeting to pass a hearty vote of thanks to the author for the trouble he had taken in preparing them.

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Professor JAMES H. COTTERILL, having been prevented from attending the meeting, sent the following remarks upon the two papers.

The experiments described in these papers are very interesting and instructive. It is perhaps to be regretted that the feed-water measurements were abandoned; but from statements made in page 481 it is possible that they were carried sufficiently far to show that no very serious cause of error existed in the measurement of condensed steam. Also, though not expressly mentioned, it may be assumed that leakage did not exist to any important extent. The consumption of steam appears large; but it must be admitted that it is not greater than is often found in engines of the same size working under the same conditions.

The author has endeavoured in a very original way to investigate systematically the laws of cylinder condensation. Something has been done in America by Professor Marks and others in this direction, but on the whole with little success as yet. The law obtained experimentally in page 505 by the author is expressed by the formula $X = \frac{B}{\sqrt{N}}$; where N is the number of revolutions per second, B a quantity proportional to the density of the steam, and X the heat per square foot of surface abstracted alternately by the cylinder from the steam and by the steam from the cylinder in one revolution, that is in one cycle of changes of temperature. It was pointed out long ago * that XN, the condensation per second, must be greatly augmented in a process of alternate condensation and re-evaporation; and it is easy to infer that it will be greater the quicker the rate of alternation. This is shown by the theoretical formula $X = \frac{\theta}{\sqrt{10N}}$, where the quantity θ is the range of temperature; and it will be seen that this theoretical formula agrees with the formula derived from the author's experiments when the range of temperature is $B\sqrt{10}$. This theoretical formula is obtained by the three following assumptions:—

* The Steam Engine considered as a Heat Engine; by James H. Cotterill, 1878, page 252.

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1. That the question is one simply of conduction through metal, without any obstruction to the passage of heat from steam to metal or conversely.

2. That the coefficient of conduction has an average value * derived from Forbes's experiments on the conduction of heat in iron bars.

3. That the cycle of changes of temperature is of that simple kind known as "harmonic;" † whereas the actual cycle is much more complex.

It is not easy to conceive how cylinder condensation can be independent of θ the range of temperature; and in fact the author finds that B increases in proportion to the density of the steam, that is it is greater the higher its temperature. The values of B obtained in the author's supplementary experiments range from 3 to 10, giving values of θ much less than the actual range of temperature of the steam. There is therefore nothing in the theoretical formula which excludes the supposition that the question is one of conduction in metal, with a range of temperature reduced by thermal resistance between steam and metal. In the present state of our knowledge it seems impossible to say whether this supposition is sufficient to explain the facts; it is quite possible that cylinder condensation when large may be due to water remaining behind in the cylinder after the exhaust is complete. No doubt if the metal had no action on the water, and if no water was carried over periodically from the steam passages, there could be none left after exhaust, unless the ratio of expansion exceeded a certain critical value. But it seems quite conceivable that a film of water may permanently adhere to the surface; and it is difficult to distinguish the action of such a film from the action of the metal itself.

The author concludes that the clearance surface is the principal thing to be considered, including in this, as he very rightly does, the

* The Steam Engine considered as a Heat Engine; by James H. Cotterill, 1878, page 251.

† Theory of Heat; by J. Clerk Maxwell, fifth edition, 1877, page 263.

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(Professor Cotterill.)
exposed surface of the passages leading to the cylinder. If this be the case, it seems clear that most important results might be obtained by coating the whole clearance surface with some suitable substance. If a substance could be found which was impervious to heat, and did not permit the adherence of a film of moisture, great economy should result. It is however very difficult to admit with the author that the subsequent treatment of the steam has no influence on initial condensation. Condensation and re-evaporation are two parts of the same process; one necessarily involves the other. Any cause therefore which influences the re-evaporation must also influence the condensation.

It is to be hoped that the author will continue these researches; for a systematic investigation should lead to results of great practical importance. At present little is known with certainty of the reasons why cylinder condensation is to all appearance so much greater in some cases than in others.

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MEMOIR.

JOHN MAYLOR was born in Liverpool on 10th June 1827, and served his apprenticeship with Messrs. Fawcett Preston and Co., engineers, Liverpool. In 1848 he went out to the Brazils as an engineer in the Brazilian steam frigate "Dom Affonço." He was soon afterwards appointed engineer in charge of the marine arsenal at Rio de Janeiro, and in 1853 succeeded Mr. F. C. Miers as engineer to the Ponta d'Area Iron Works, one of the largest engineering and shipbuilding establishments in South America. In January 1858 he joined Messrs. J. and F. Miers in their extensive engineering and shipbuilding works at Rio de Janeiro; and on the retirement of his partners in 1862 carried on the business with continued success in connection with Mr. A. G. de Mattos till 1871, when he returned to England, and settled at Churton near Chester, where his death took place on 5th November 1887, at the age of sixty. During his residence in Brazil he received many marks of favour and approval from the Emperor, who invested him with the Order of the Rose in recognition of his services to the government. He became a Member of this Institution in 1865.

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TRIPLE-EXPANSION ENGINES. *Plate 1.*

Diagrams showing course of Steam from High to Intermediate Cylinder.

Fig. 48. *Sequence of Cranks — High, Low, Intermediate.*

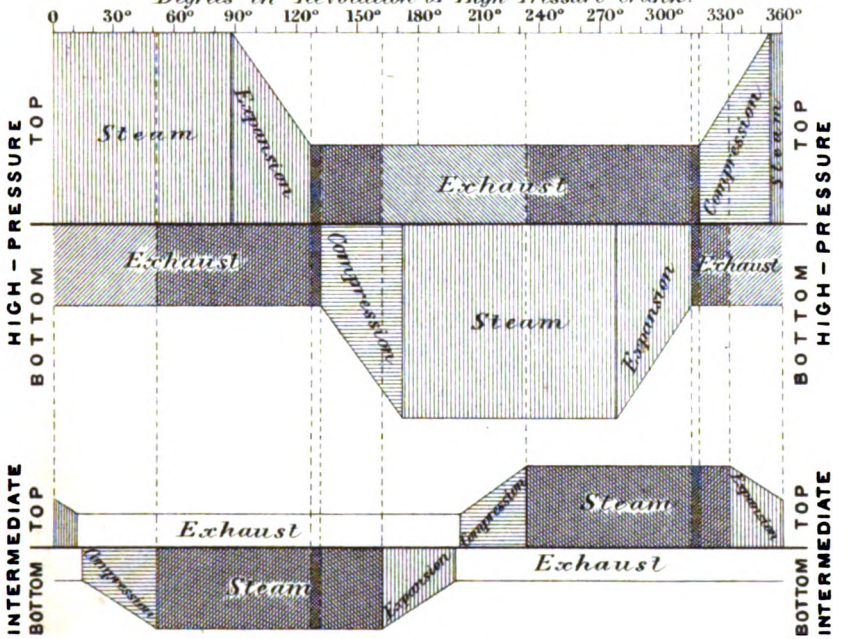
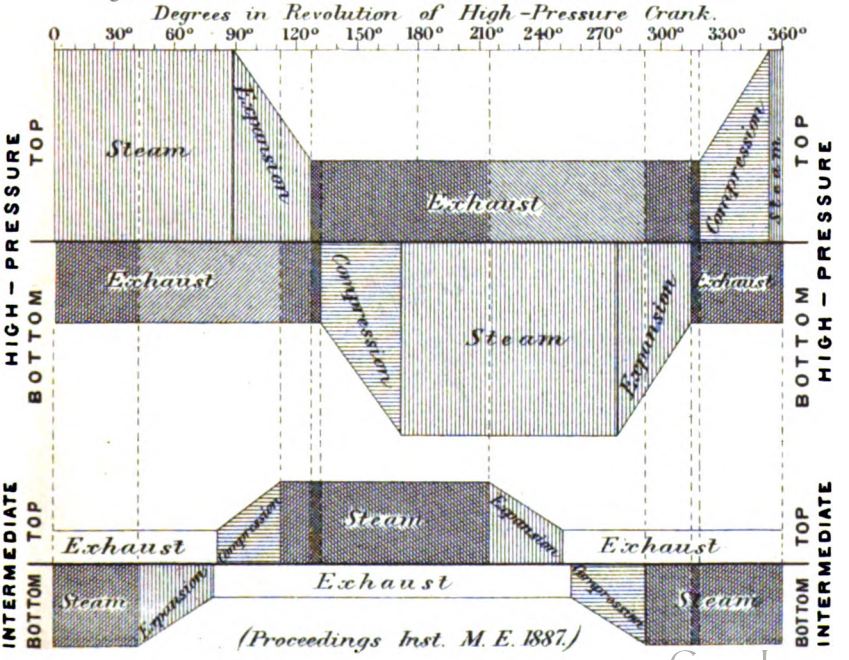


Fig. 49. *Sequence of Cranks — High, Intermediate, Low.*



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Twisting Moments on Crank-shaft of "Shakespear."

Fig. 50. *Weight of Moving Parts neglected.*

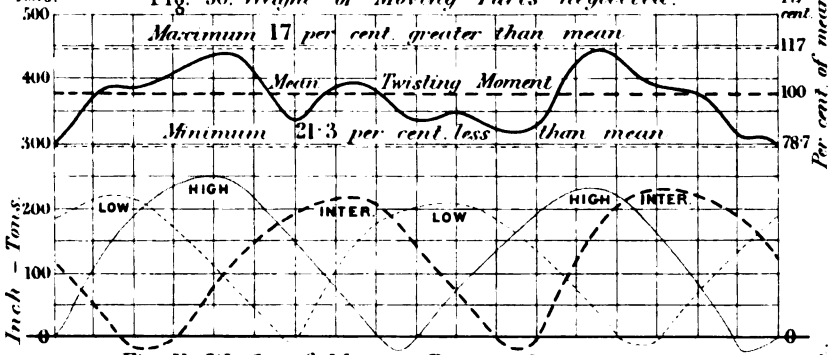
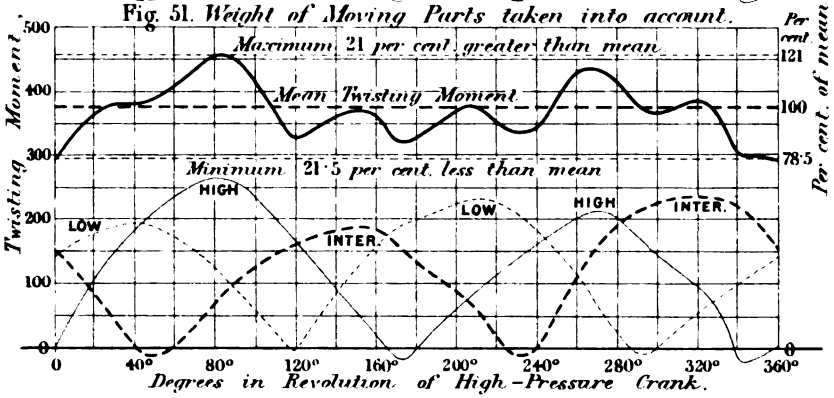


Fig. 51. *Weight of Moving Parts taken into account.*



Combining of Indicator Diagrams.

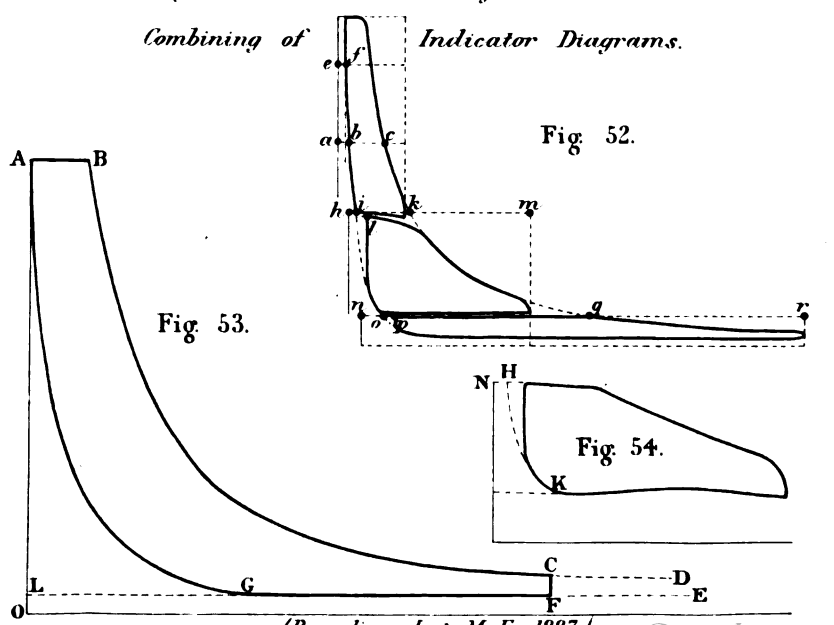


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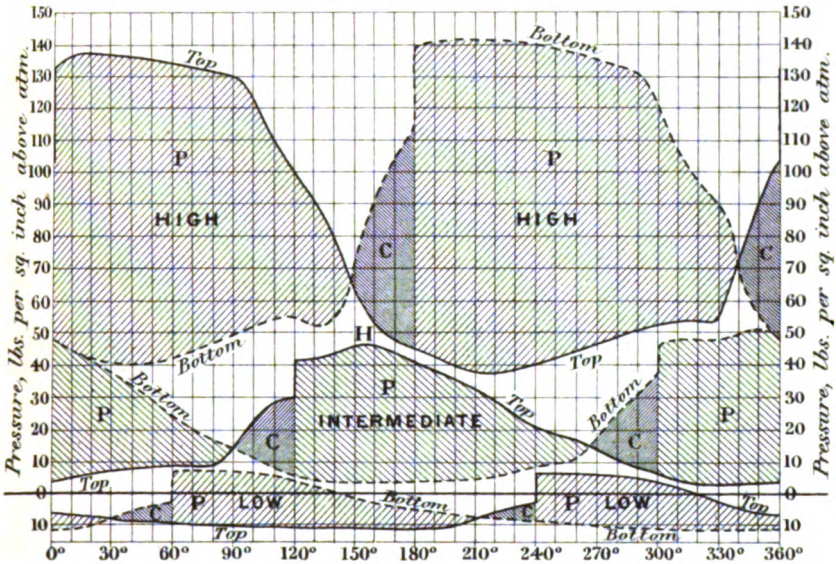
Fig. 55. *Continuous Development of Indicator Diagrams from "Abeona". See Figs. 42 to 45, Plate 107.*



Combining of Indicator Diagrams.

Fig. 56.

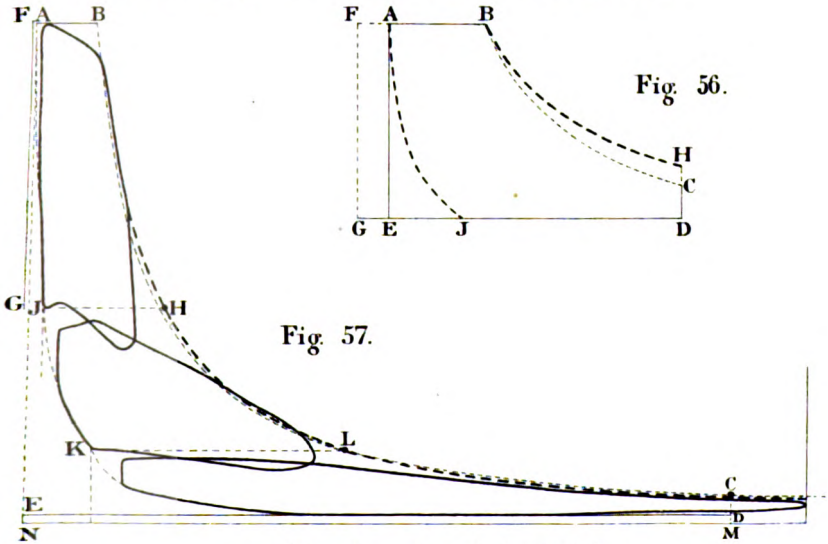


Fig. 57.

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PORTABLE HYDRAULIC DRILL. *Plate 4.*

1 H.P. Direct-Acting Hydraulic Drill.

Fig. 1. *Side Elevation.*

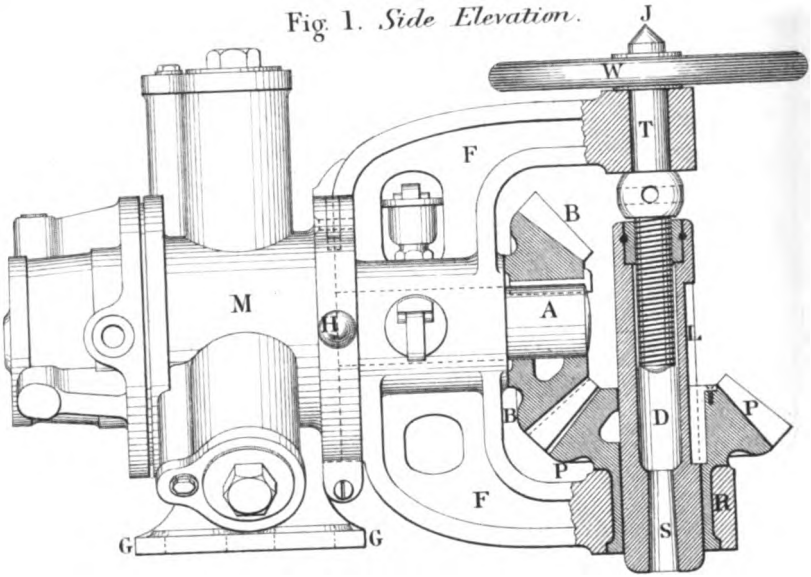
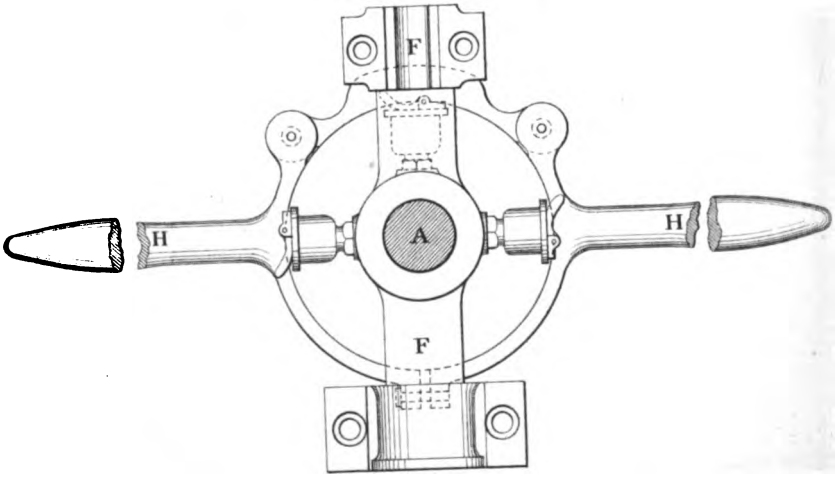
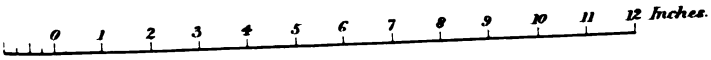


Fig. 2. *End Elevation.*



(Proceedings Inst. M. E. 1887.)

Scale 1/4 th



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PORTABLE HYDRAULIC DRILL. *Plate 5.*

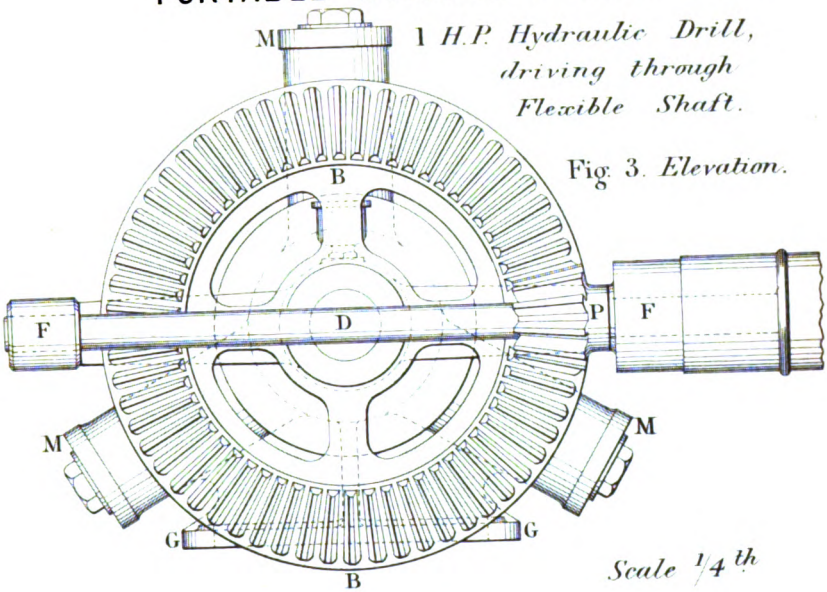


Fig. 3. *Elevation.*

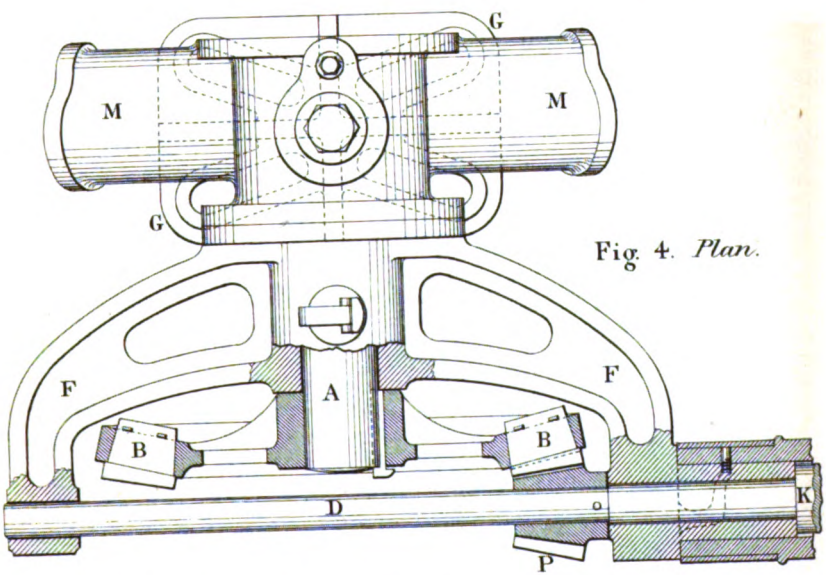
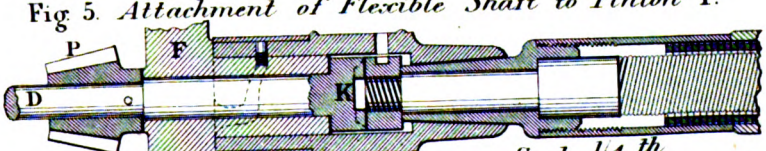
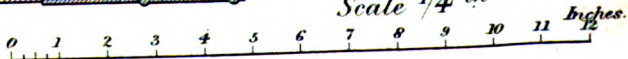


Fig. 4. *Plan.*

Fig. 5. *Attachment of Flexible Shaft to Pinion* P.



Scale 1/4 th



(*Proceedings Inst. M.E. 1887.*)

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LAKE SUPERIOR COPPER MINING.

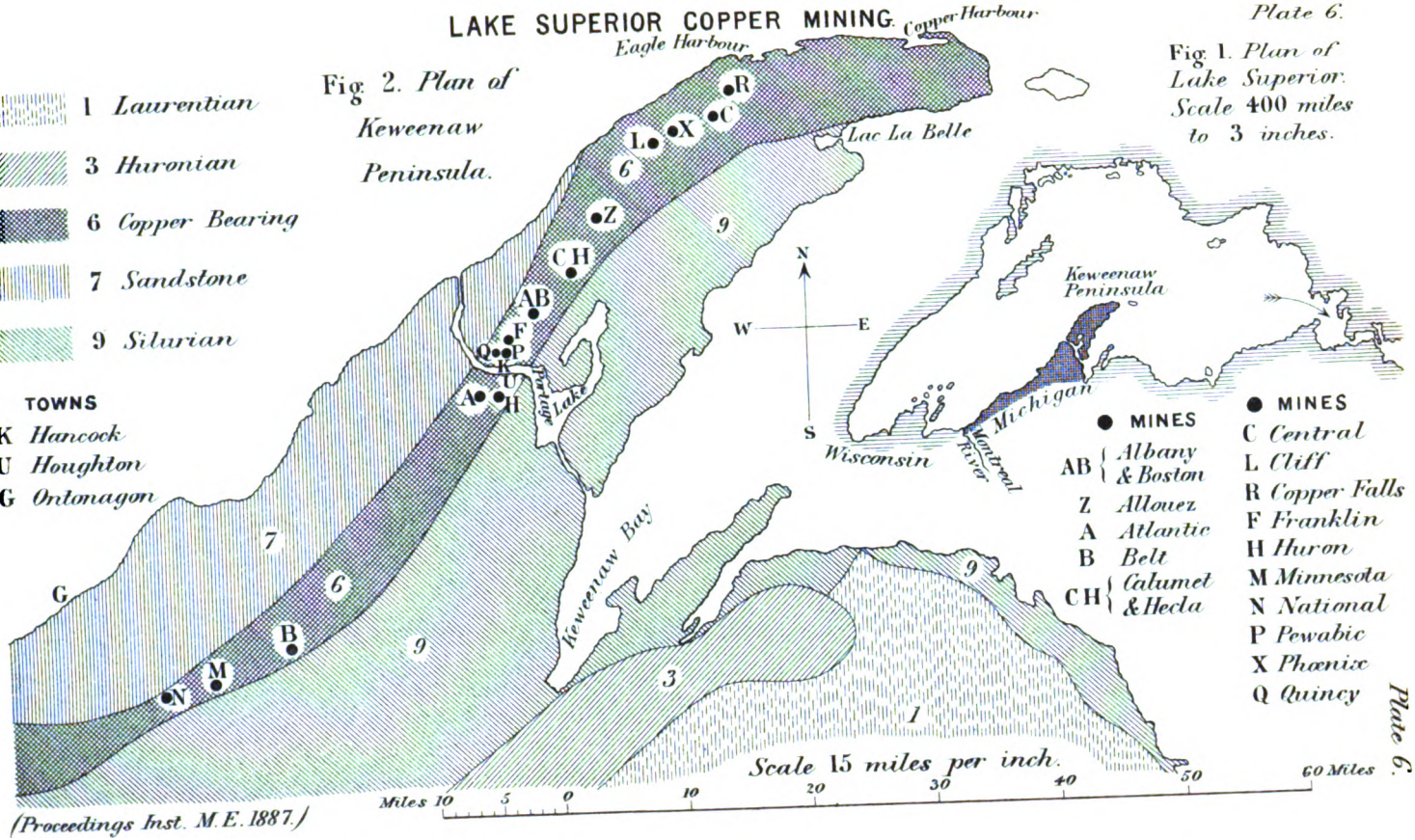

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Plate 7.

Fig. 3. *Longitudinal Section of Central Mine.*

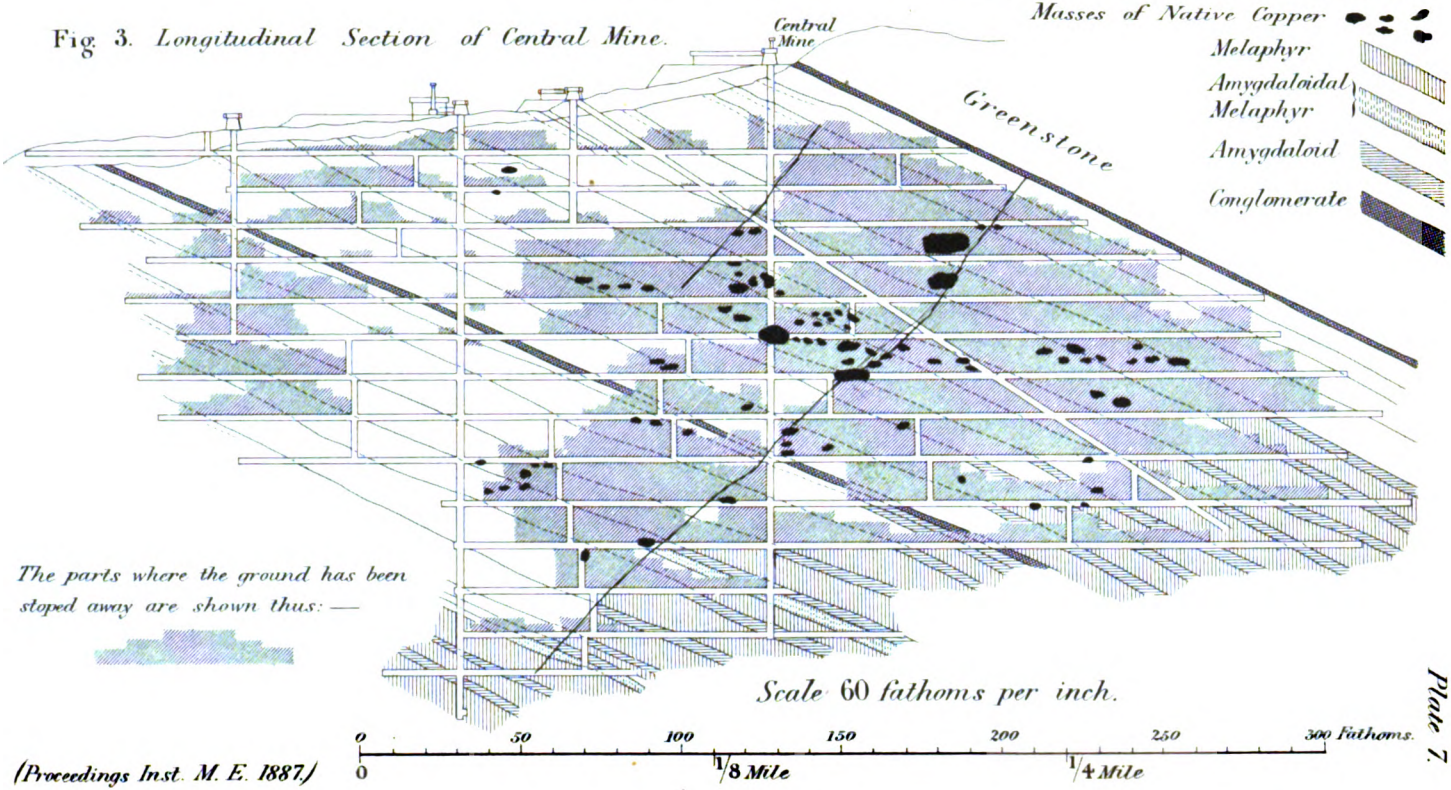

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Plate 7.

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Plate 8.

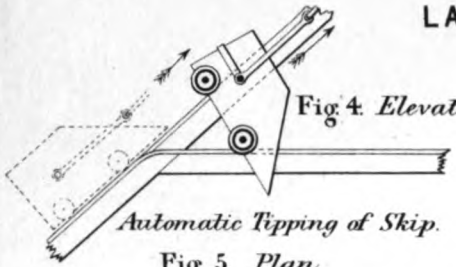
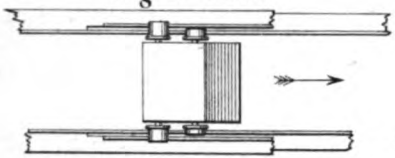


Fig. 4. *Elevation.*

Automatic Tipping of Skip.

Fig. 5. *Plan.*



Scale 1/100 th

Fig. 6. *Skip in inclined Shaft.*

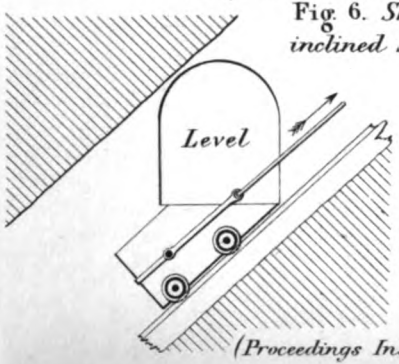


Fig. 7.

Rock House at mouth of inclined shaft.

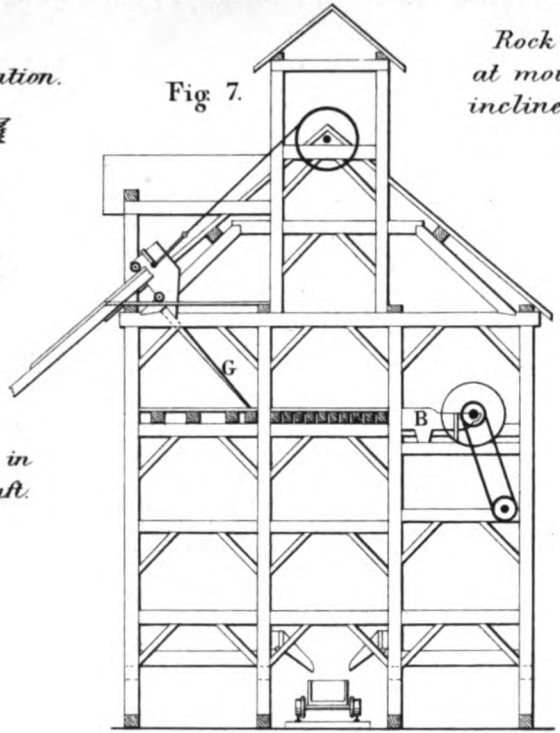
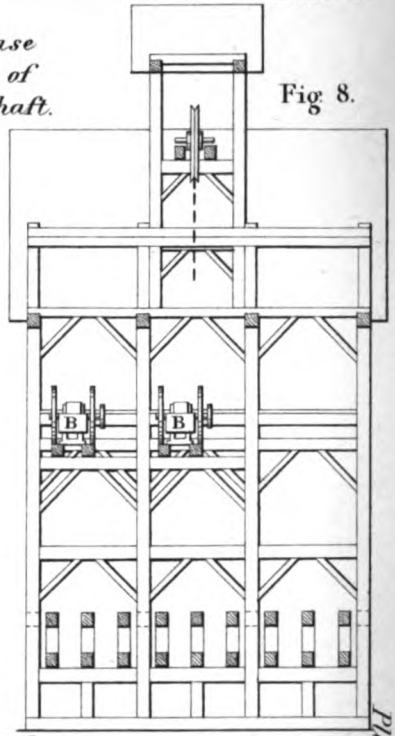


Fig. 8.



Scale 1/200 th

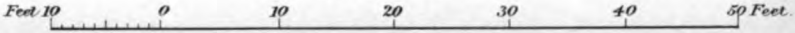


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Plate 8.

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LAKE SUPERIOR COPPER MINING.

Plate 9.

Fig. 9. *Rock House connected with Shaft House by road on trestles.*

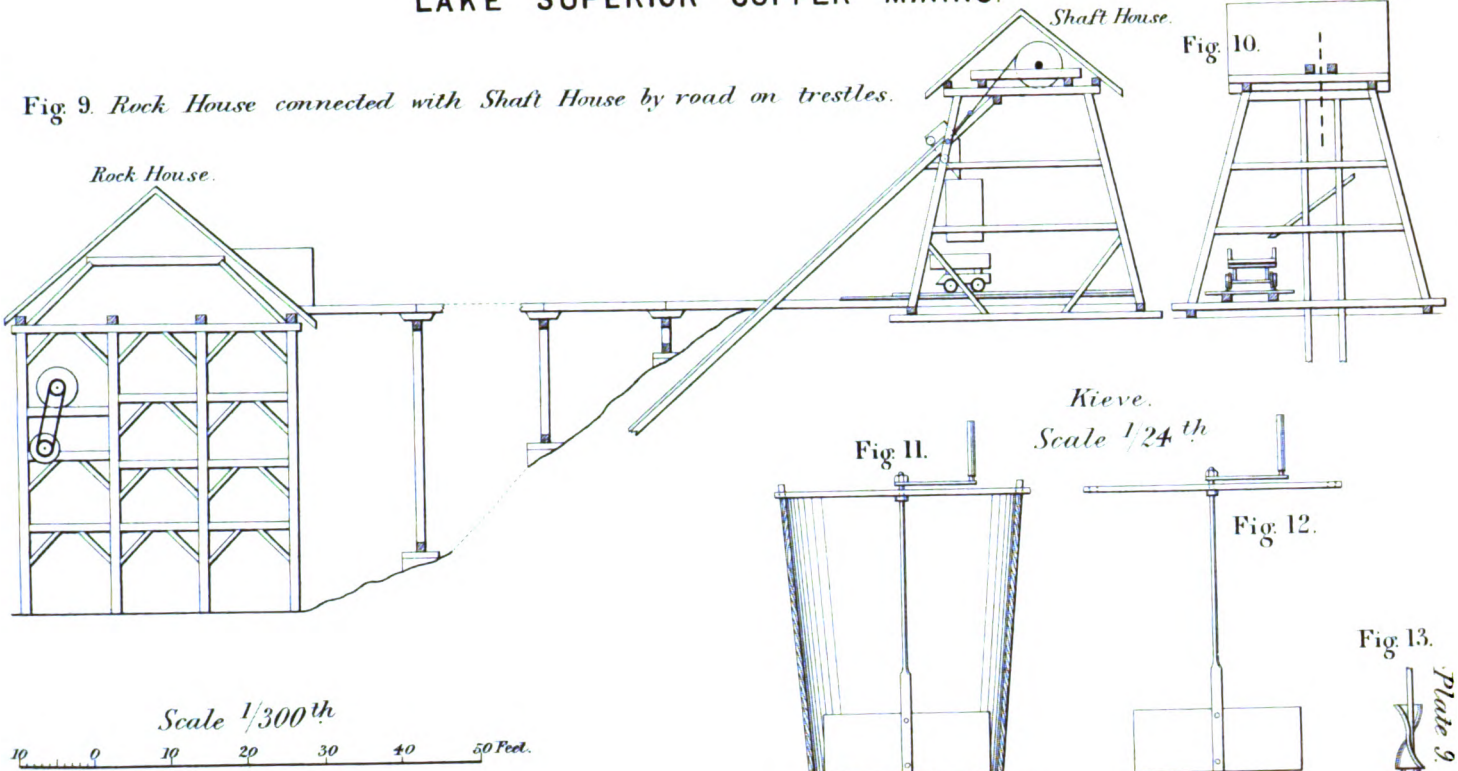

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Plate 9.

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Stamp Mill.

Fig. 14. *Elevation*

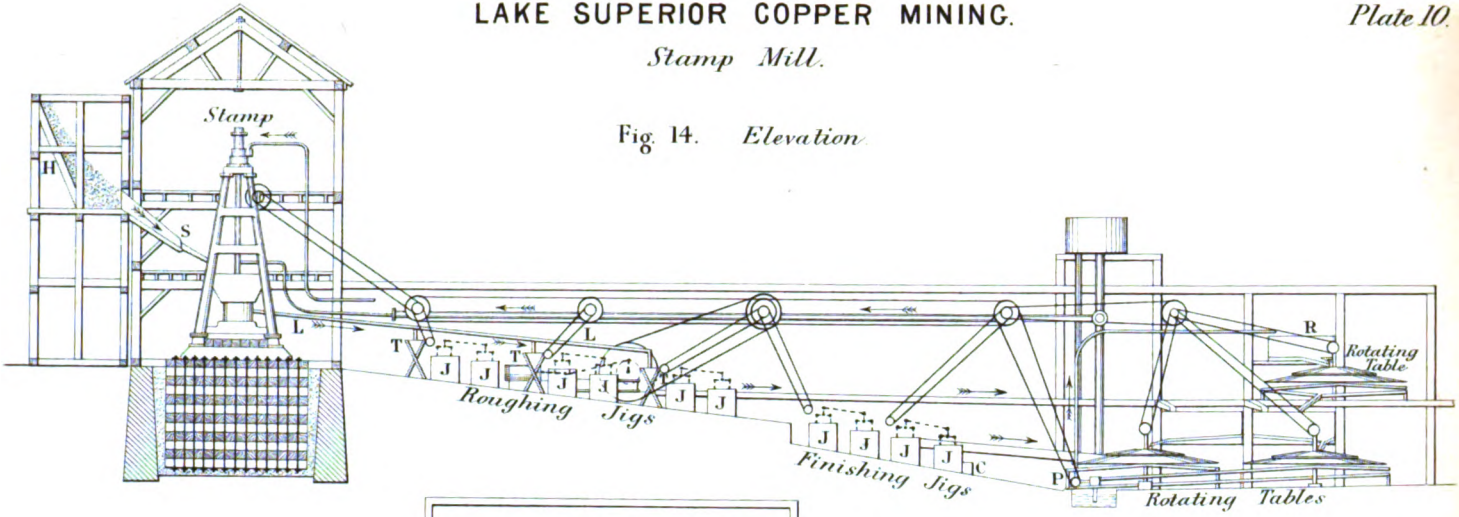

Fig. 15. *Plan of one bay.*

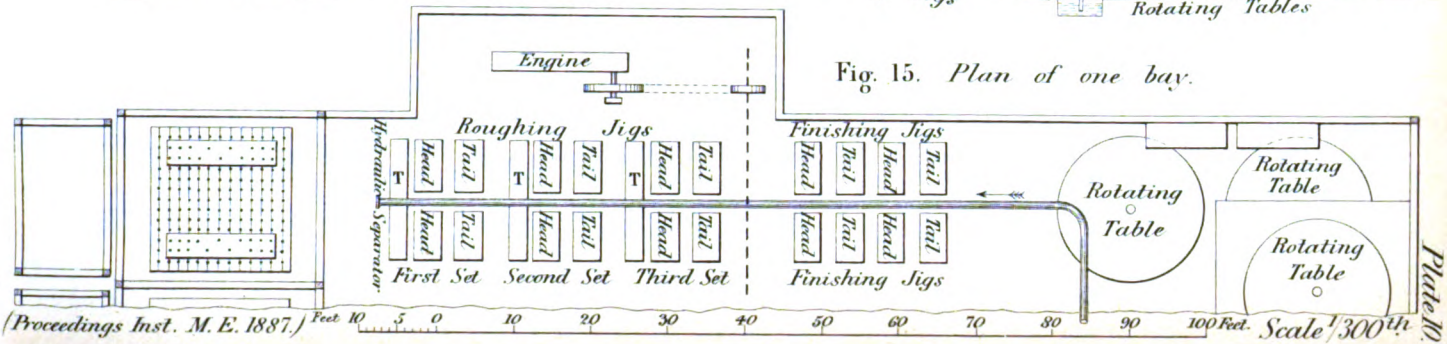

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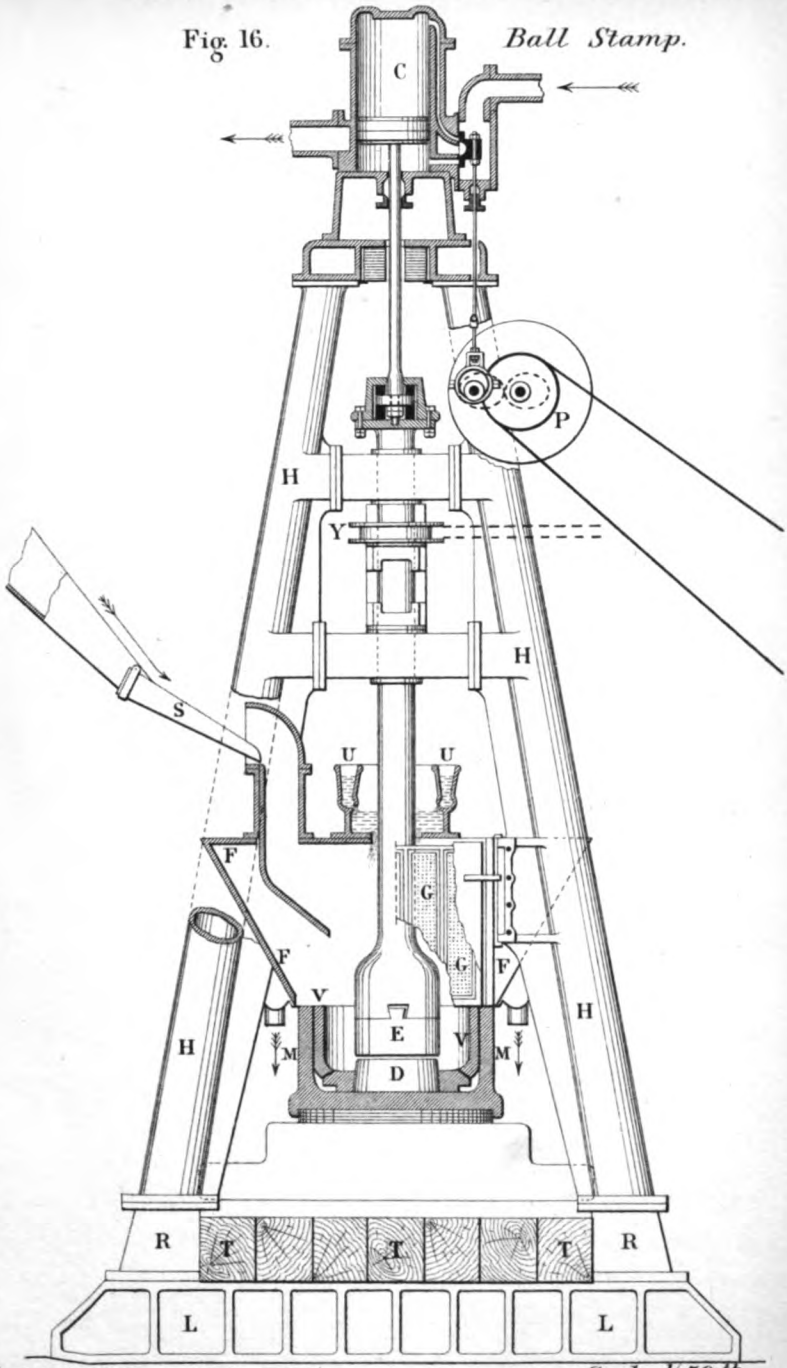
Fig. 16. *Ball Stamp.*



(*Proceedings Inst. M.E. 1887.*) *Scale 1/50th*

Ins. 12 6 0 5 10 15 Feet.

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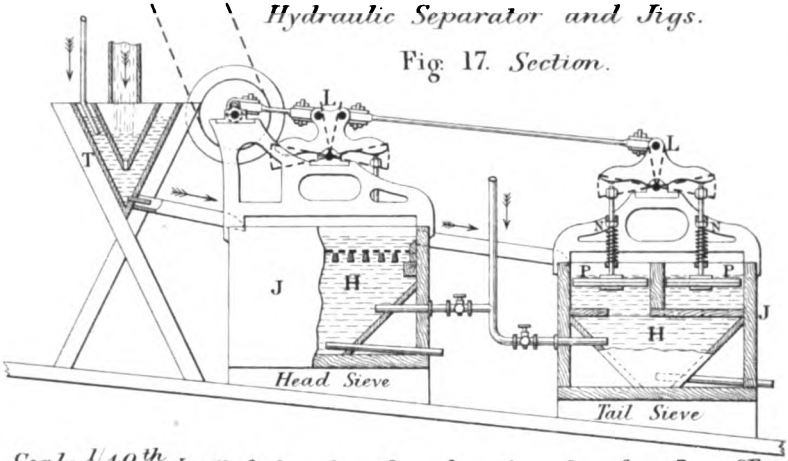
Hydraulic Separator and Jigs.

Fig. 17. *Section.*



Scale 1/40th Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet.

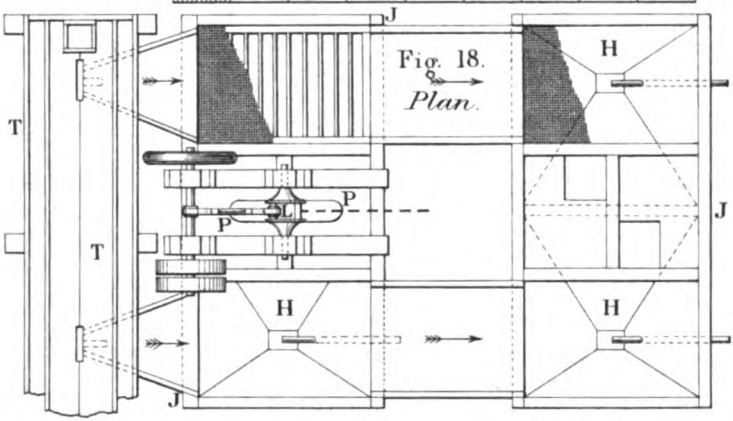


Fig. 18. *Plan.*

Buddle. *Scale 1/50th*

Ins. 12 0 1 2 3 4 5 6 7 8 9 10 Feet.

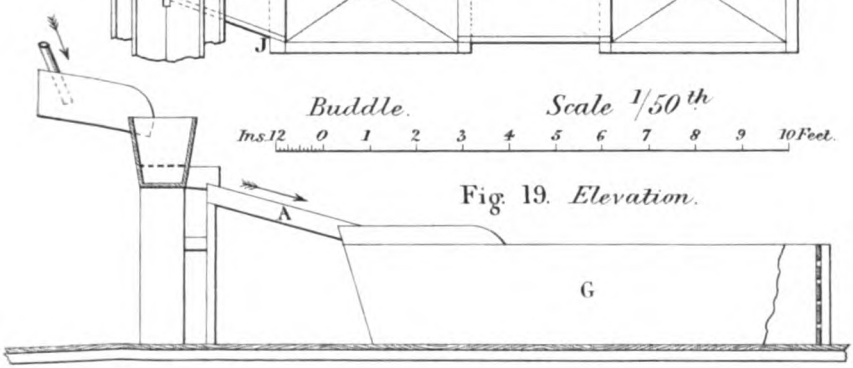


Fig. 19. *Elevation.*

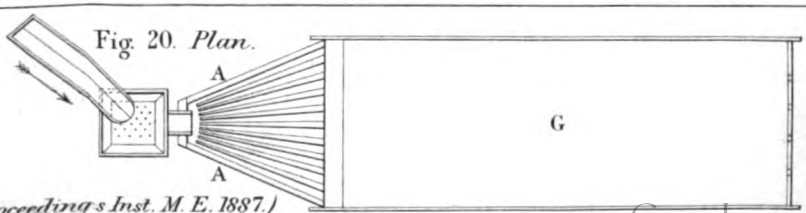


Fig. 20. *Plan.*

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Rotating Table.

Fig. 21. *Elevation.*

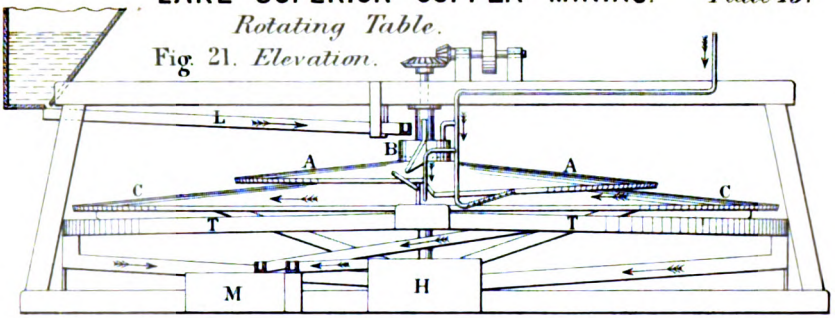
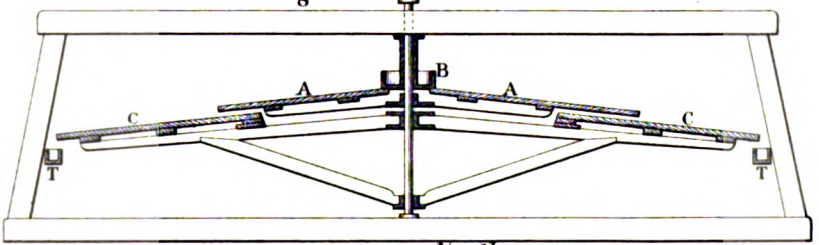


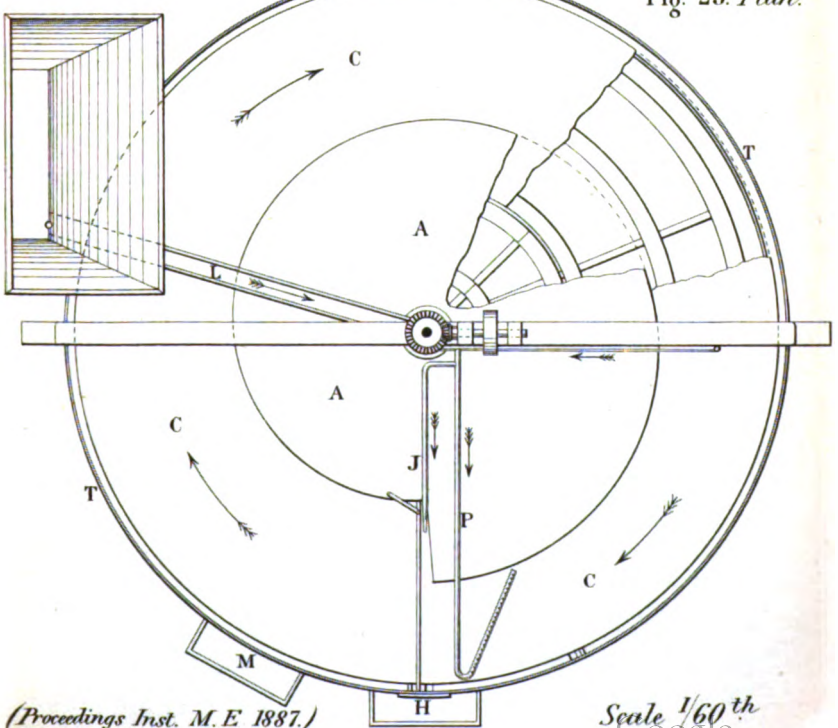
Fig. 22. *Section.*



Scale 1/60th

Ins. 12 0 5 10 15 20 Feet.

Fig. 23. *Plan.*



(Proceedings Inst. M.E. 1887.)

Scale 1/60th

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Fig. 1.
Sims' Original Compound Engine.
Cornwall 1836.
Lincoln 1848.

Scale 1/150th

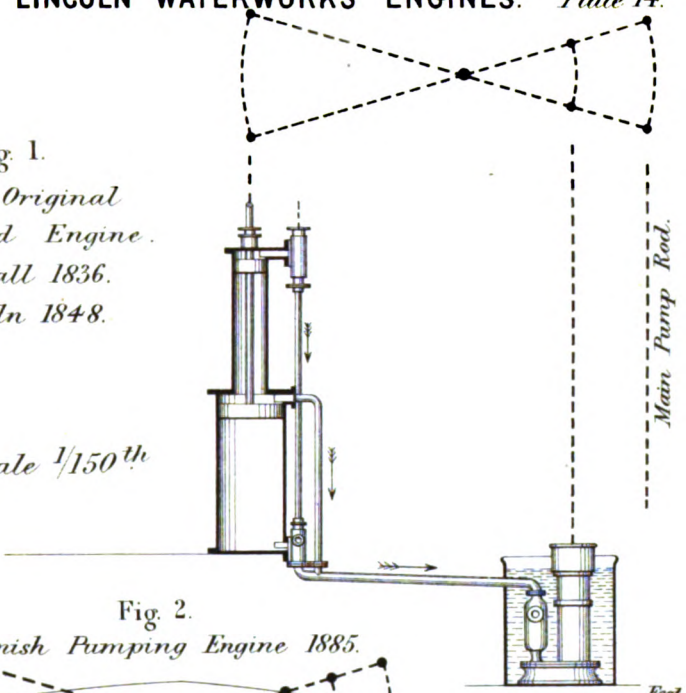
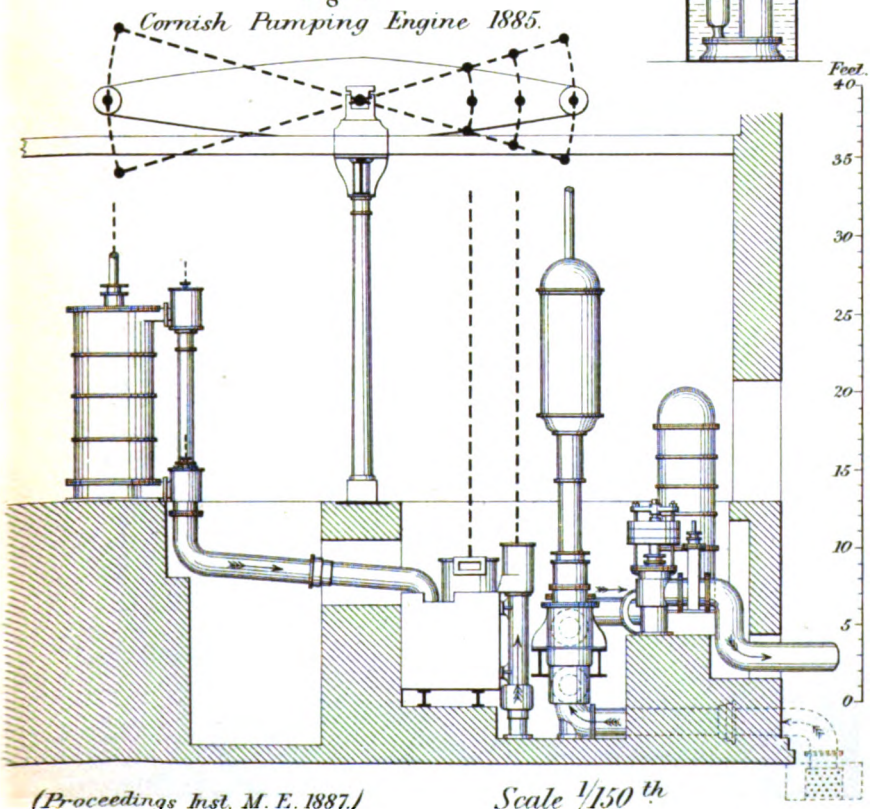


Fig. 2.
Cornish Pumping Engine 1885.



(Proceedings Inst. M. E. 1887.)

Scale 1/150th

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Fig. 3.
Scale 1/150th

Double-acting Fly-wheel Engine, 1862.

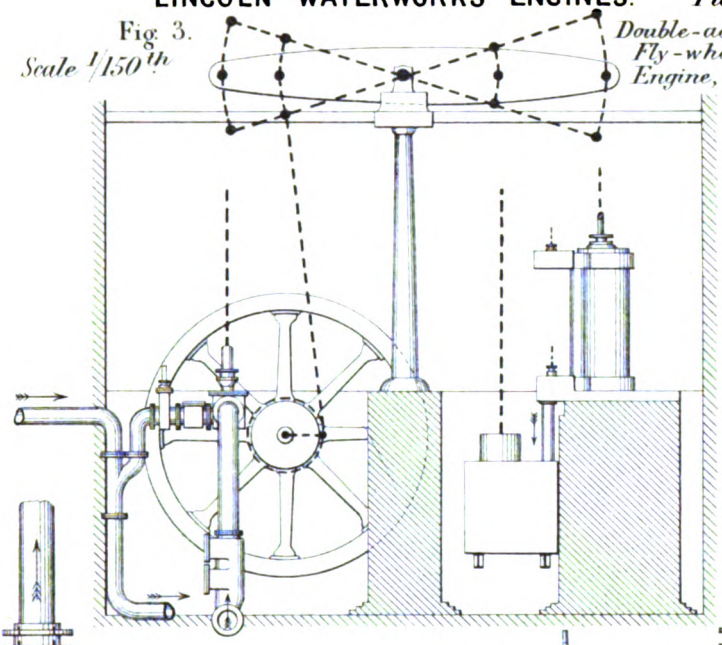
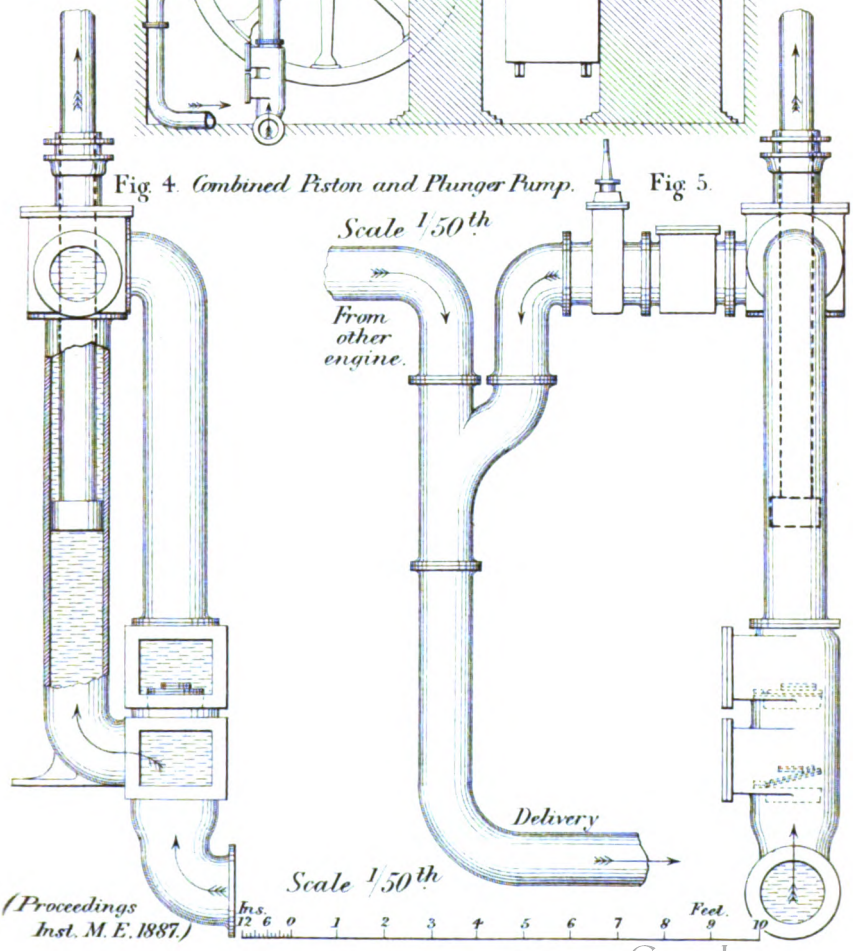


Fig. 4. *Combined Piston and Plunger Pump.*

Fig. 5.

Scale 1/50th



(*Proceedings Inst. M. E. 1887.*)

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Break - Valve.

Fig. 6.

Scale 1/8th

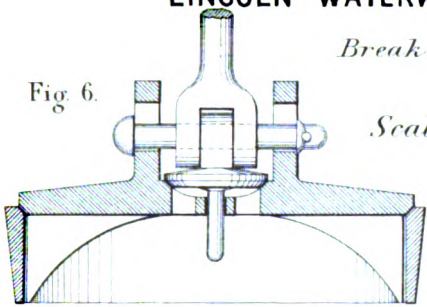


Fig. 7.

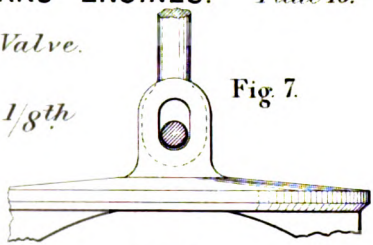
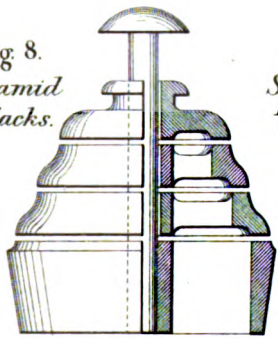


Fig. 9.

Dead-weight in delivery *Balance-Valve main.*

Fig. 8.
Pyramid of Clacks.

Scale 1/16th



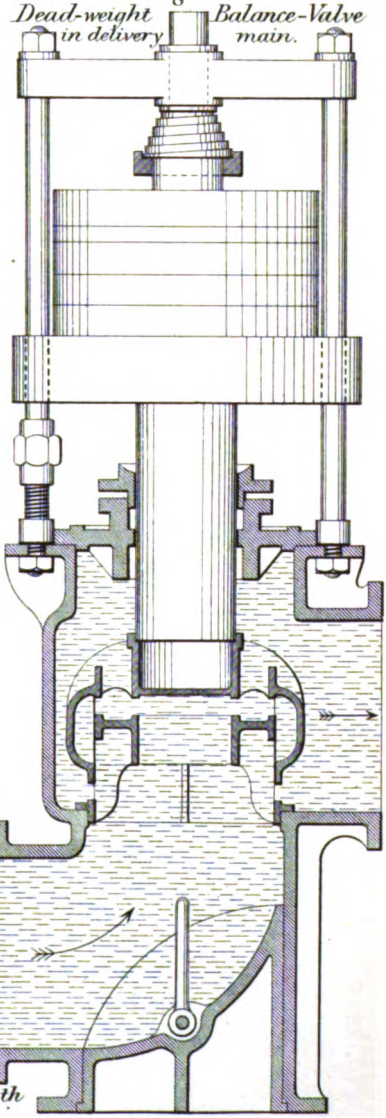
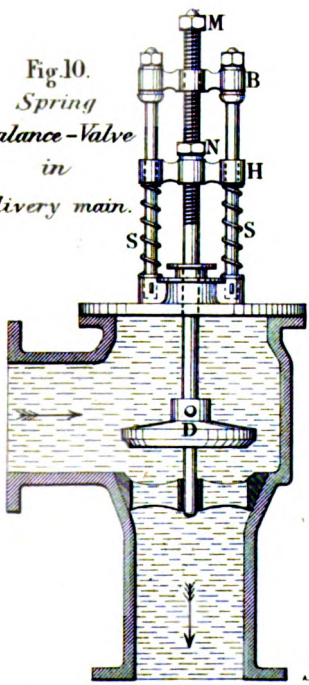


Fig. 10.
Spring Balance-Valve in delivery main.



Scale 1/16th

(Proceedings Inst. M.E. 1887.)

Ins. 12 6 0 1 2 Feet.

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Exhaust and Equilibrium Valve - Catches, and Check Throttle-Valve.

Break Clack.
Scale 1/16th

Fig. 11.

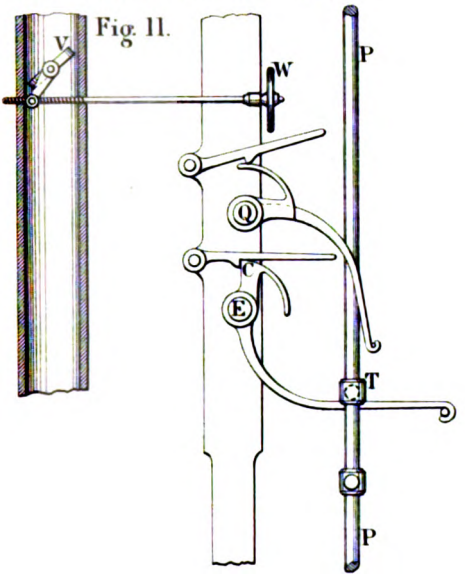


Fig. 12. *Section.*

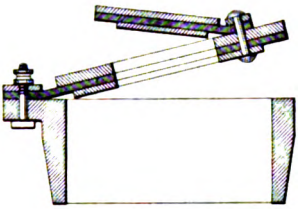
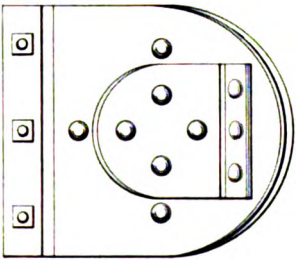


Fig. 13. *Plan.*



Indicator Diagrams showing vacuum above and below Foot Valve.

Fig. 14. *Vacuum above Foot Valve.*

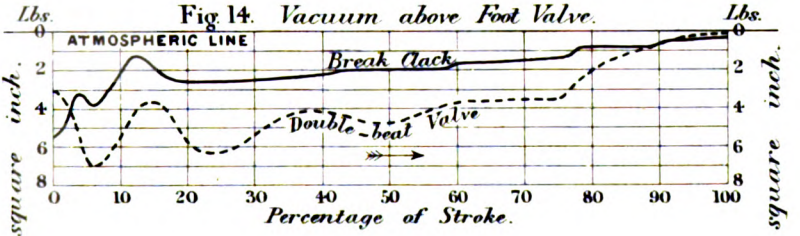


Fig. 15. *Vacuum below Foot Valve.*

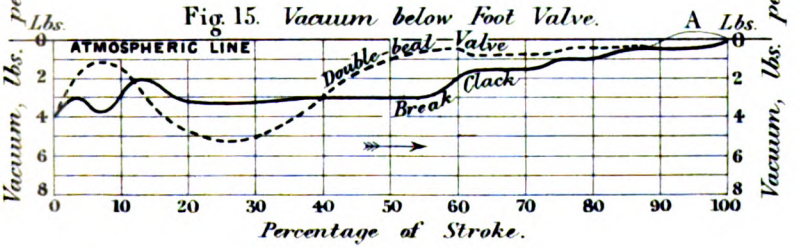


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Fig 16. *Velocity of Flow from Double-acting Pump worked by crank.*

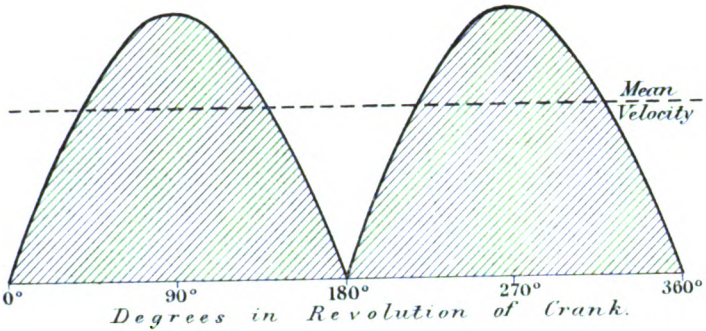


Fig. 17. *Velocity of Flow from two Double-acting Pumps worked by cranks at right angles.*

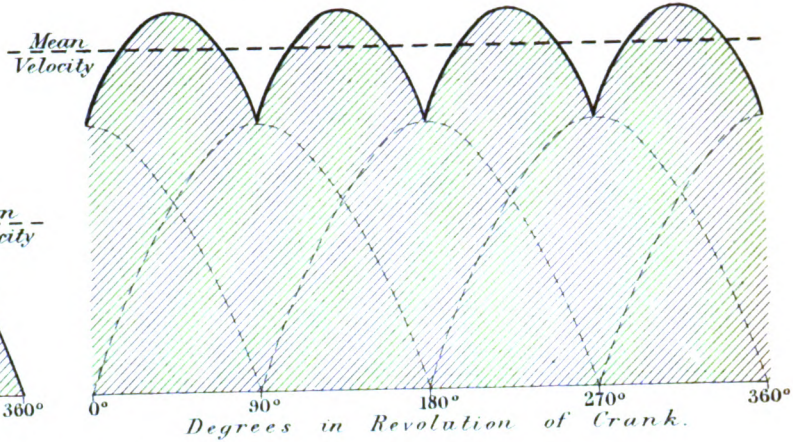
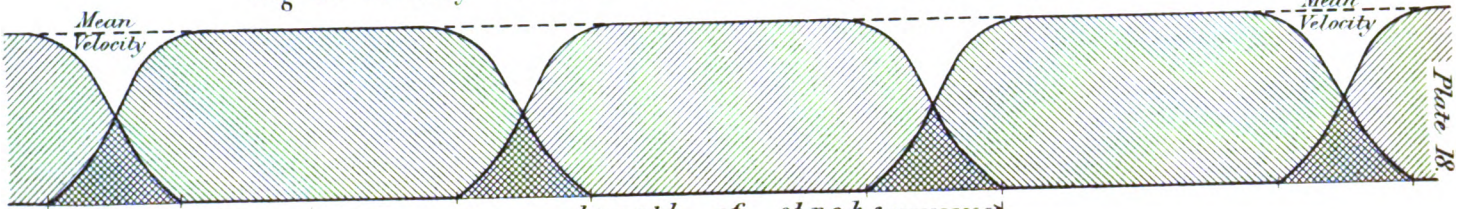


Fig 18. *Velocity of Flow from Worthington Pumping Engines.*



(Proceedings Inst. M.E. 1887.)

Plate 18.

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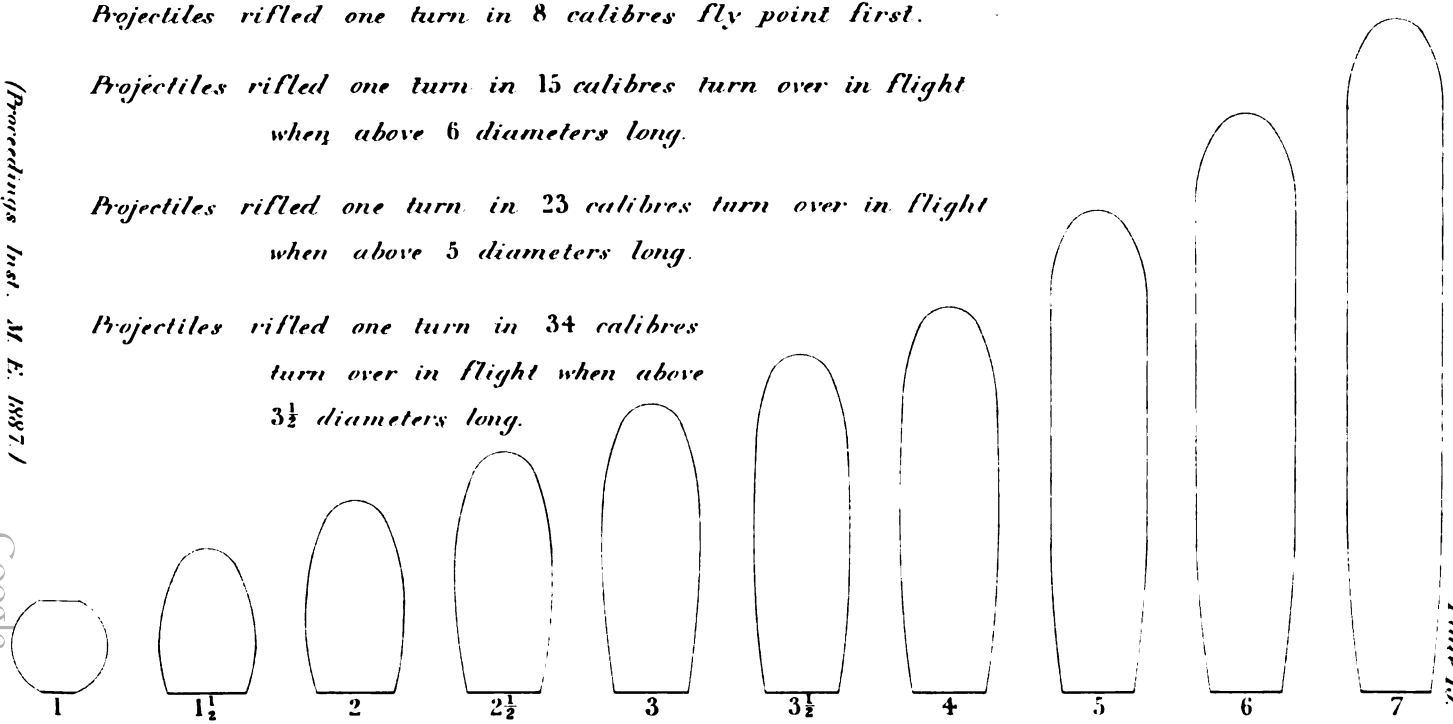
Fig. 1. *Projectiles of* 1, 1½, 2, 2½, 3, 3½, 4, 5, 6, *and* 7 *diameters in length, used in Sir J. Whitworth's experiments.*

Projectiles rifled one turn in 8 *calibres fly point first.*

Projectiles rifled one turn in 15 *calibres turn over in flight when above* 6 *diameters long.*

Projectiles rifled one turn in 23 *calibres turn over in flight when above* 5 *diameters long.*

Projectiles rifled one turn in 34 *calibres turn over in flight when above* 3½ *diameters long.*



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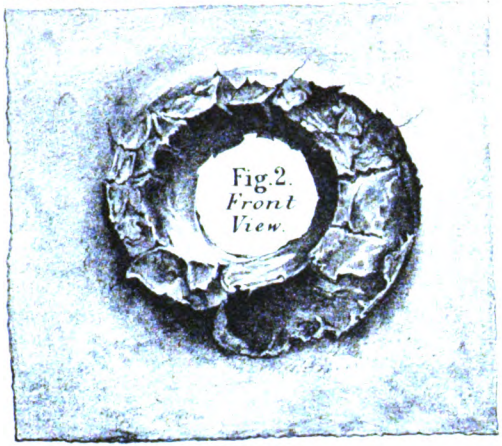
Perforation of 18-inch wrought-iron armour-plate by Whitworth 9-inch 20-ton Gun.



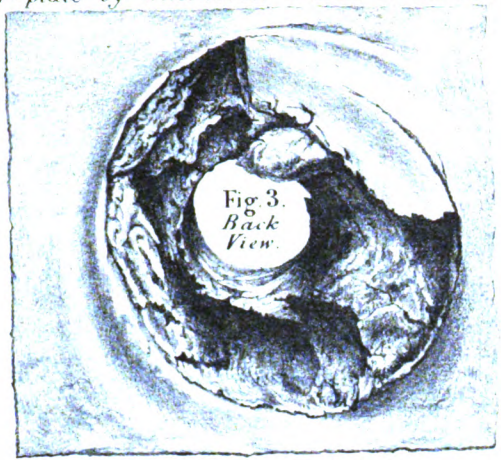
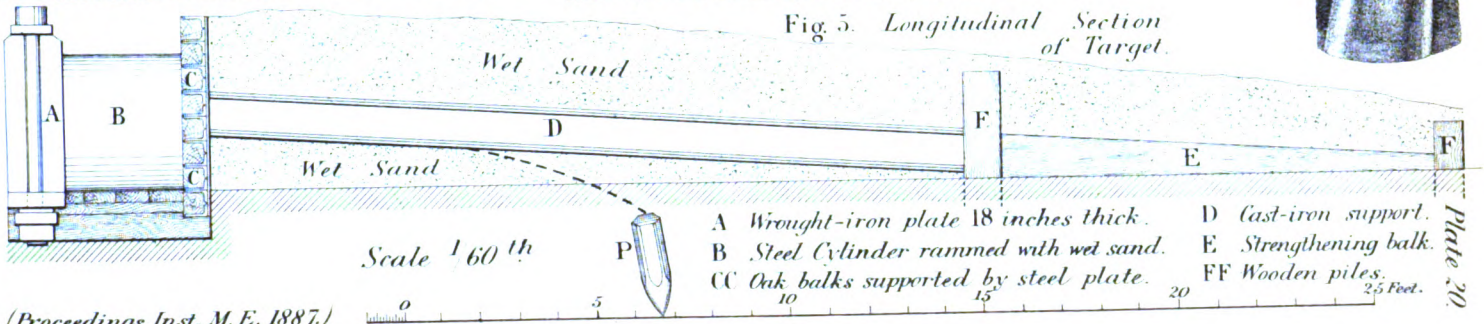


Fig. 4.
Projectile P after perforating the plate.

Scale 1/12th

Fig. 5. *Longitudinal Section of Target.*



A *Wrought-iron plate 18 inches thick.*
B *Steel Cylinder rammed with wet sand.*
CC *Oak balks supported by steel plate.*
D *Cast-iron support.*
E *Strengthening balk.*
FF *Wooden piles.*

Plate 20.

(Proceedings Inst. M. E. 1887.)

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PRESIDENT'S ADDRESS.

Hydro-pneumatic Carriage for Disappearing Gun.

Fig. 6.

Gun lowered for loading.

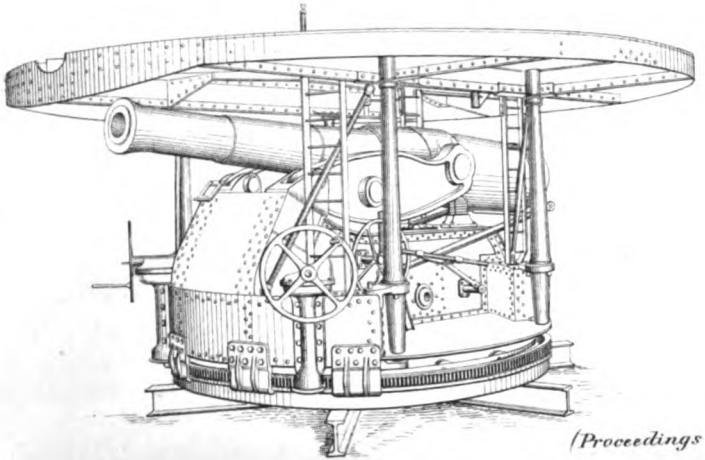

Fig. 7.

Gun raised for firing.

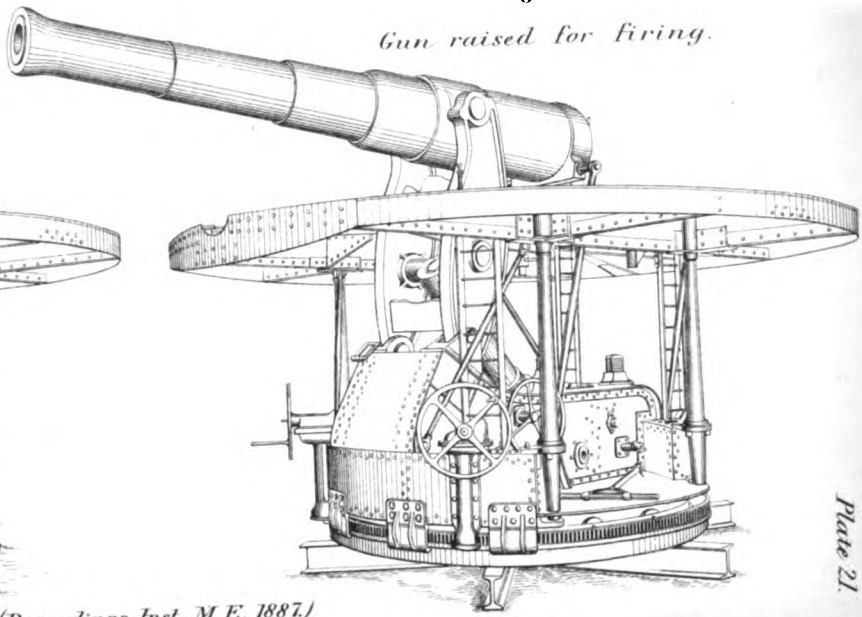

Plate 21.

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Fig. 8. 65 - *cwt. Gun, 1837.*
Diameter of Bore 8·12 *inches. Length of Bore* 107·9 *inches.*
Charge 10 *lbs. Shot* 68 *lbs. Muzzle Velocity* 1600 *ft. per sec.*

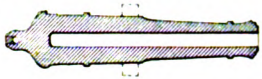


Fig. 9. 69 - *ton Gun, 1887.*
Diameter of Bore 13·5 *inches. Length of Bore* 405 *inches.*
Charge 630 *lbs. Muzzle Velocity* 2020 *ft. per sec.*
Projectile 1250 *lbs. Muzzle Perforation* 30·1 *inches.*

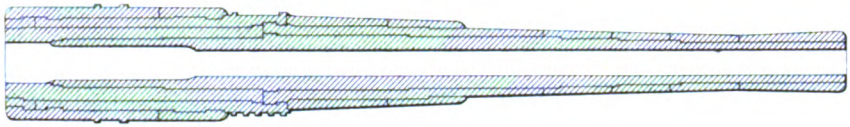


Fig. 10. 110 - *ton Gun, 1887.*
Diameter of Bore 16·25 *inches. Length of Bore* 487·5 *inches.*
Charge 1000 *lbs. Muzzle Velocity* 2128 *ft. per sec.*
Projectile 1800 *lbs. Muzzle Perforation* 34 *inches.*

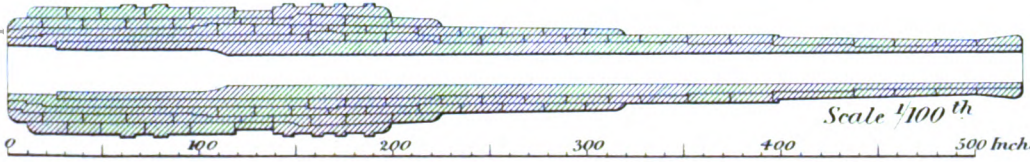
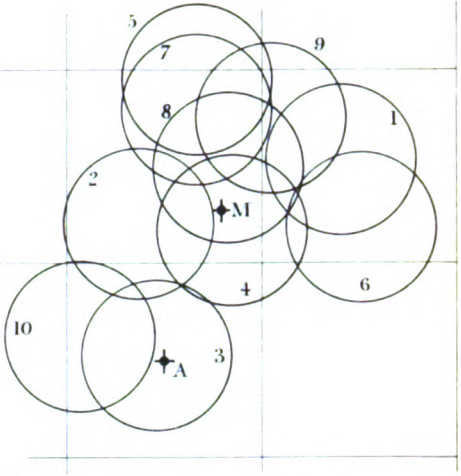


Fig. 11. *Diagram of practice with* 9·2 *inch Breech-loading Gun. Range* 1000 *yards. Common Shell* 320 *lbs.*

Scale 1/12th



✦A *Point aimed at.*

✦M *Point of mean impact.*

Plate 22.

(Proceedings Inst. M. E. 1887.)

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Fig. 12.

Perspective View of 110-ton Gun with Carriage and Appliances.

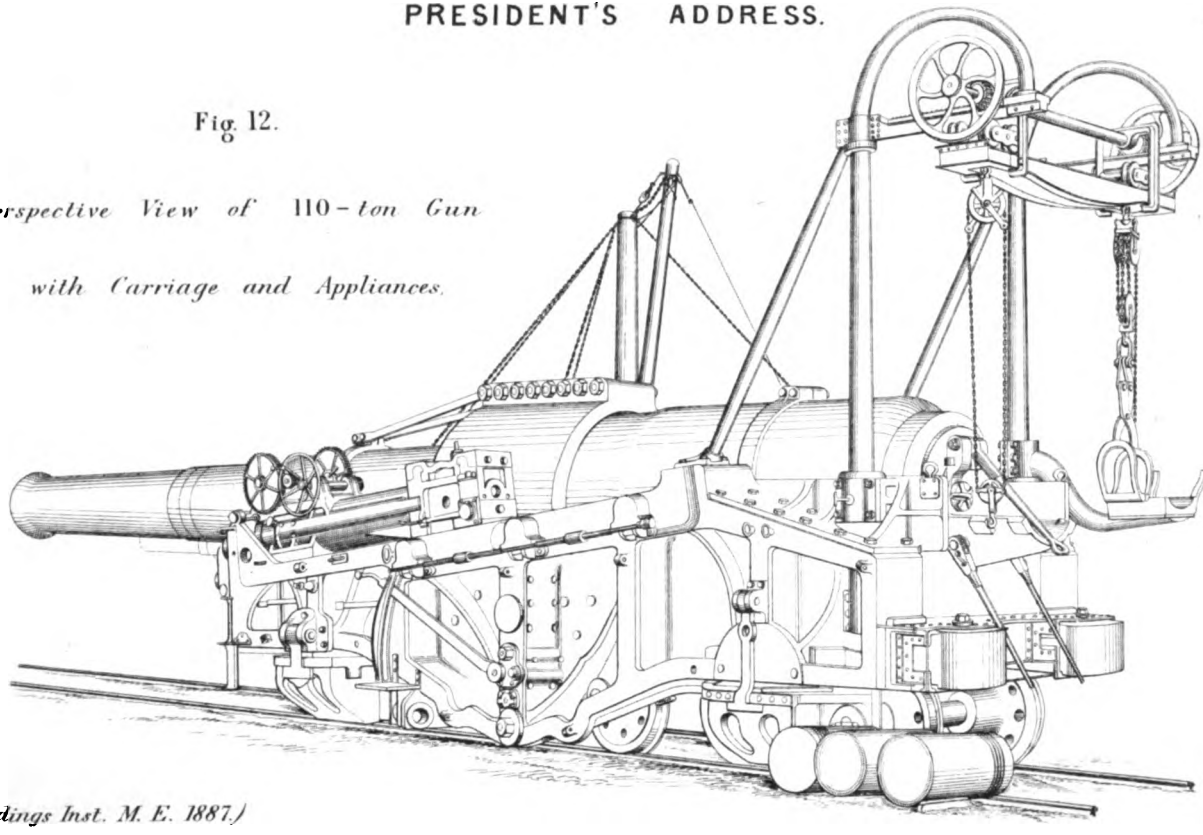

Plate 23.

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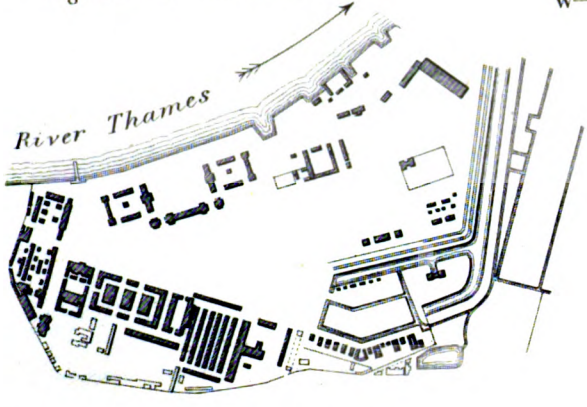
PRESIDENT'S ADDRESS.

Growth of Woolwich Arsenal from 1837 to 1887.

Scale 4 inches to a mile.

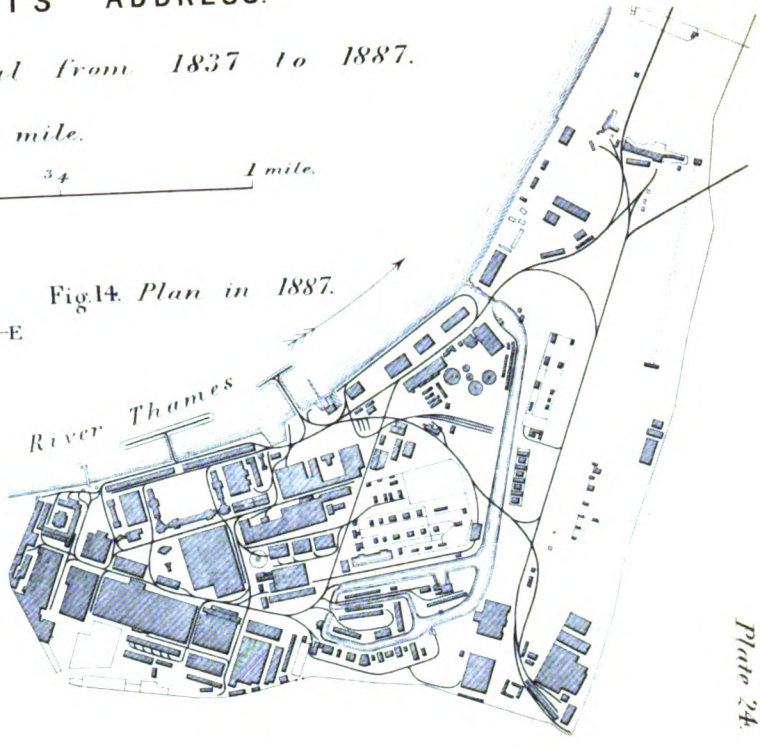
0 1/4 1/2 3/4 1 mile.

Fig. 13. *Plan in 1837.*



N
W E
S

Fig. 14. *Plan in 1887.*



(Proceedings Inst. M. E. 1887.)

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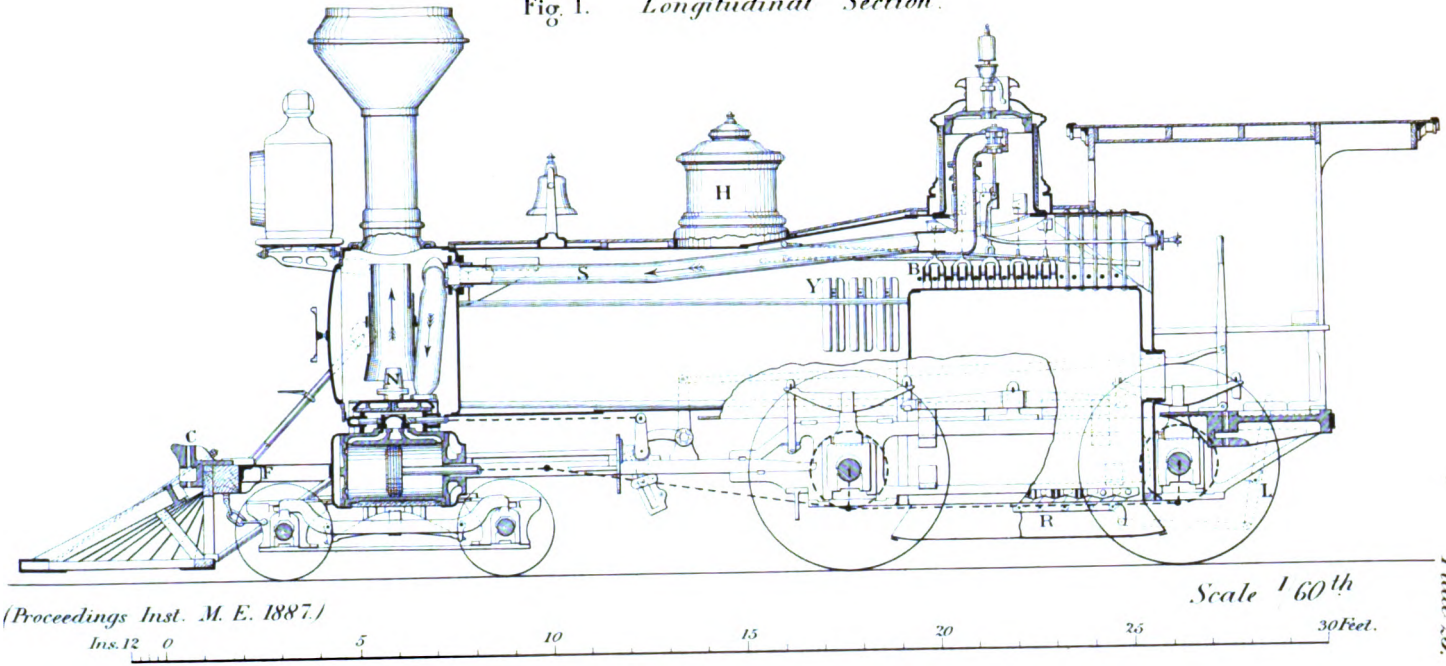
CANADIAN LOCOMOTIVES.

S. A. Light Engines for Freight and Mixed Traffic.

Fig. 1. *Longitudinal Section.*



(Proceedings Inst. M. E. 1887.)

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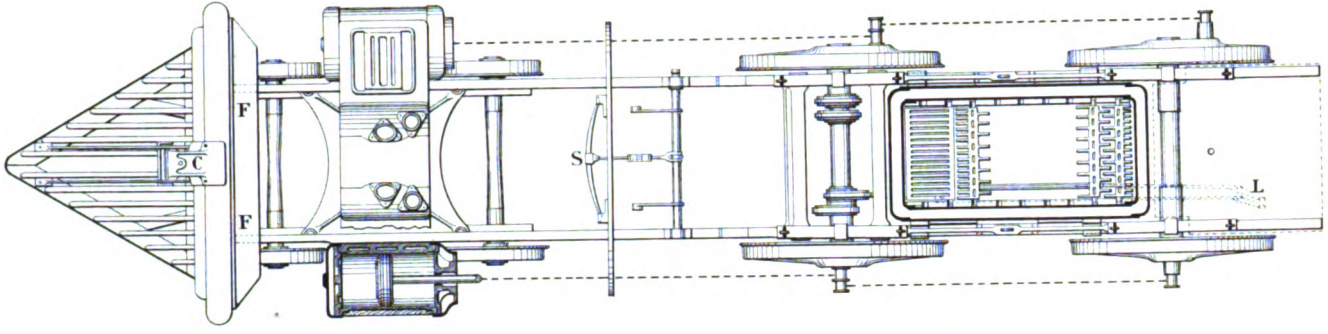
CANADIAN LOCOMOTIVES.

S. A. Light Engines for Freight and Mixed Traffic.

Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1887.)

Scale 1/60 th

Ins. 12 0 5 10 15 20 25 30 Feet.

Plate 26.

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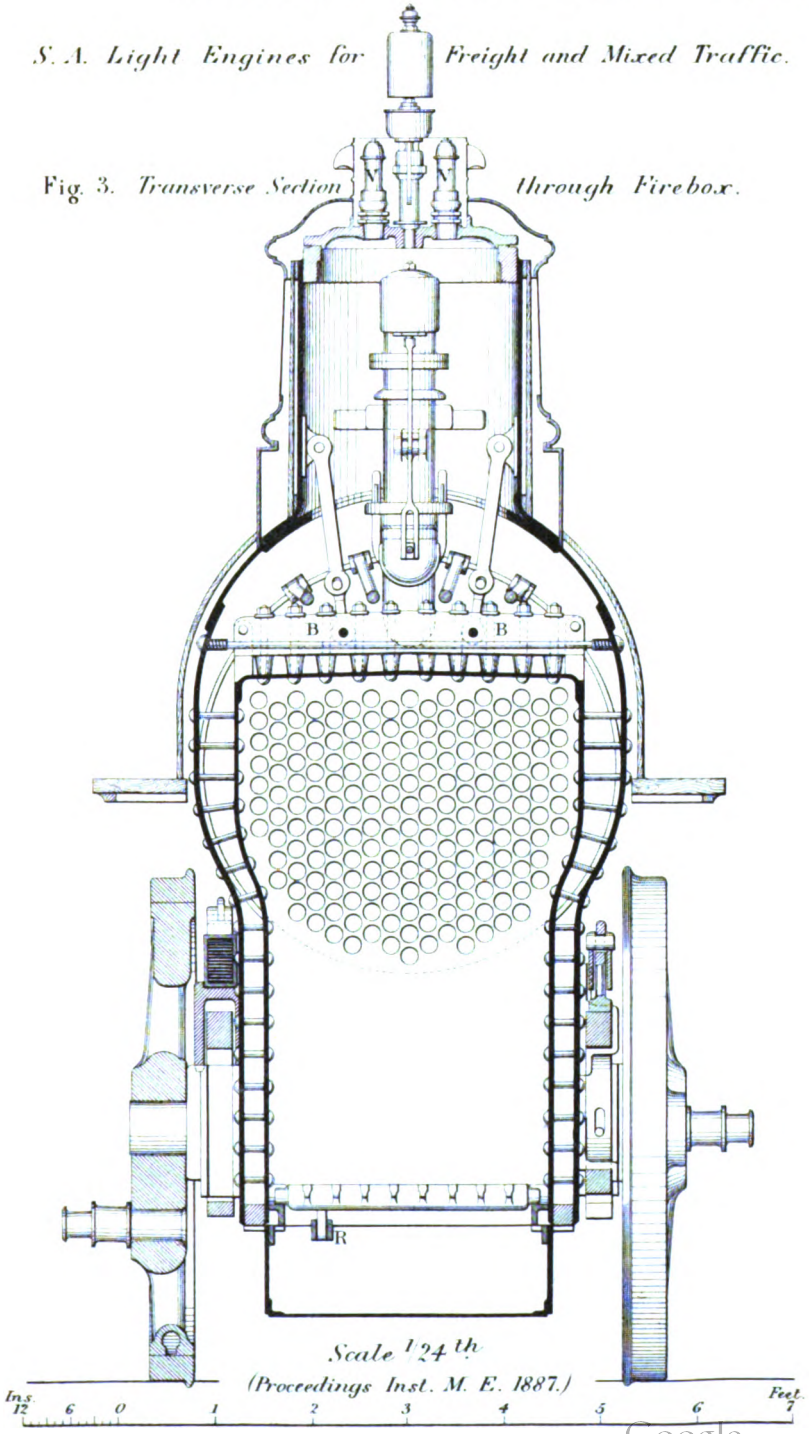
S. A. Light Engines for Freight and Mixed Traffic.

Fig. 3. *Transverse Section through Firebox.*



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S.A. Light Engines for Freight and Mixed Traffic.

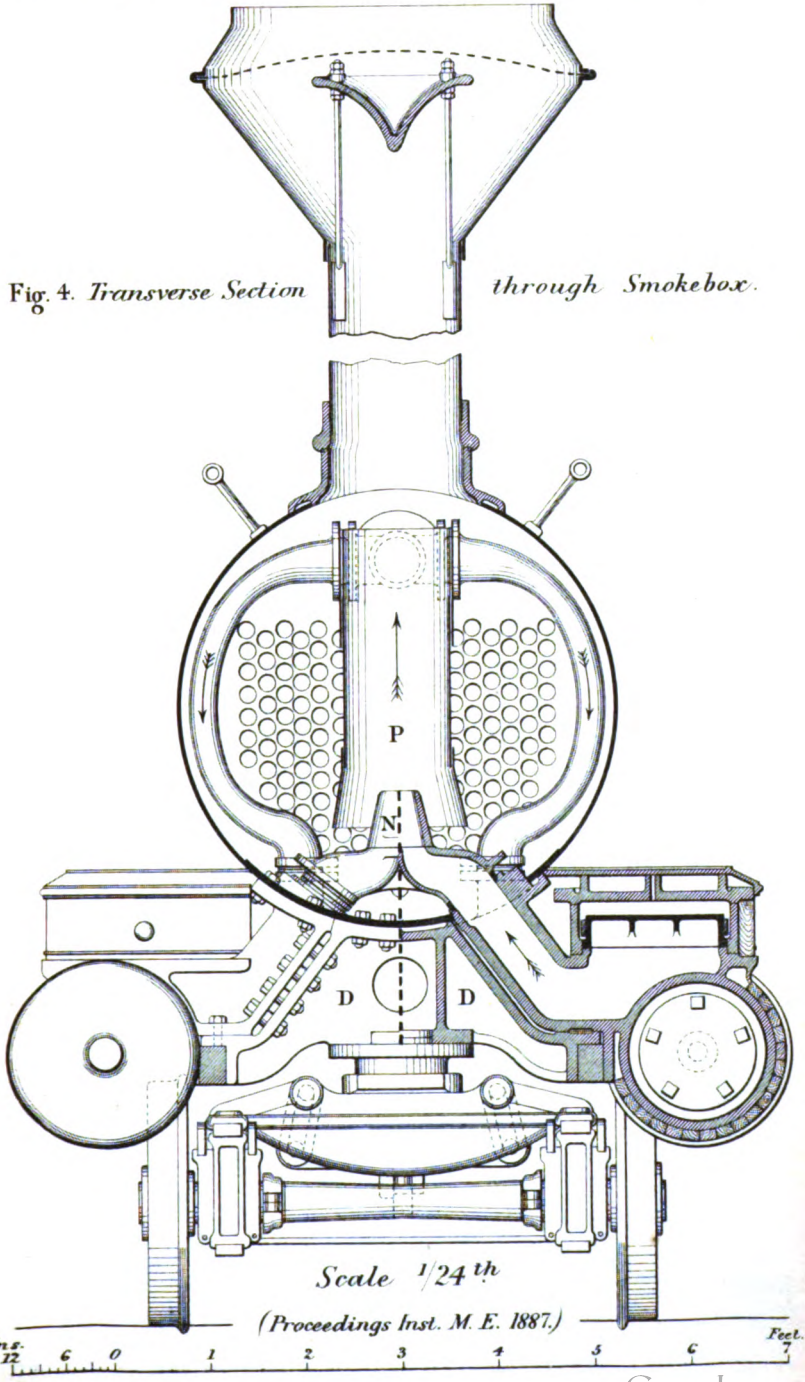

Fig. 4. *Transverse Section through Smokebox.*

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S. A. Light Engines for Freight and Mixed Traffic.

Four-wheeled lateral-motion Truck.

Fig. 5. *Transverse Section.*

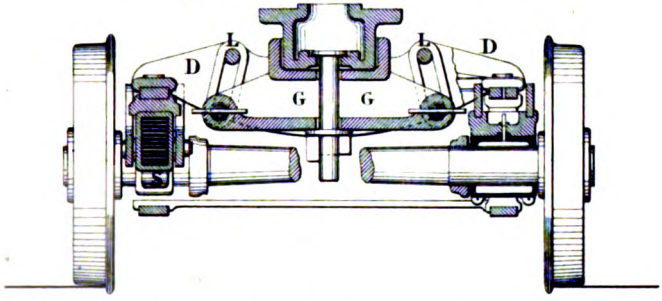


Fig. 6. *Side Elevation.*

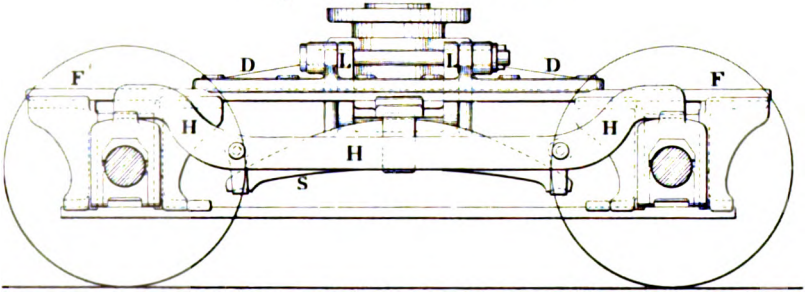
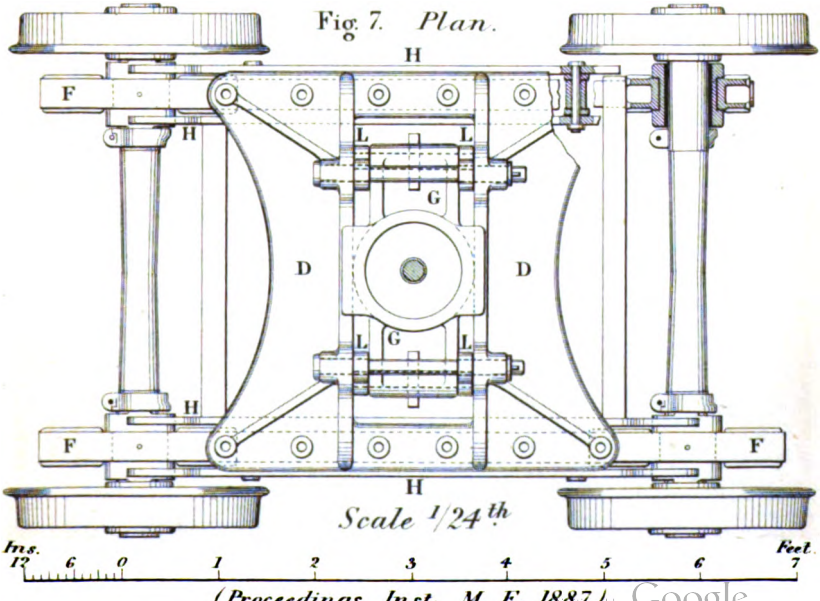


Fig. 7. *Plan.*



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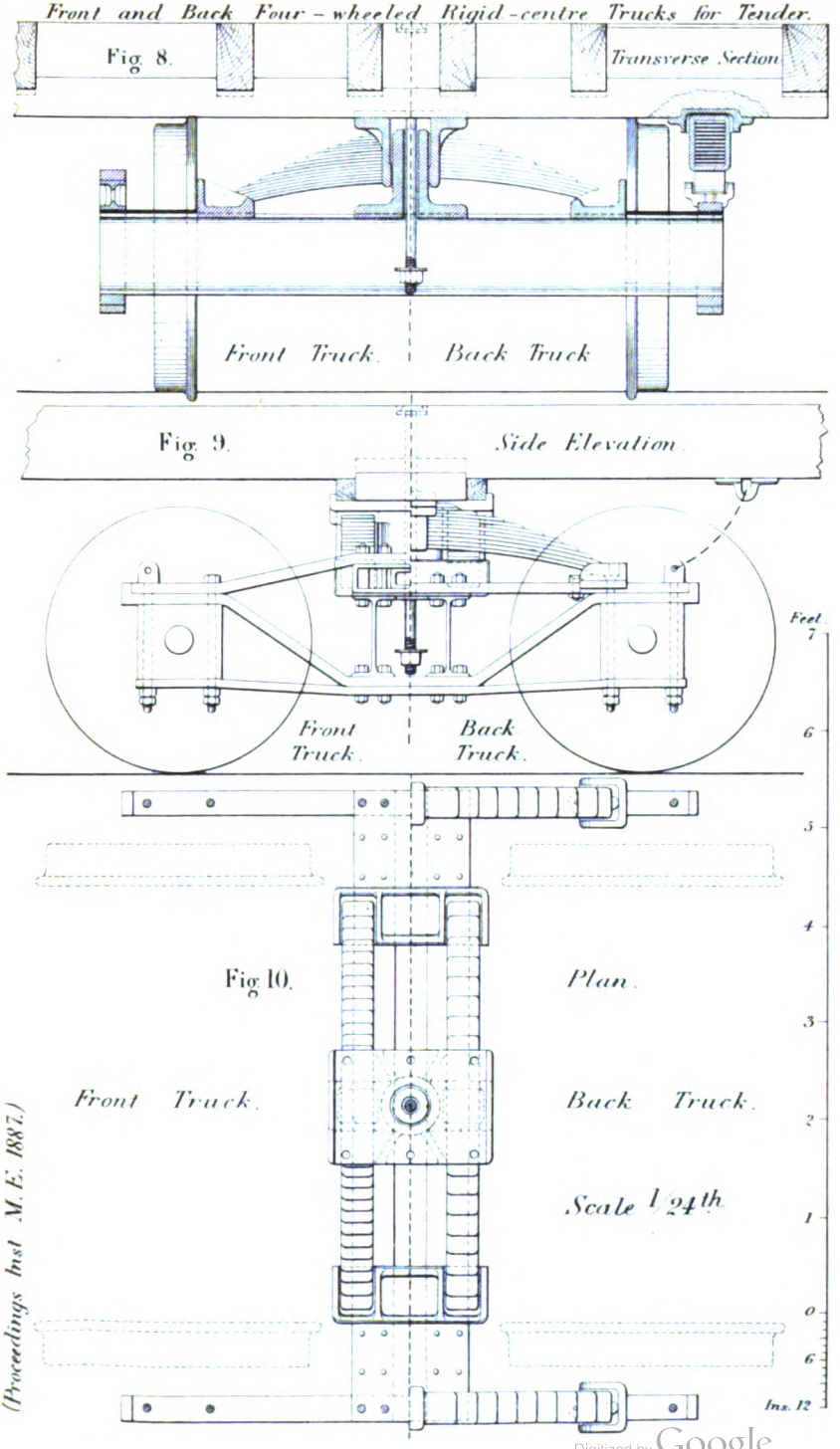
Front and Back Four-wheeled Rigid-centre Trucks for Tender.



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CANADIAN LOCOMOTIVES.

S. C. Light Passenger Engines.

Driving - Wheel Brake.

Fig. 11. End Elevation.

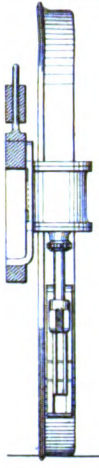


Fig. 12. Side Elevation.

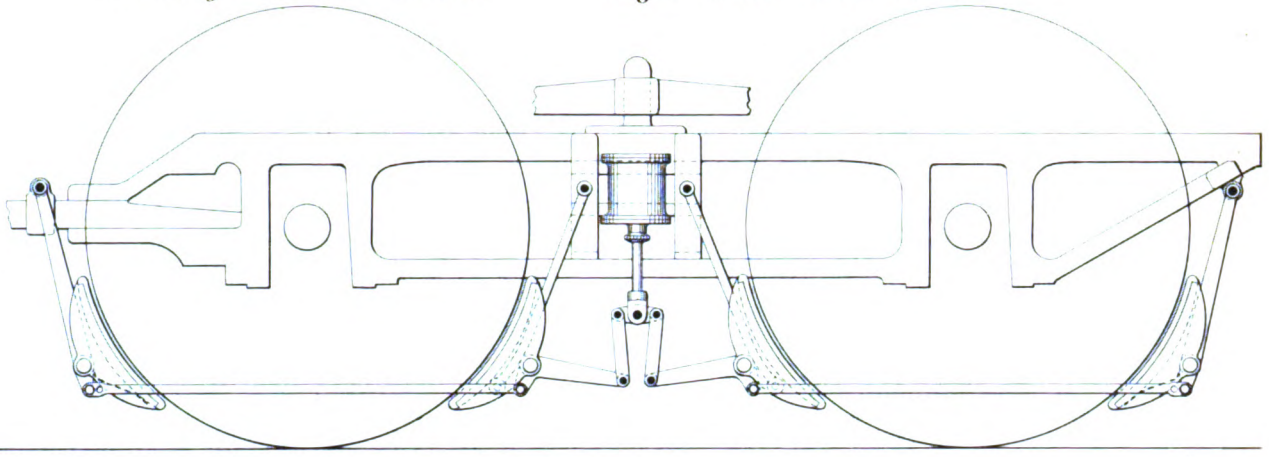
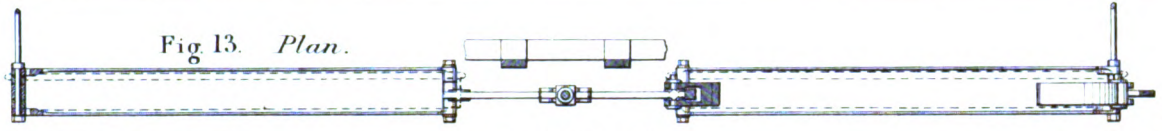


Fig. 13. Plan.



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Scale 1/30th

Ins. 12 6 0 5 10 15 Feet.

Plate 31.

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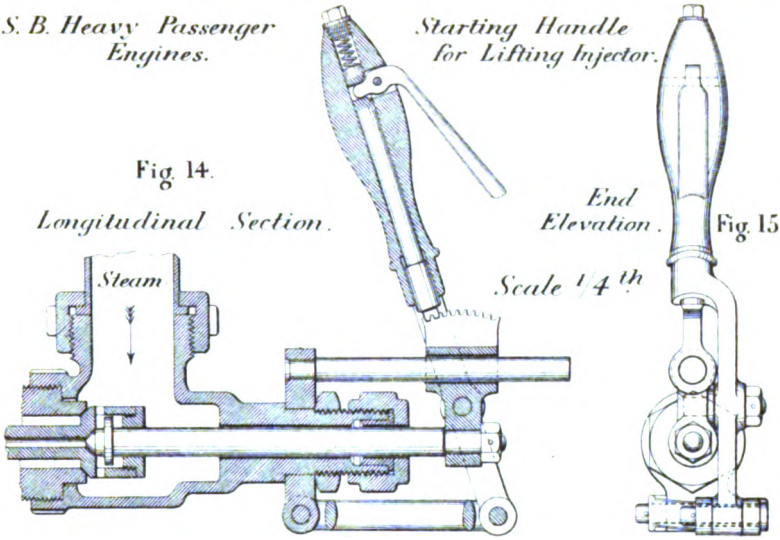
S. B. Heavy Passenger Engines.

Starting Handle for Lifting Injector.

Fig. 14.

Longitudinal Section.

End Elevation. Fig. 15.



S. D. Consolidation Engines.

Crosshead.

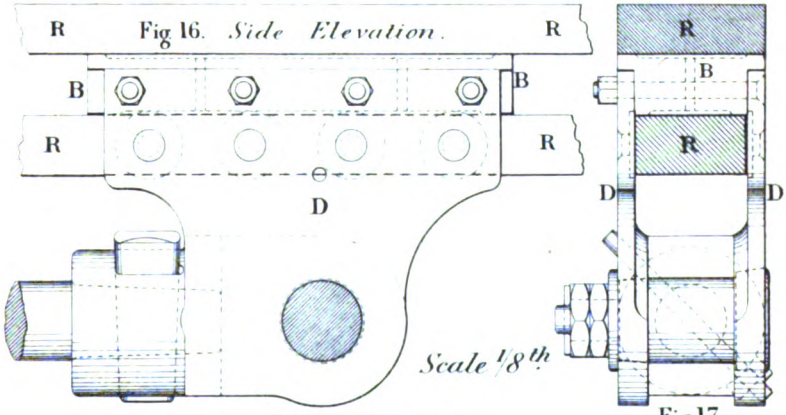


Fig 16. *Side Elevation.*

Fig. 17. *Transverse Section.*

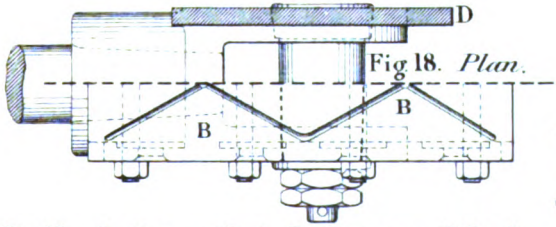
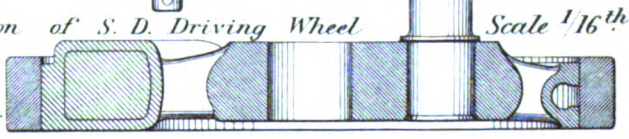


Fig 18. *Plan.*

Fig 19. *Section of S. D. Driving Wheel with Lead counterbalance.*



Scale 1/16th

(Proceedings Inst. M. E. 1887.)

Scale 1/16th

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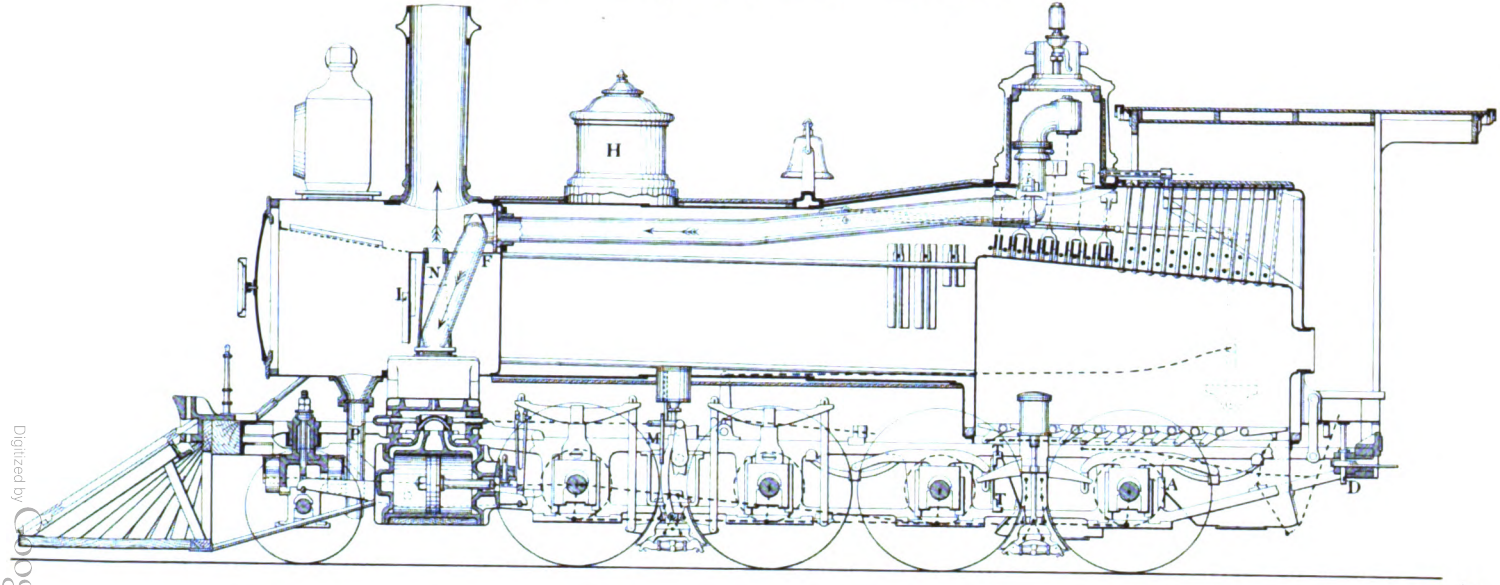
CANADIAN LOCOMOTIVES.

S. D. Consolidation Engines.

Fig. 20. *Longitudinal Section.*



(Proceedings Inst. M. E. 1887.)

Scale 1/60th

Ins. 12 6 0 5 10 15 20 25 30 Feet.

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S. D. Consolidation Engines.

Fig. 21. *Transverse Section through Smokebox.*

F F N S E B

Scale 1/24th

Fig. 22. *Plan of Cylinders.*

S E E S

Ins. 12 6 0 1 2 3 4 5 6 7 Feet.

(Proceedings Inst. M. E. 1887.)

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S. D. Consolidation Engines. *Two-wheeled Truck.*

Fig. 23. *Transverse Section.*

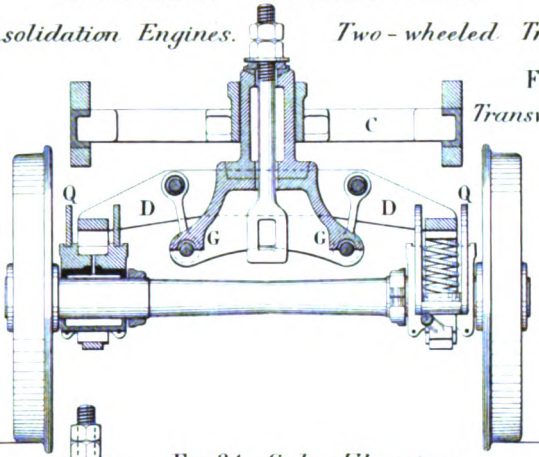


Fig. 24. *Side Elevation.*

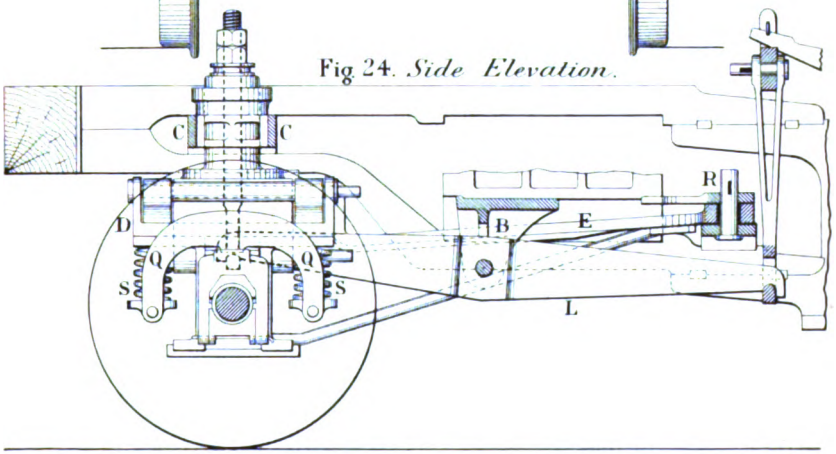
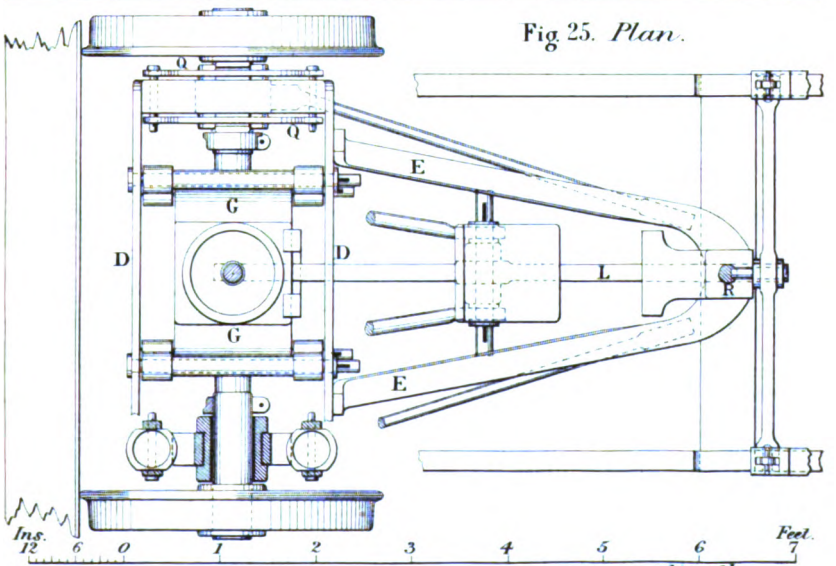


Fig. 25. *Plan.*



(Proceedings Inst. M. E. 1887.) *Scale 1/24th*

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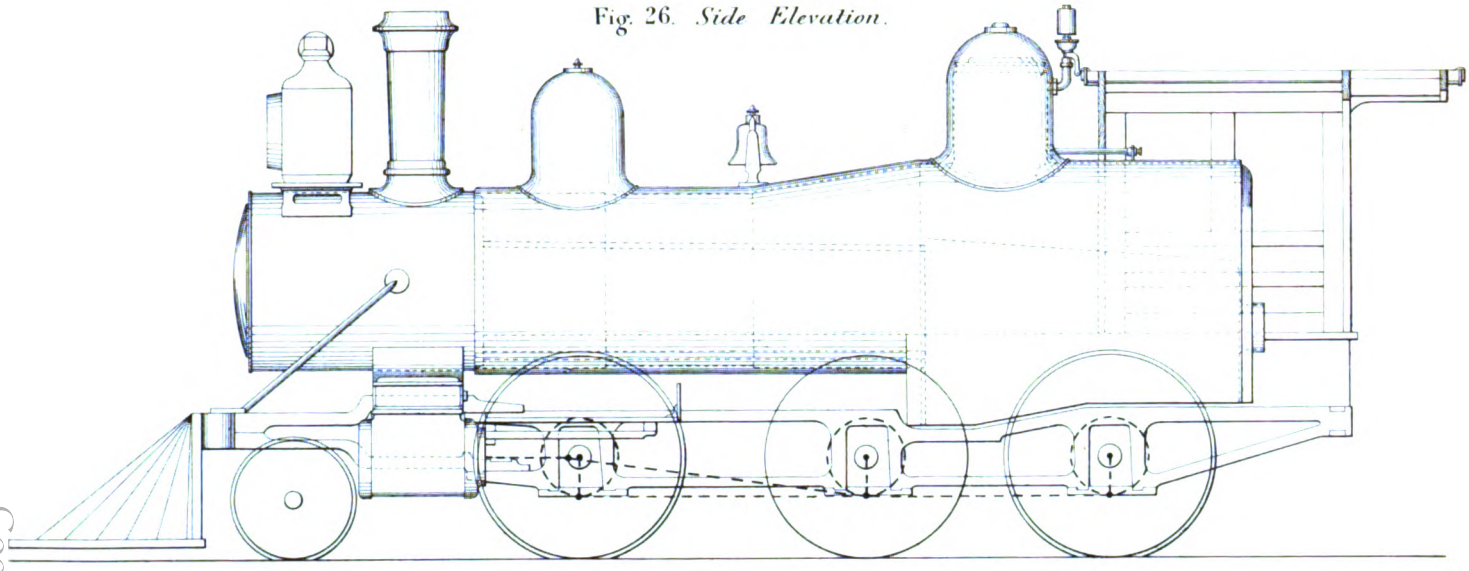
CANADIAN LOCOMOTIVES.

S. G. Mogul Engines.

Fig. 26. *Side Elevation.*



Scale 1/60th

Ins. 12 6 0 5 10 15 20 25 30 Feet.

(Proceedings Inst. M. E. 1887.)

Plate 36.

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S. G. Mogul Engines.
Balanced Slide - Valve.

Fig. 27.
Plan of Top Slide

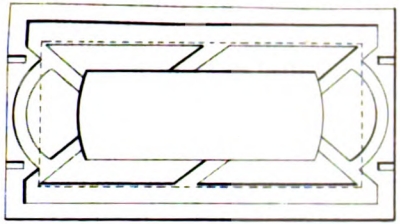


Fig. 28. *End Strips.*

Fig. 29. *Side Strips.*

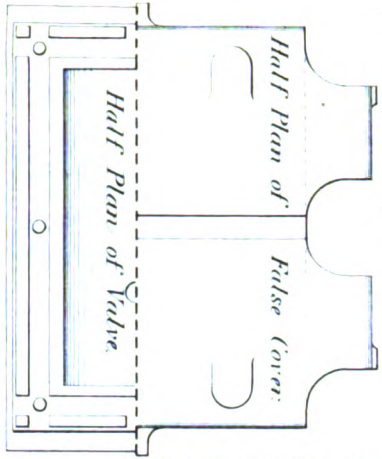
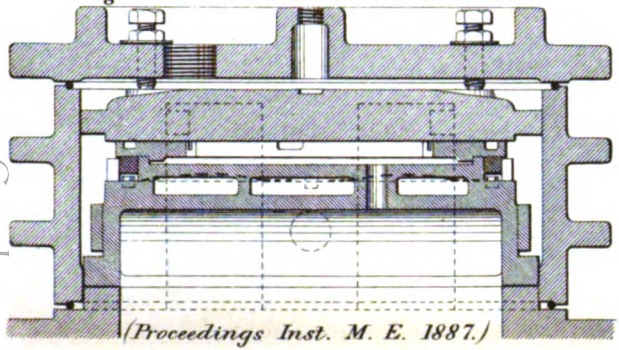


Fig. 30.
Plan.

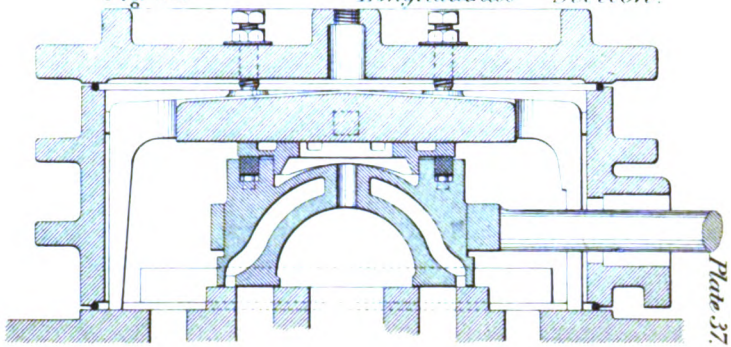
0 5 10 15 20 Inches. *Scale 1/8th*

Fig. 31. *Transverse Section.*



(Proceedings Inst. M. E. 1887.)

Fig. 32. *Longitudinal Section.*



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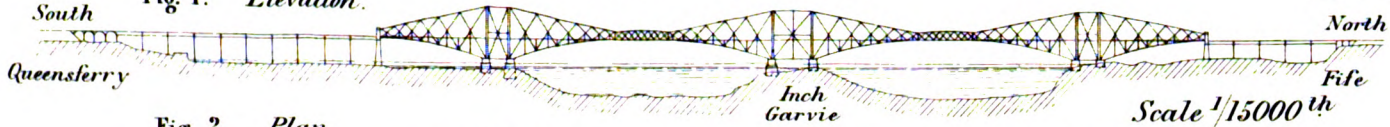
FORTH BRIDGE.

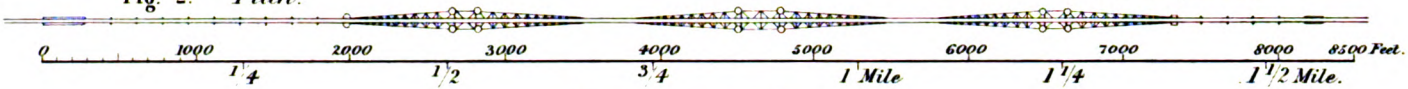
Plate 38.

Fig. 1. Elevation.



Scale 1/15000th

Fig. 2. Plan.



Middle Pier and Cantilevers.

Fig. 3. Elevation.

Scale 1/3000th

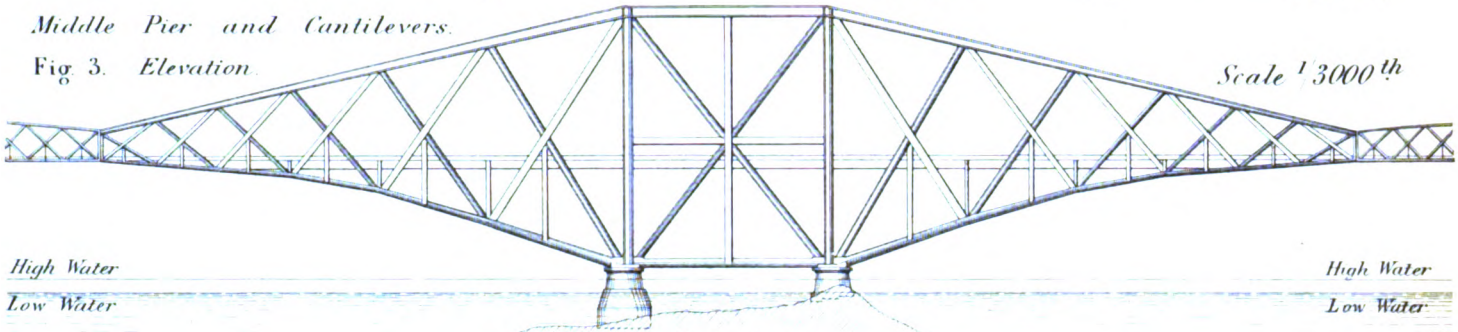
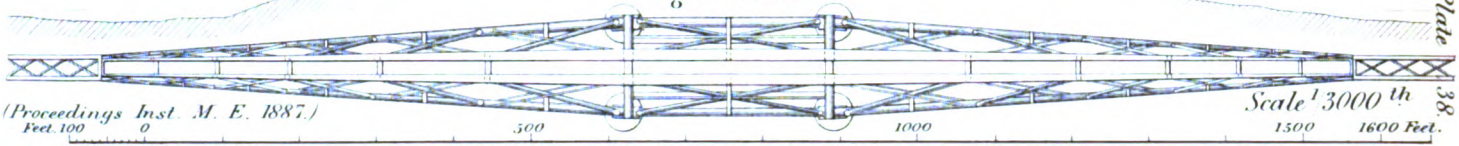


Fig. 4. Plan



Scale 1/3000th

(Proceedings Inst. M. E. 1887.)

Plate 38.

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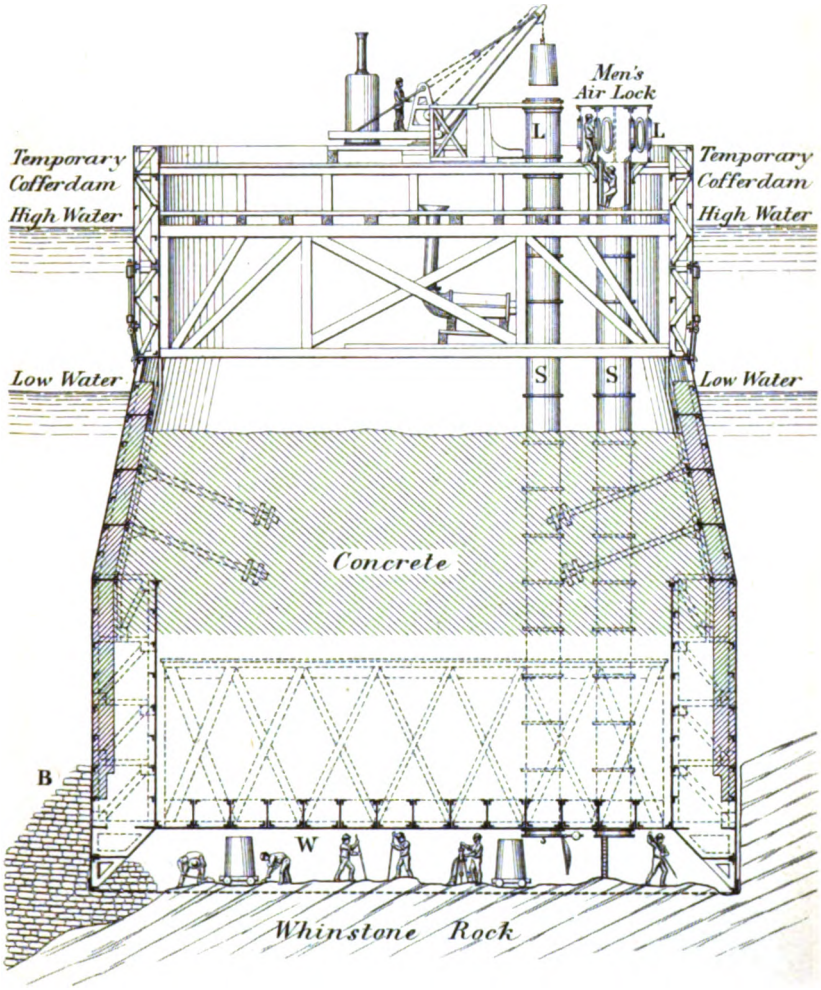
Fig. 5.

Caisson at Centre Main Pier.



Scale 1/250th

Feet 10 0 10 20 30 40 50 60 Feet. 70

(Proceedings Inst. M. E. 1887.)

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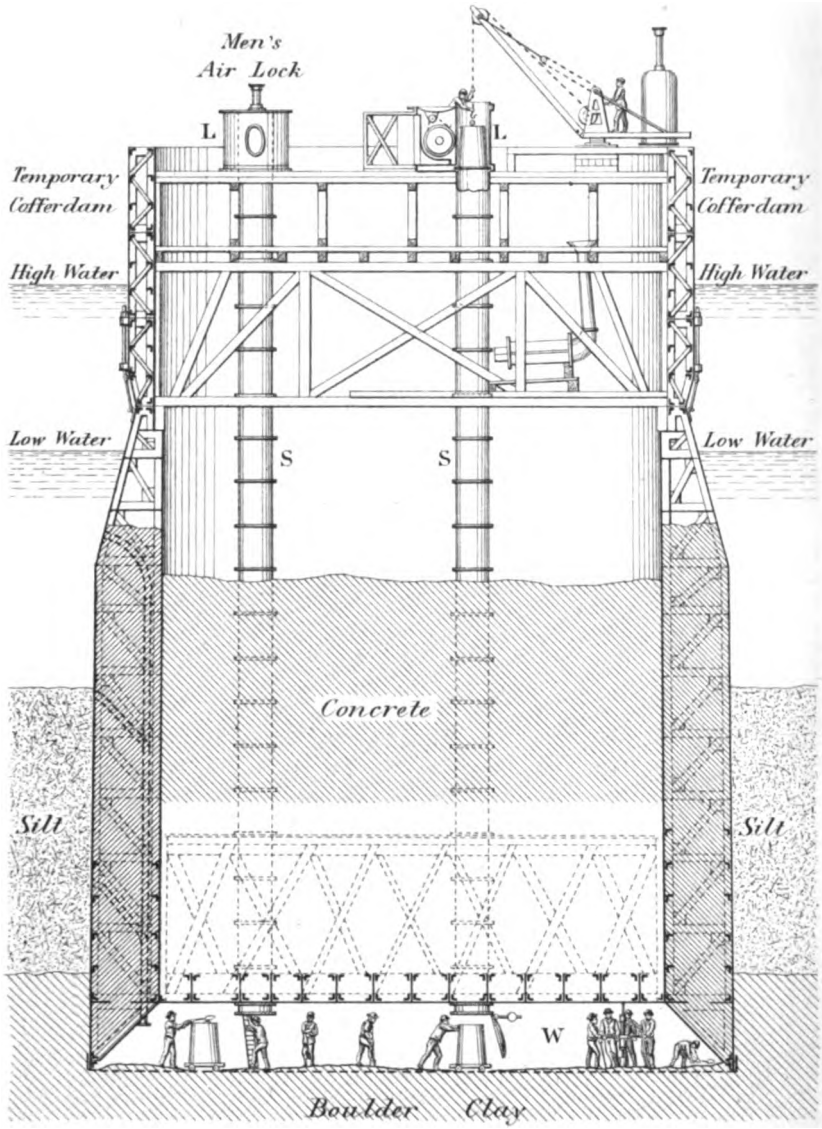
Fig. 6.

Caisson at South Main Pier.



Scale 1/250th

Feet. 10 0 10 20 30 40 50 60 Feet 70

(Proceedings Inst. M. E. 1887.)

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Fig. 7.

Cross Section at South Main Pier.

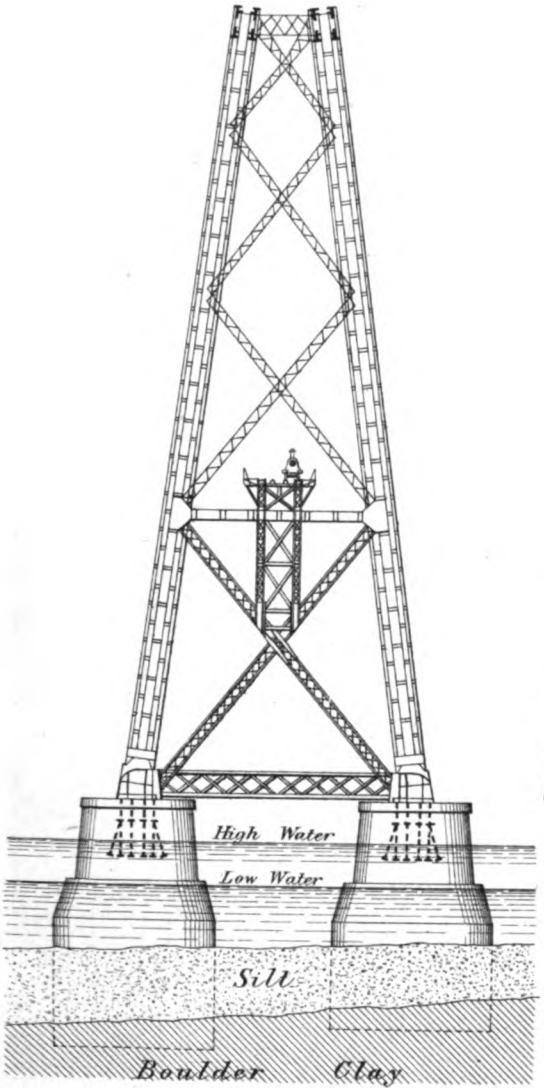


Fig. 8.

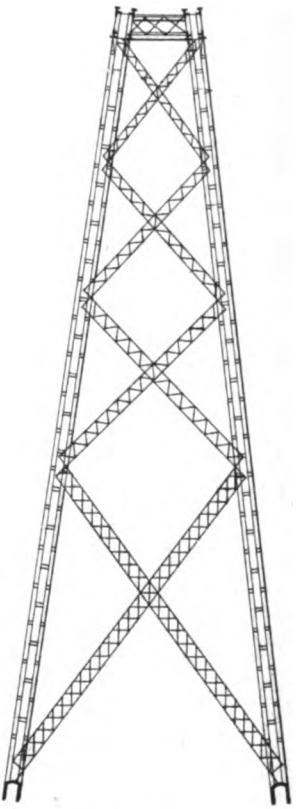
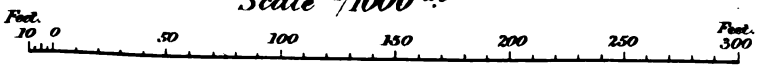


Fig. 8.

Elevation of End Strut next main pier.

Scale 1/1000th.



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Cross Sections of Component Members.

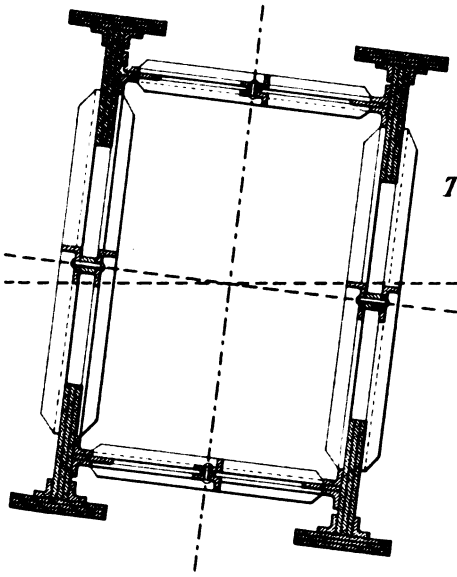


Fig. 9.

Top Member.

Fig. 11. *Tie.*

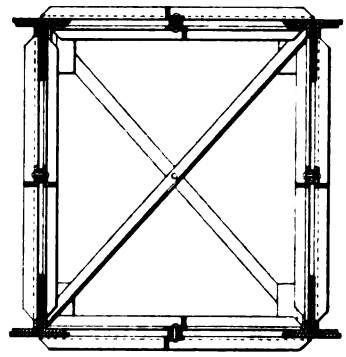


Fig. 10. *Main Columns and Bottom Members.*

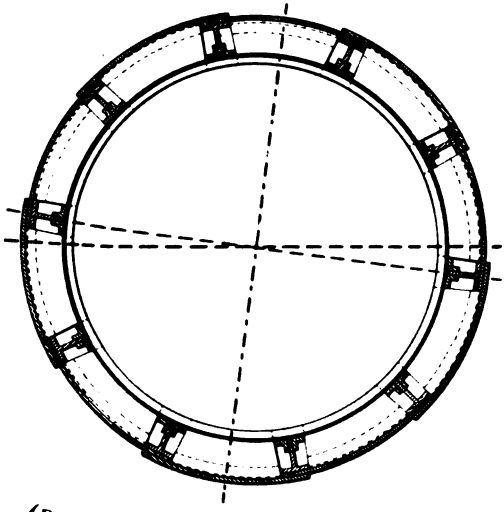
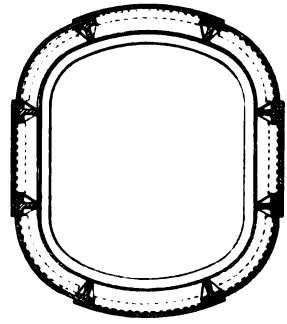


Fig. 12. *Strut.*



Scale 1/60th

(Proceedings Inst. M. E. 1887.)

Ins. 12 0 5 10 15 Feet.

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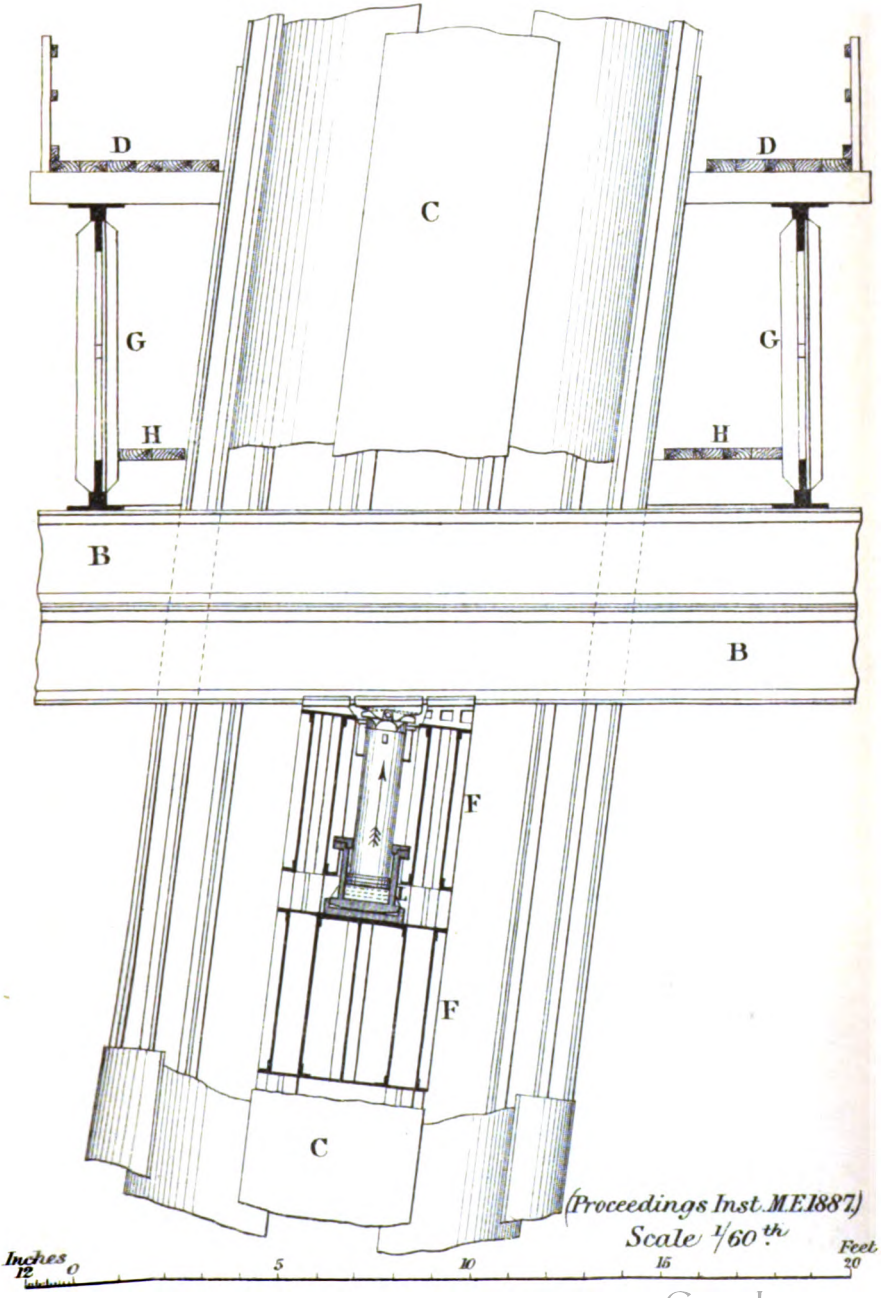
Lifting Gear for raising the Erecting Platforms at the main piers.

Fig. 13. *End Elevation.*



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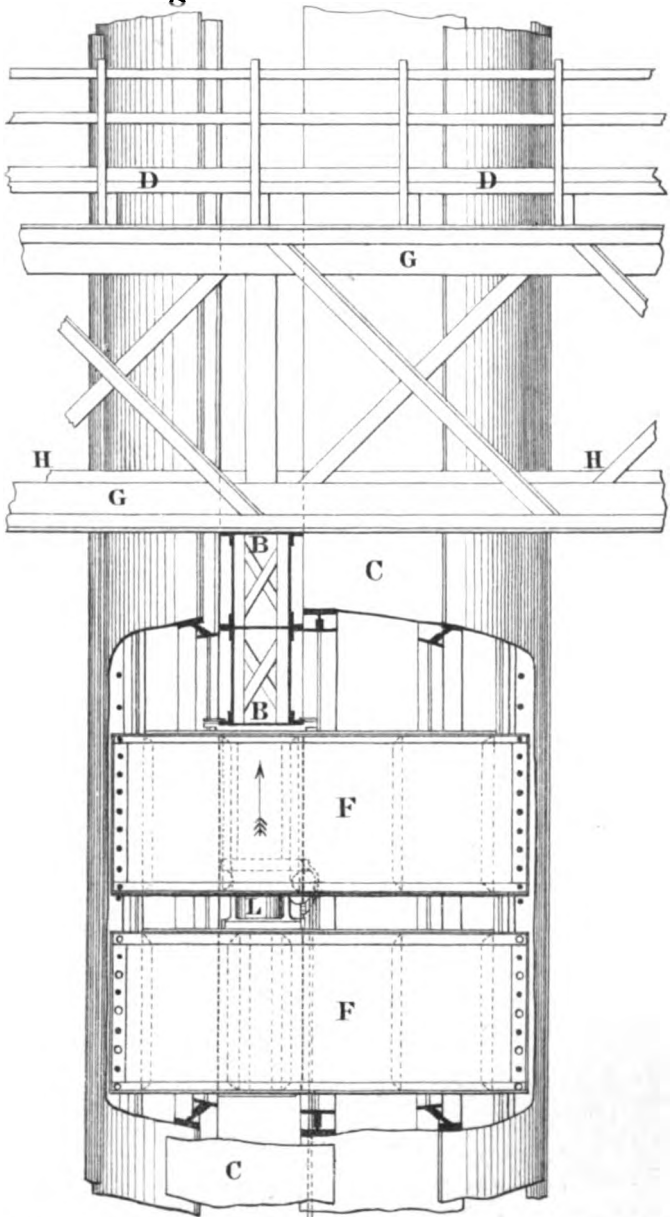
FORTH BRIDGE.

Plate 44.

Lifting Gear for raising the Erecting Platforms at the main piers.

Fig. 14. *Side Elevation.*



(*Proceedings Inst. M.E. 1887.*)

Scale 1/60th.

Inches 12 0 5 10 15 Feet 20

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FORTH BRIDGE MACHINERY.

Plate 45.

Hydraulic Bending Press.

Fig. 1. *Transverse Section.*

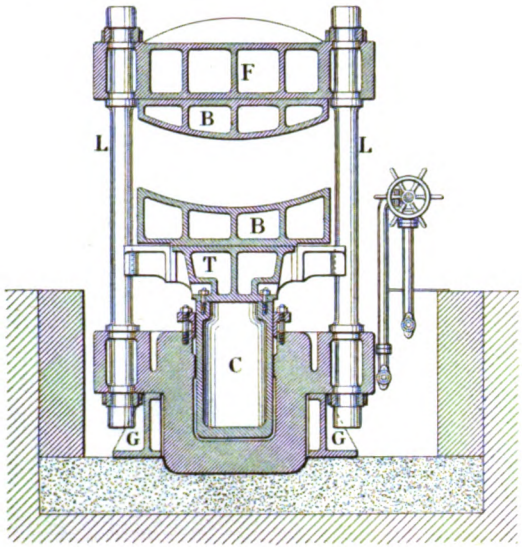
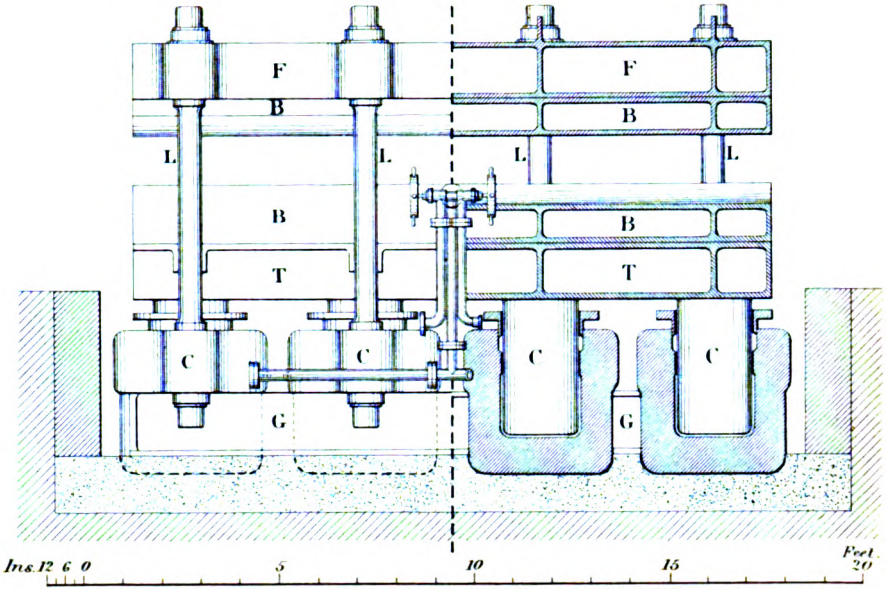


Fig. 2. *Half Side Elevation.* | *Half Longitudinal Section.*



(*Proceedings Inst. M. E. 1887.*) *Scale* 1/60th

Plate 45.

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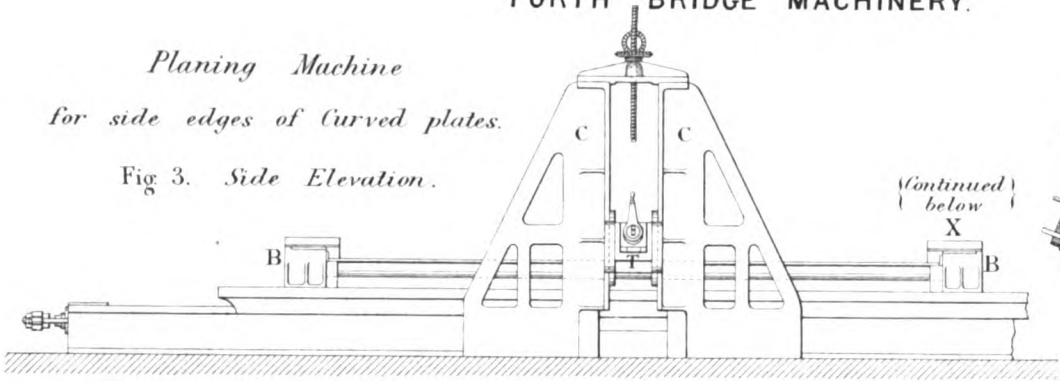
FORTH BRIDGE MACHINERY.

Planing Machine

for side edges of Curved plates.

Fig. 3. *Side Elevation.*



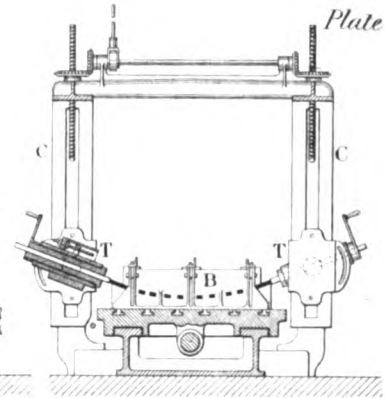
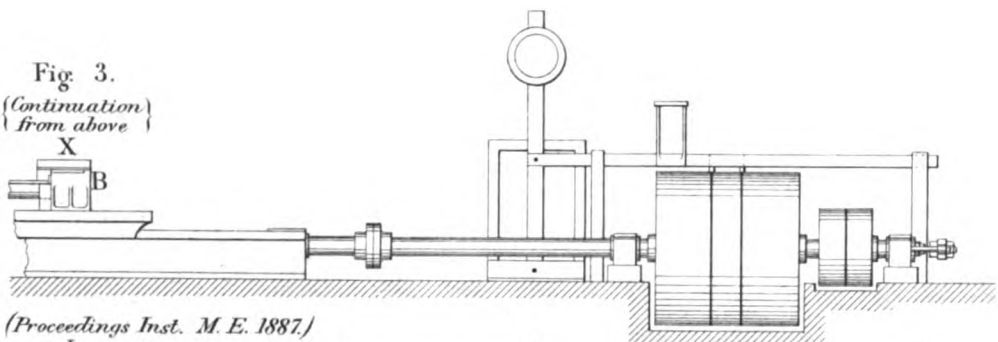


Fig. 4.
Transverse Section.

Fig. 3.
(*Continuation from above*)



Scale 1/60th

(*Proceedings Inst. M. E. 1887.*)

Ins. 12 0 5 10 15 20 25 30 Feet.

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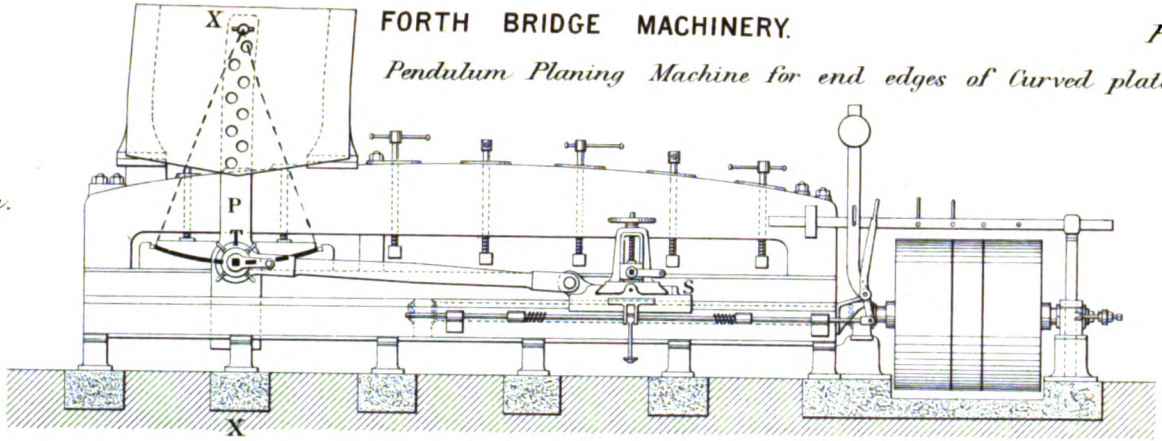
FORTH BRIDGE MACHINERY.

Pendulum Planing Machine for end edges of Curved plates.

Fig. 5.
Front Elevation.



Scale 1/60th

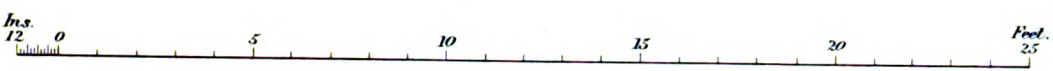


Fig. 7.
End Elevation of Bed supporting plate.

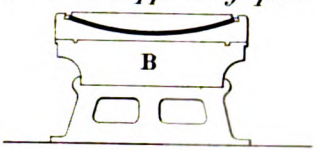


Fig. 6.
Side Elevation of Bed supporting plate.

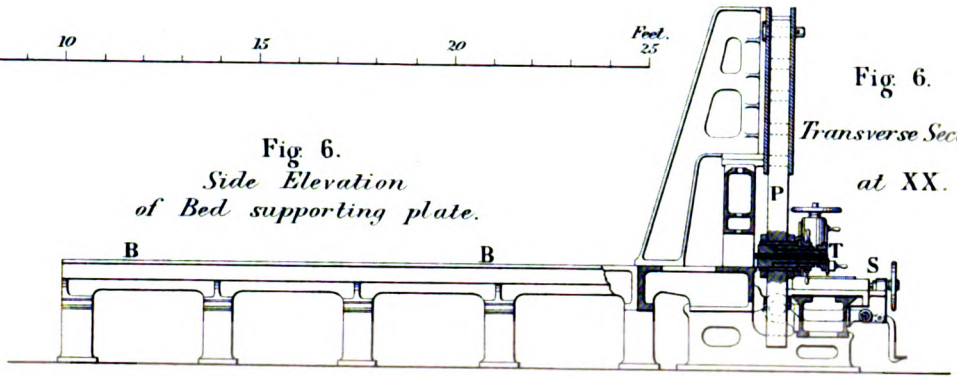


Fig. 6.
Transverse Section at XX.

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Plate 48.

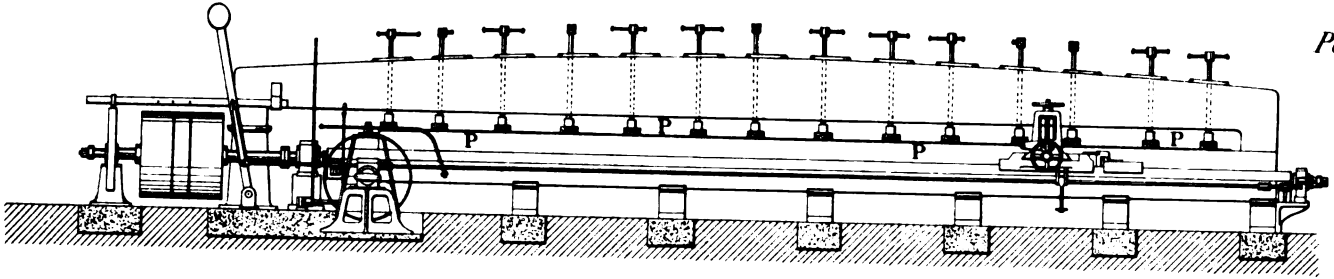
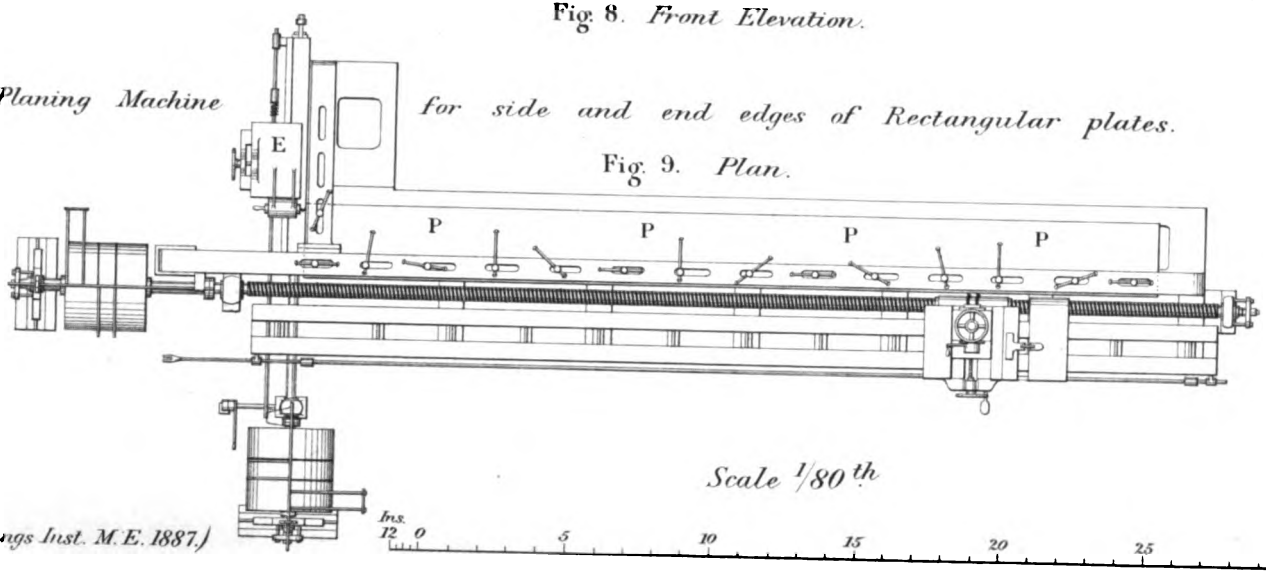


Fig. 8. *Front Elevation.*

Planing Machine for side and end edges of Rectangular plates.

Fig. 9. *Plan.*



(Proceedings Inst. M.E. 1887.)

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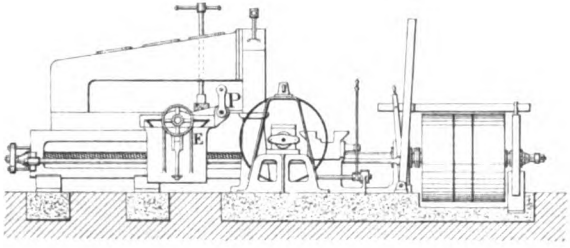
Planing Machine
for side and end edges
of Rectangular plates.

Fig. 10. *End Elevation.*



Scale 1/80th

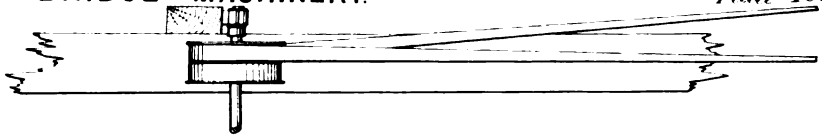
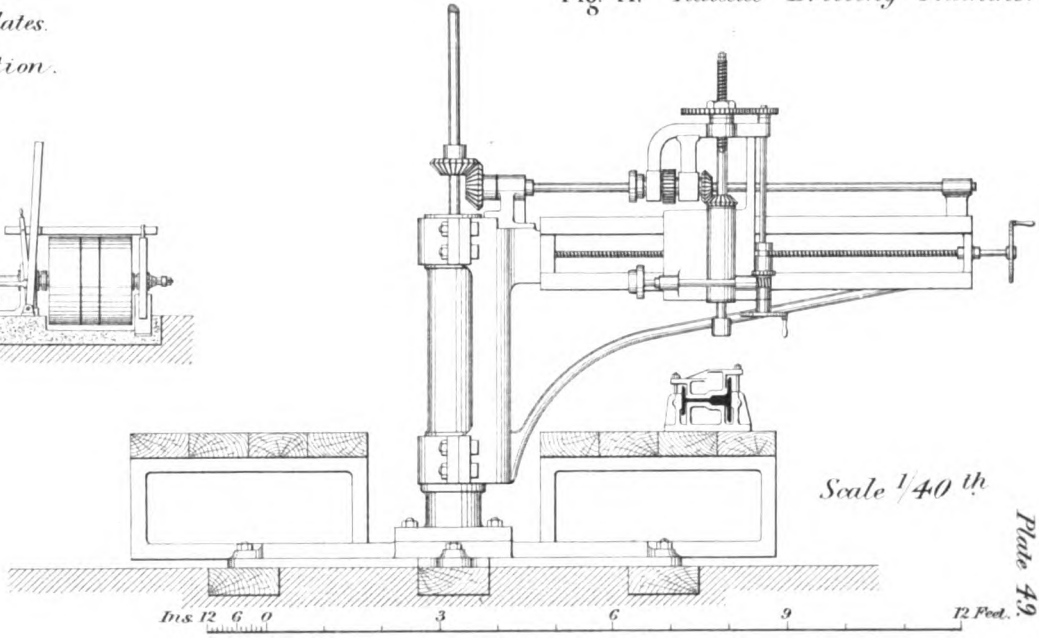


Fig. 11. *Radial Drilling Machine.*



Scale 1/40th

(Proceedings Inst. M. E. 1887.)

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FORTH BRIDGE MACHINERY.

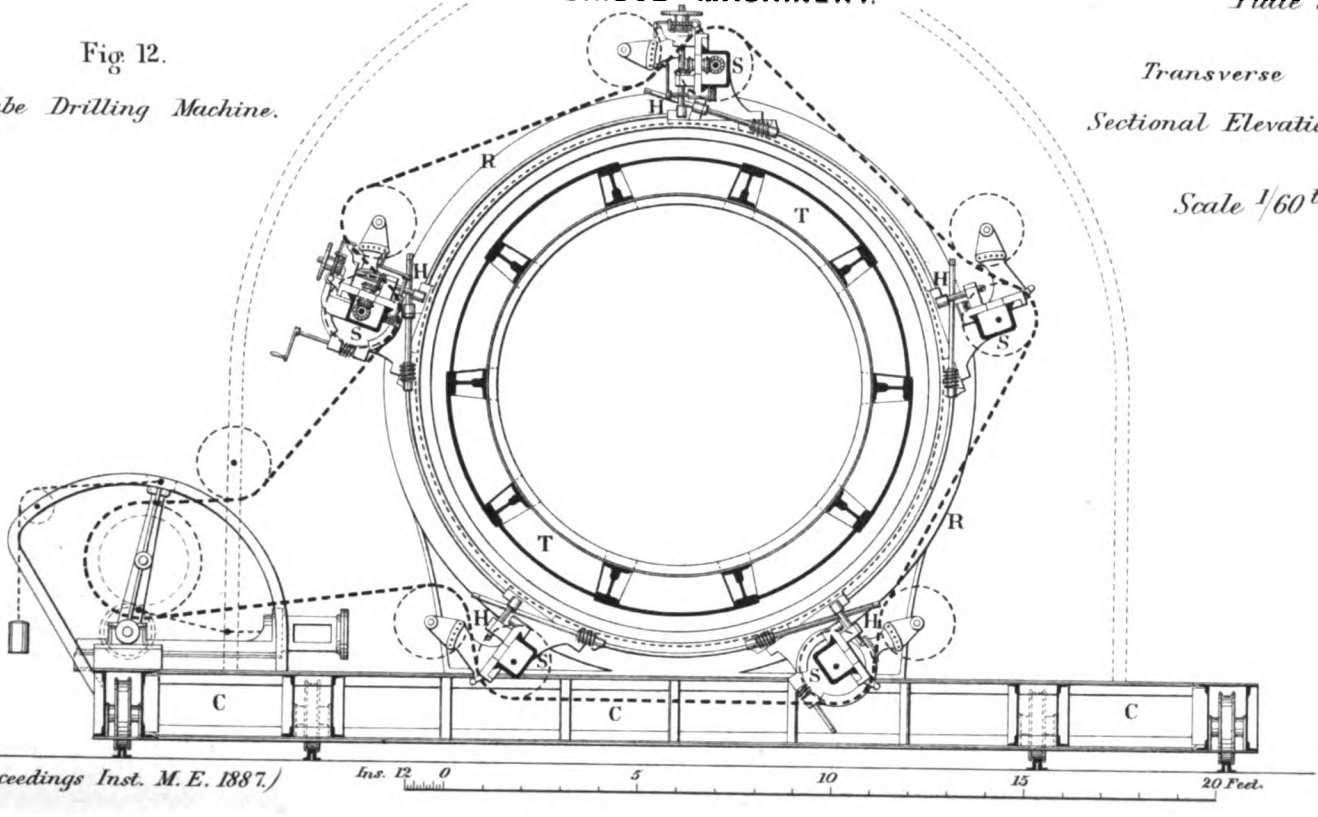
Plate 50.

Fig. 12.

Tube Drilling Machine.

Transverse Sectional Elevation.

Scale 1/60th



(Proceedings Inst. M.E. 1887.)

Plate 50.

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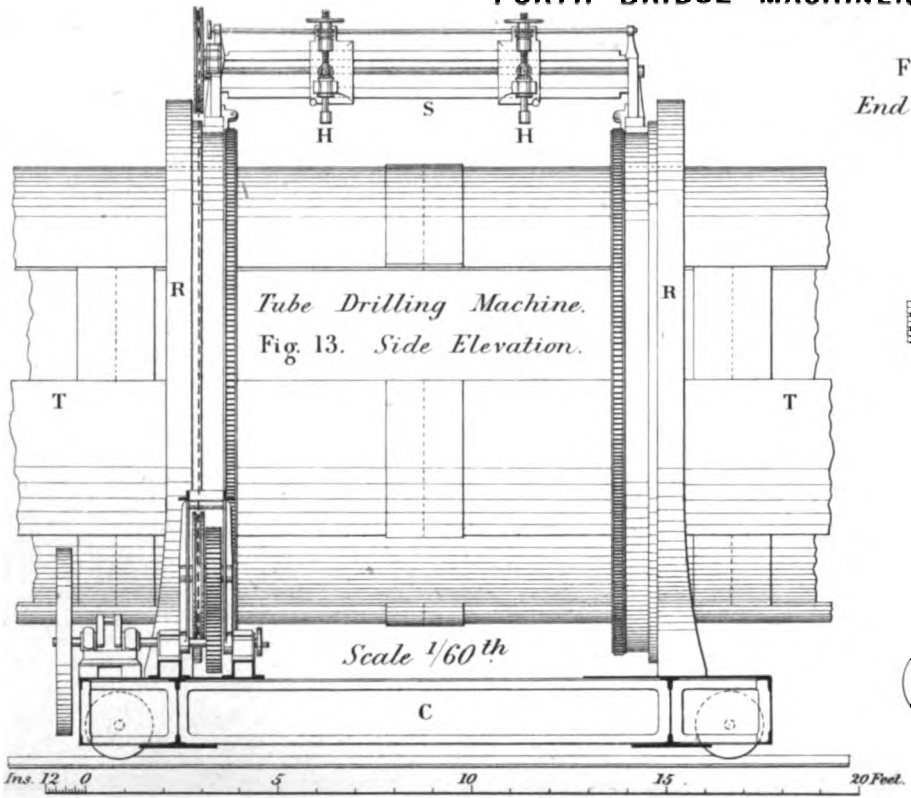
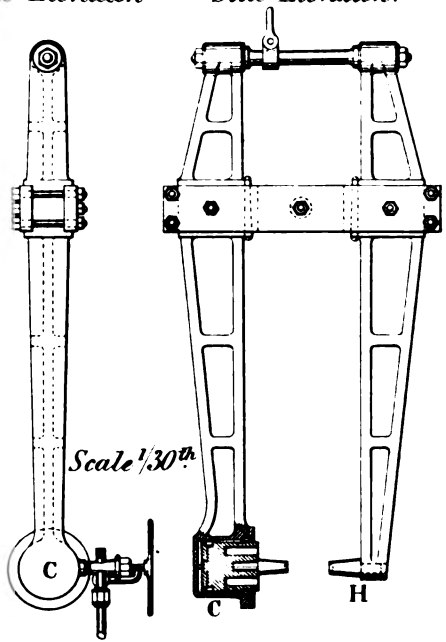
FORTH BRIDGE MACHINERY.



Tube Drilling Machine.
Fig. 13. Side Elevation.

Portable Hydraulic Riveter.

Fig. 14. End Elevation. Fig. 15. Side Elevation.



(Proceedings Inst. M. E. 1887.)

Plate 51.

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Multiple Drilling Machine.

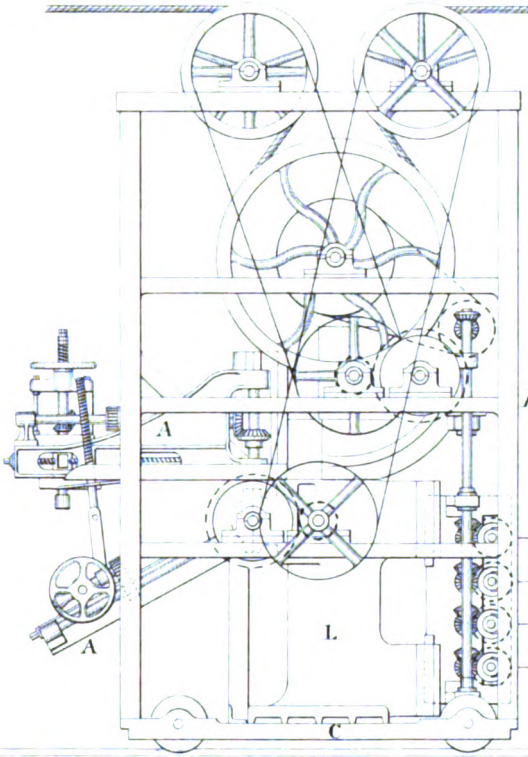


Fig. 16.

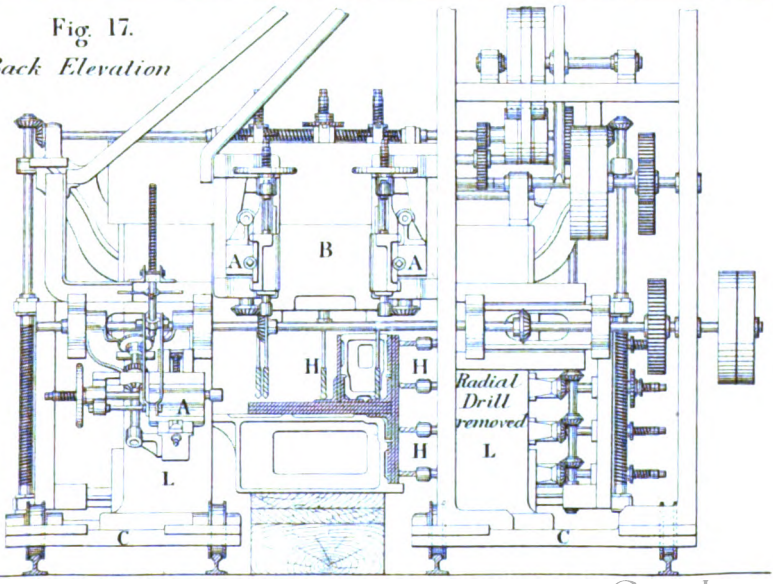
End Elevation

Scale 1/40th

(Proceedings Inst. M. E. 1887.)

Fig. 17.

Back Elevation



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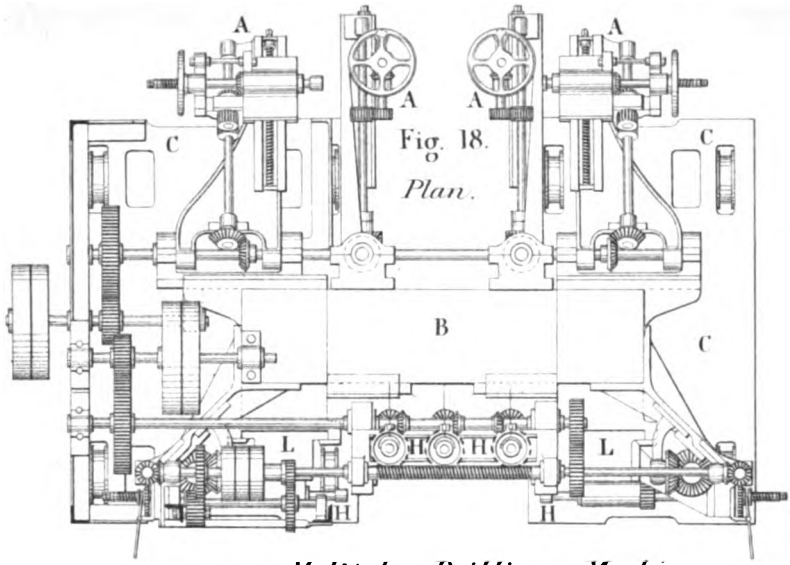


Fig. 18.

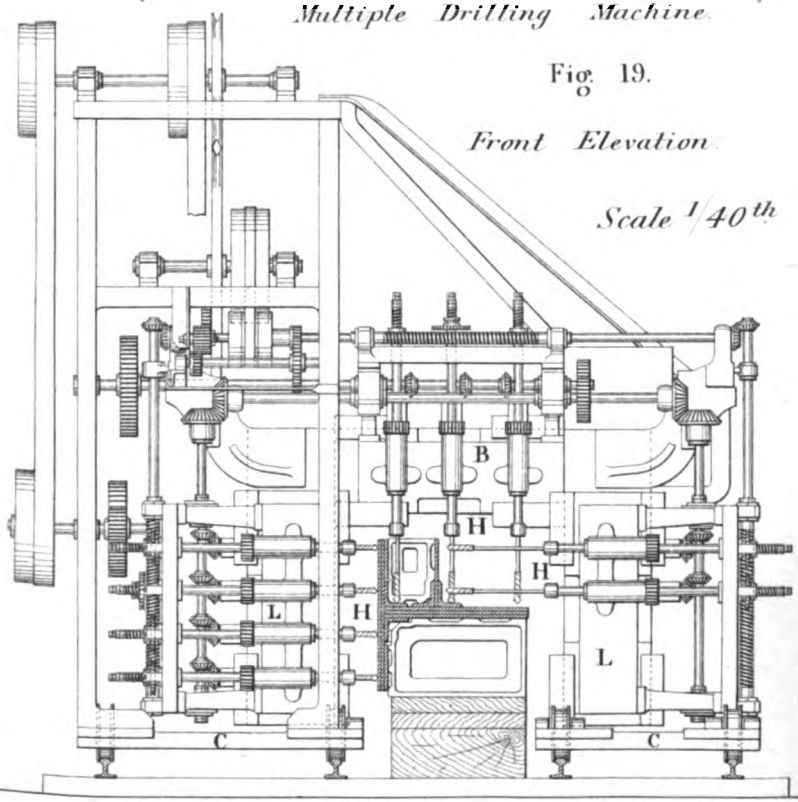
Plan.

Multiple Drilling Machine.

Fig. 19.

Front Elevation.

Scale 1/40th



Ins. 12 0 3 6 9 12 Feet.

(Proceedings Inst. M. E. 1887.)

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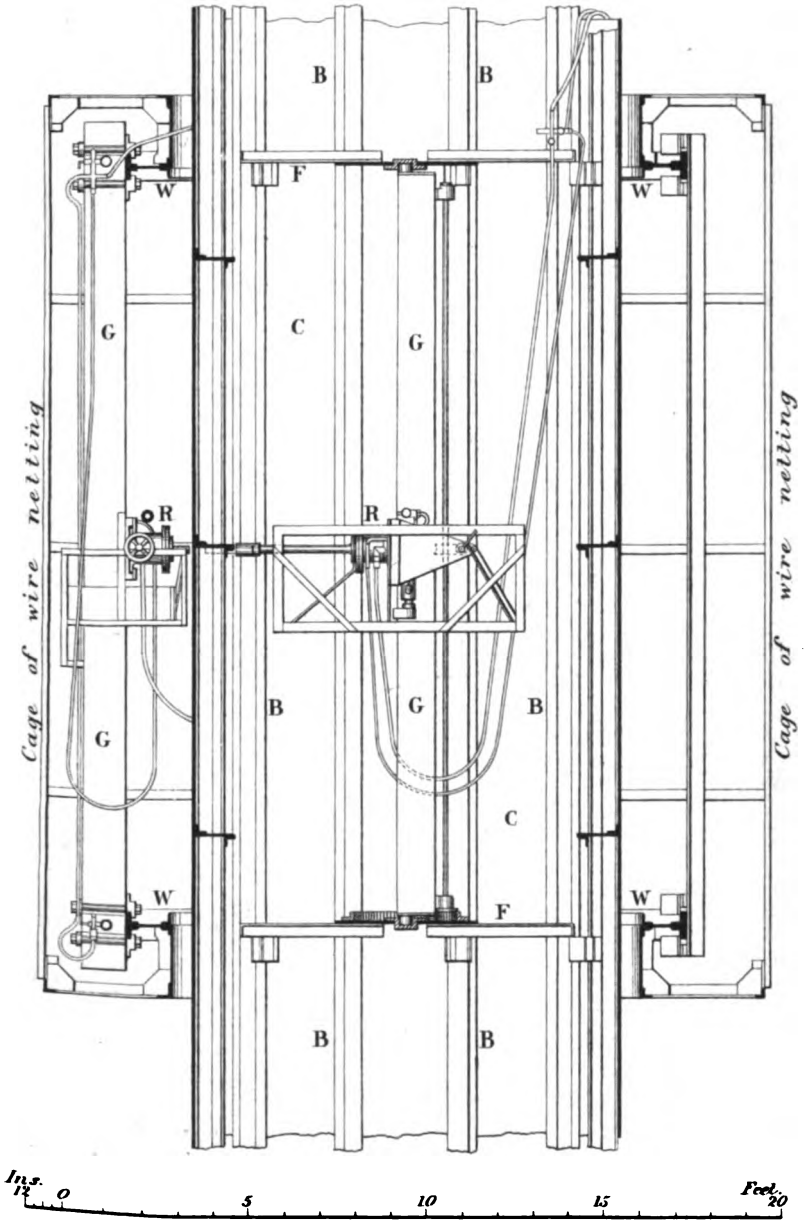
Riveting Machine for Vertical Columns of Piers.

Fig. 20. *Vertical Section.*



(*Proceedings Inst. M. E. 1887.*)

Scale 1/64th

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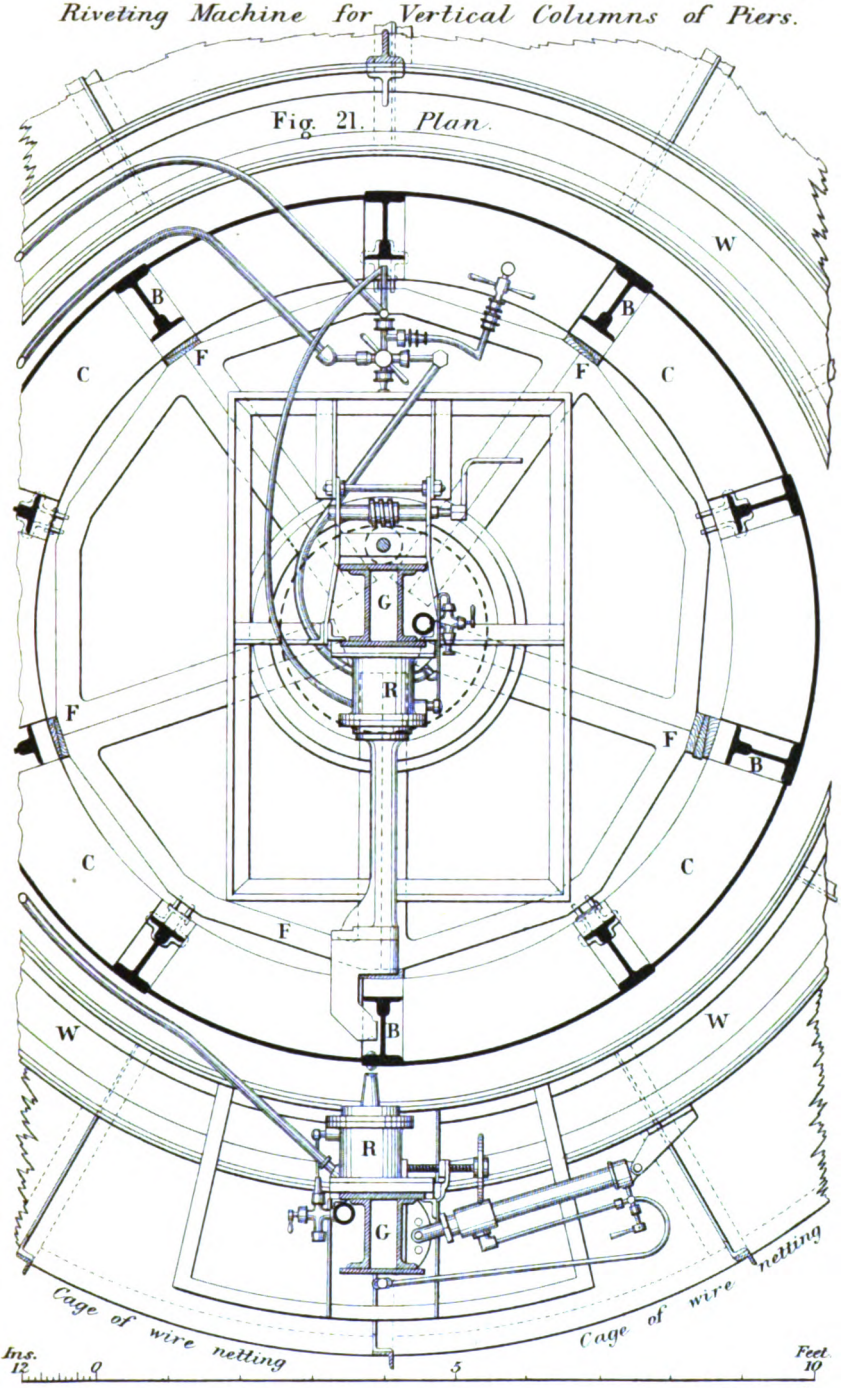
Riveting Machine for Vertical Columns of Piers.



(Proceedings Inst. M. E. 1887.)

Scale 1/32nd

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ELECTRO-MAGNETIC MACHINE-TOOLS.

Plate 56.

Riveter.

Fig. 1.

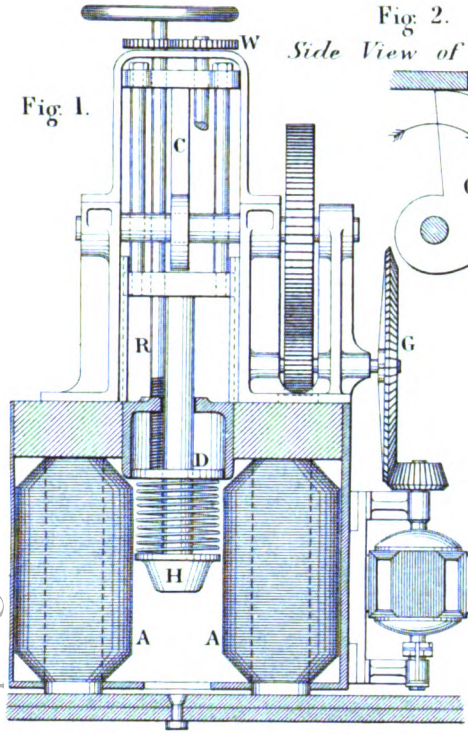
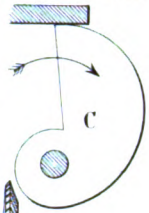


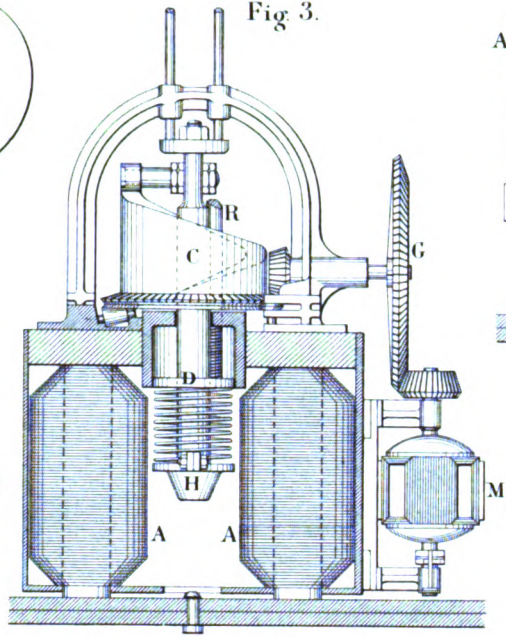
Fig. 2.

Side View of Cam.



Riveter.

Fig. 3.



Holder-up.

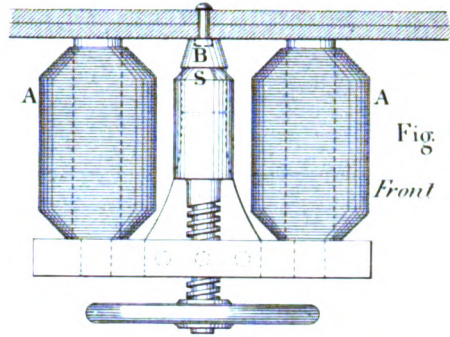


Fig. 4.

Front View.

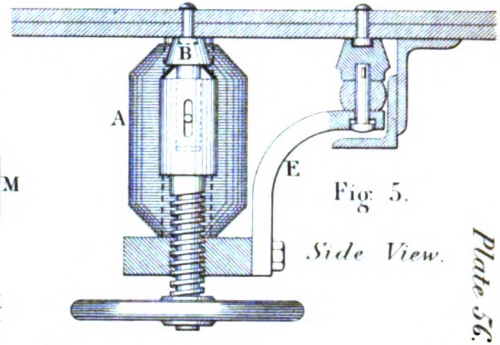


Fig. 5.

Side View.

Plate 56.

(Proceedings Inst. M. E. 1887.) *Scale 1/10th*

0 10 20 30 40 ins.

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ELECTRO - MAGNETIC MACHINE - TOOLS.

Fig. 6. *Drilling Machine with drill between magnets.*

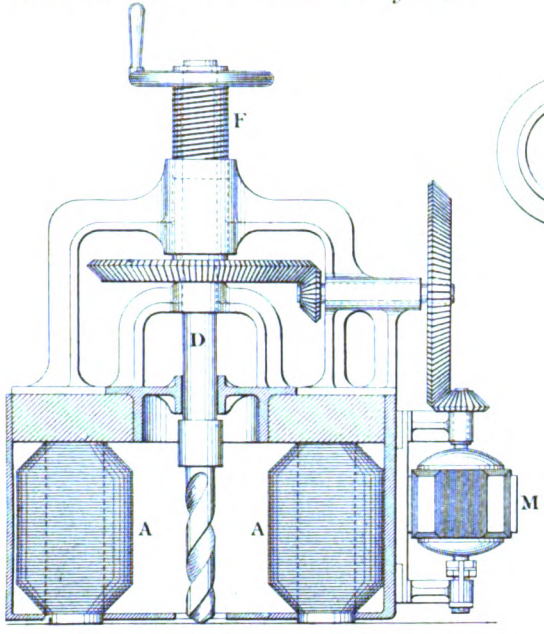
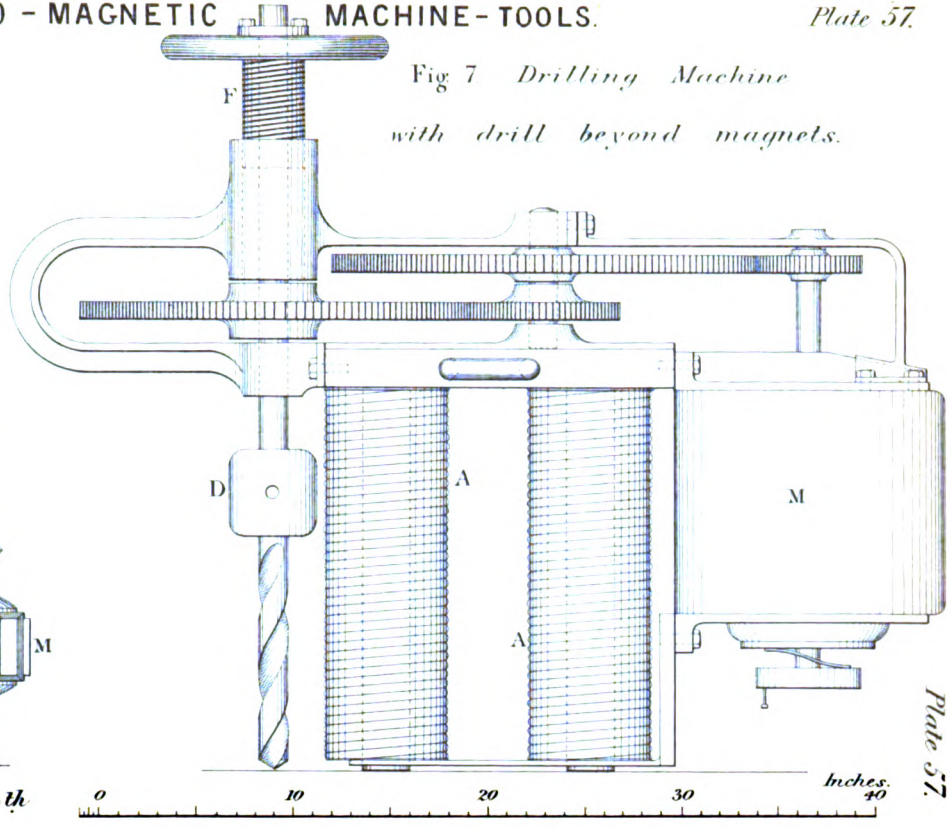


Fig. 7 *Drilling Machine with drill beyond magnets.*



(Proceedings Inst. M. E. 1887.) *Scale 1/10th.*

Plate 57.

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ELECTRO - MAGNETIC MACHINE - TOOLS.

Fig. 8. *Drilling Machine worked by hydraulic motor.*

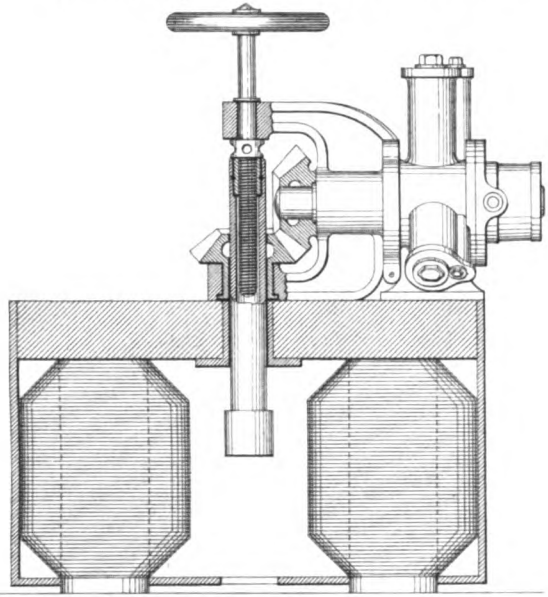
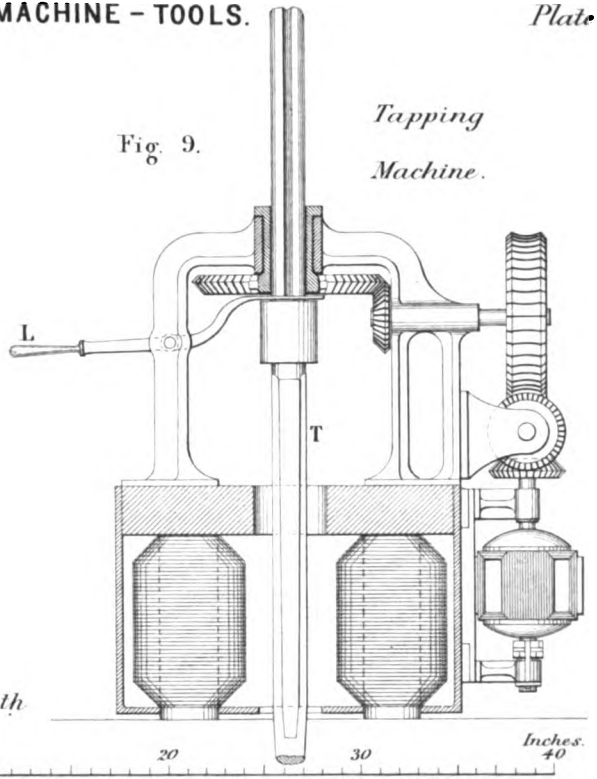
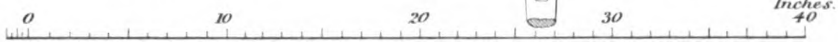


Fig. 9. *Tapping Machine.*



Scale 1/10th



(Proceedings Inst. M.E. 1887.)

Plate 58.

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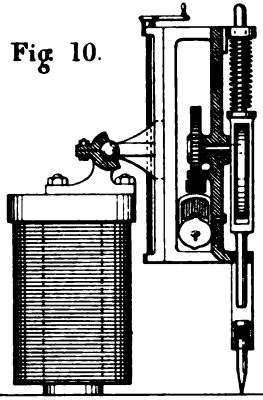
ELECTRO-MAGNETIC MACHINE-TOOLS.

Caulking and Chipping Machines.

Fig. 10.



Scale 1/10th

Fig. 11.

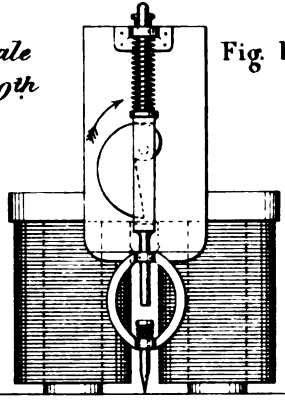
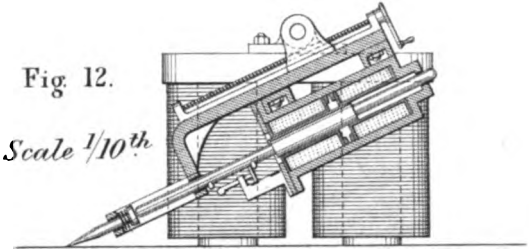


Fig. 12.

Scale 1/10th

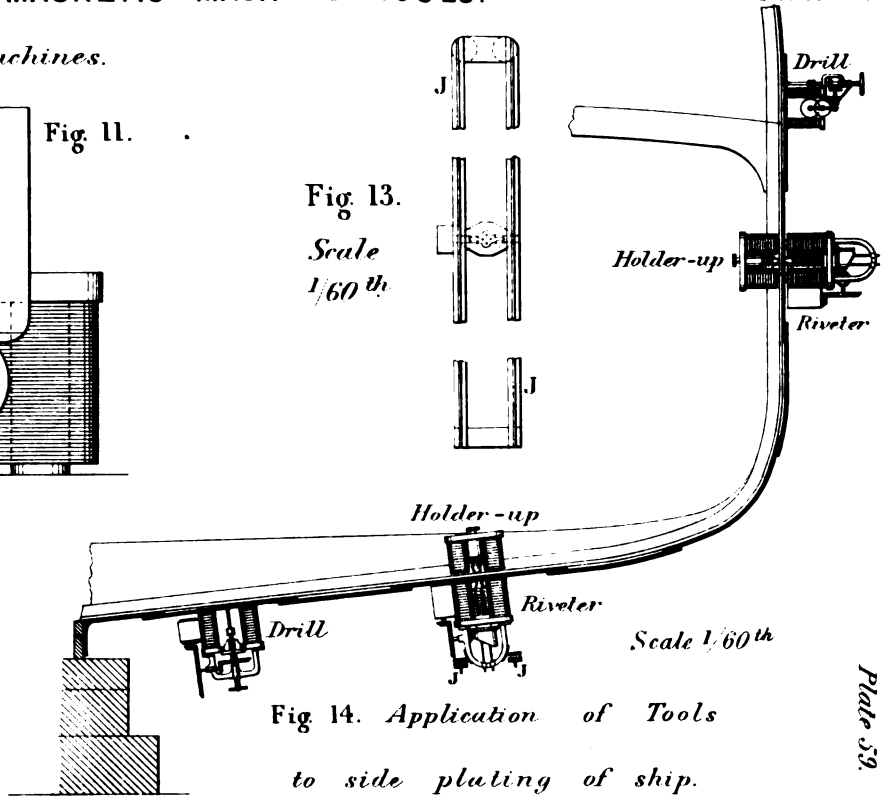


0 5 10 15 20 Inches.

(Proceedings Inst. M. E 1887.)

Fig. 13.

Scale 1/60th



Scale 1/60th

Fig. 14. *Application of Tools to side plating of ship.*

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ELECTRO - MAGNETIC MACHINE - TOOLS.

Plate 60.

Fig 15. *Plan of Tools working on same guide - bar.* Scale 1/40th

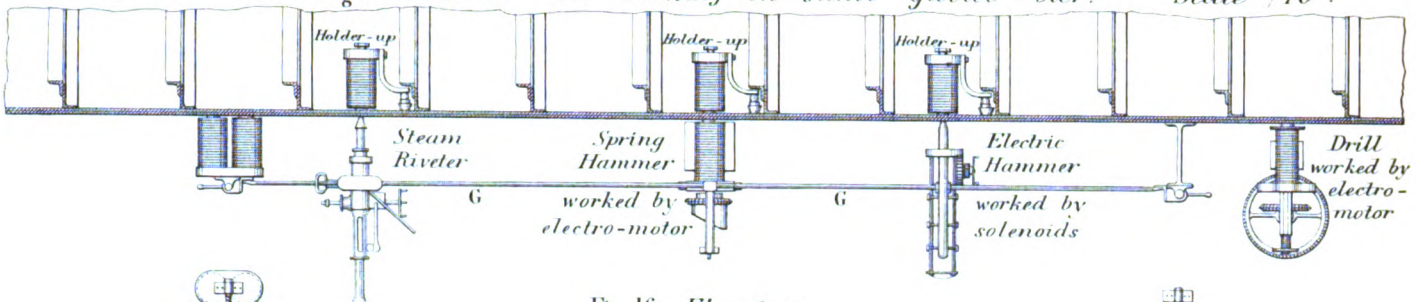


Fig 16. *Elevation.*

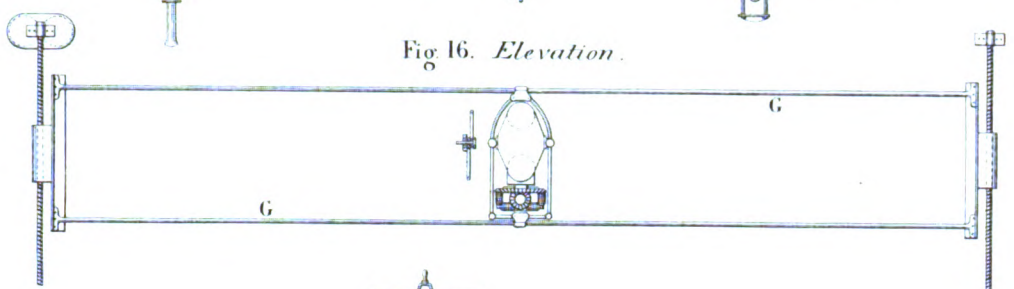
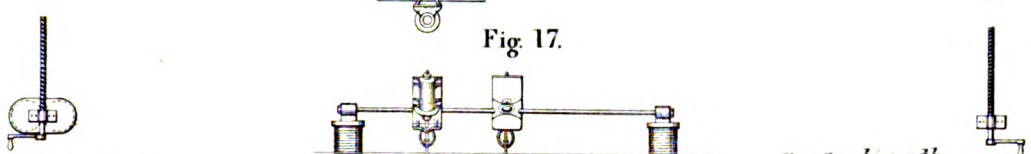


Fig. 17.



(*Proceedings Inst. M. E. 1887.*)

Scale 1/40th

Ins. 12 6 0 5 10 15 20 Feet.

Plate 60.

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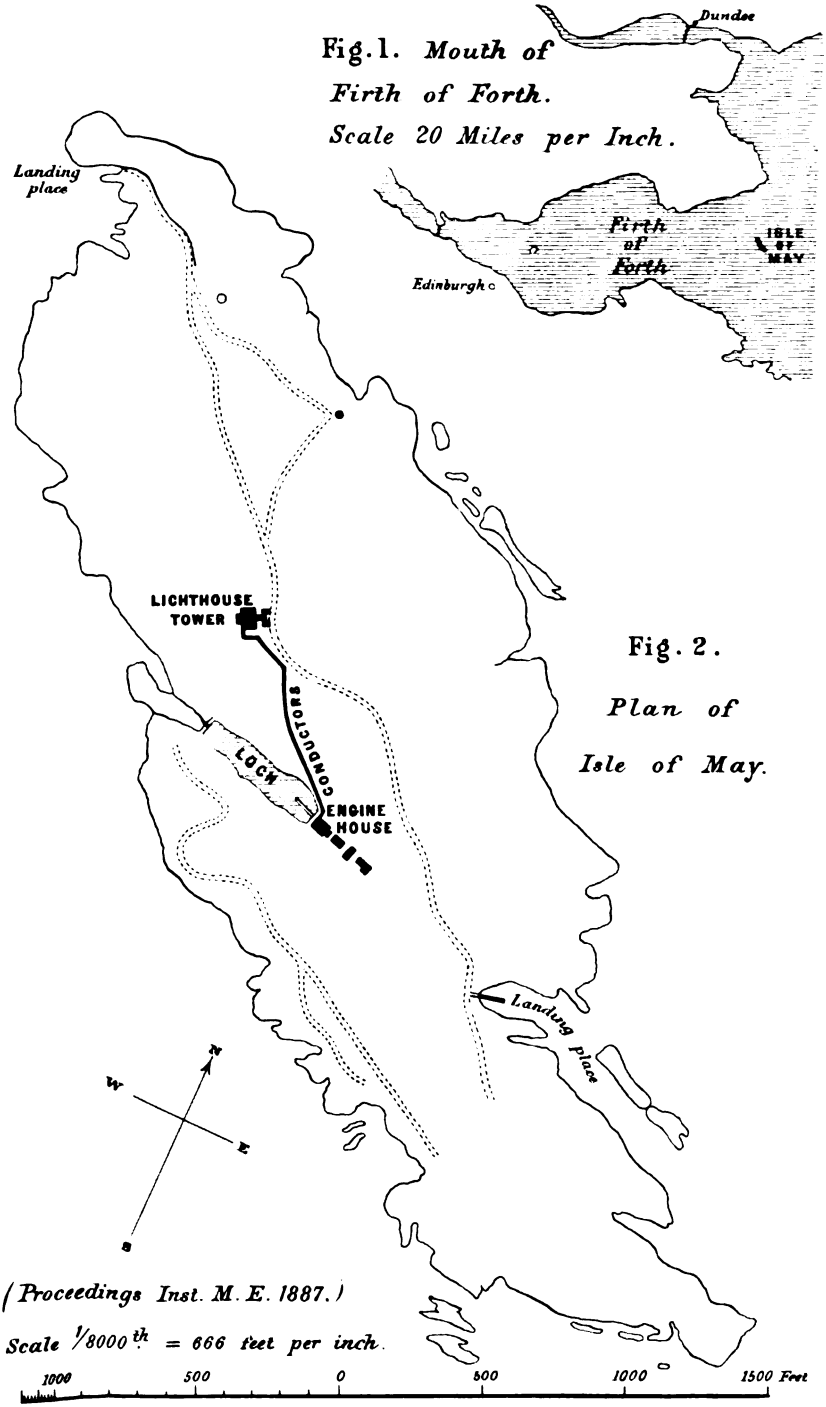

Fig. 1. *Mouth of Firth of Forth. Scale 20 Miles per Inch.*

Fig. 2. *Plan of Isle of May.*

(Proceedings Inst. M. E. 1887.)

Scale 1/8000th = 666 feet per inch.

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Engine and Boiler House &c.

Fig. 3. *Section at XX.*

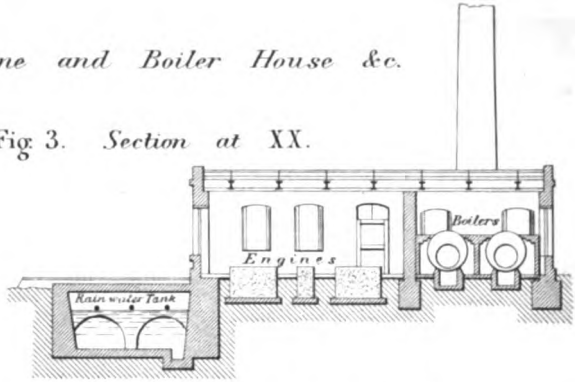


Fig. 4. *Section on line YY.*

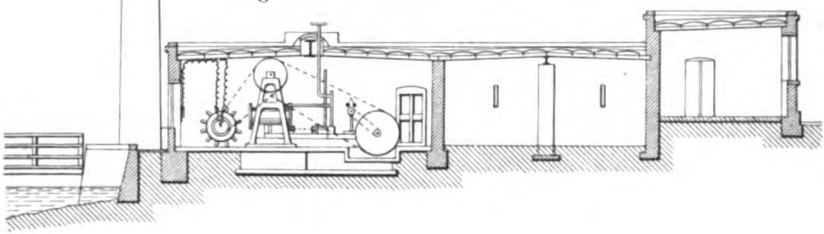
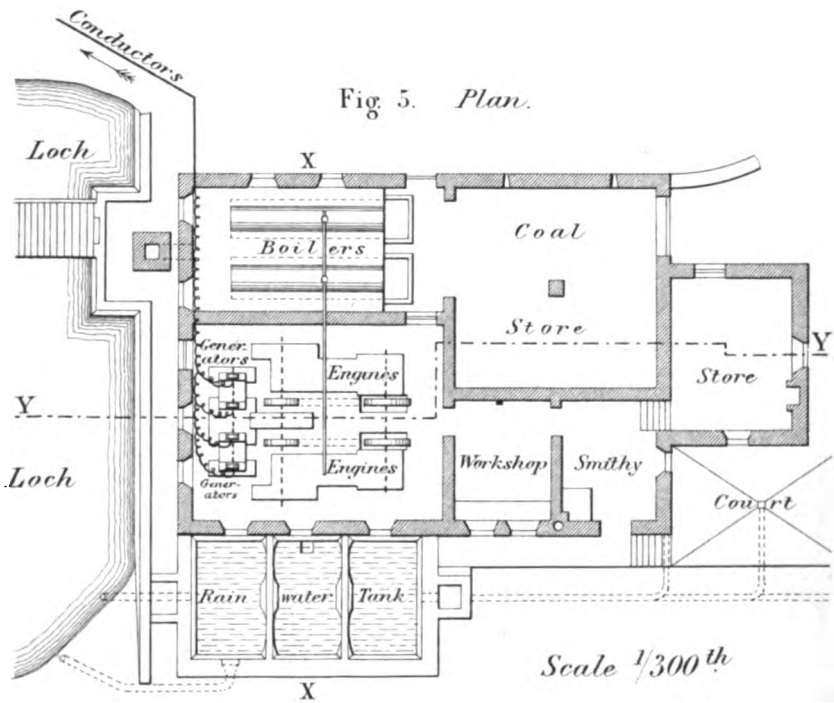


Fig. 5. *Plan.*



Feet.
10 0 10 20 30 40 50 60 70 80 90

(*Proceedings Inst. M. E. 1887.*)

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Engines and Machinery.

Fig. 6. *Elevation.*

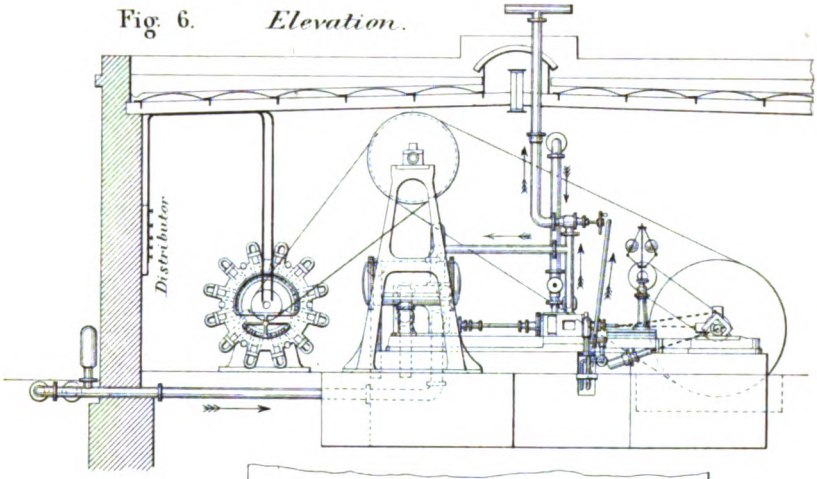
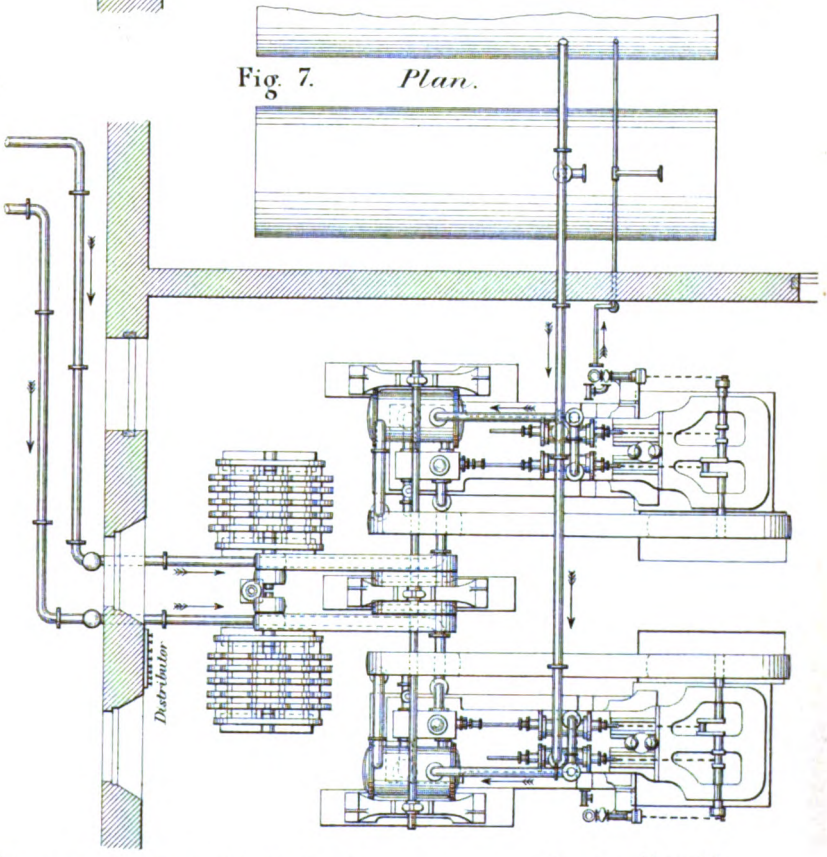


Fig. 7. *Plan.*



(Proceedings Inst. M. E. 1887.) *Scale 1/100th*

Ins. 12 0 5 10 15 20 25 30 Feet.

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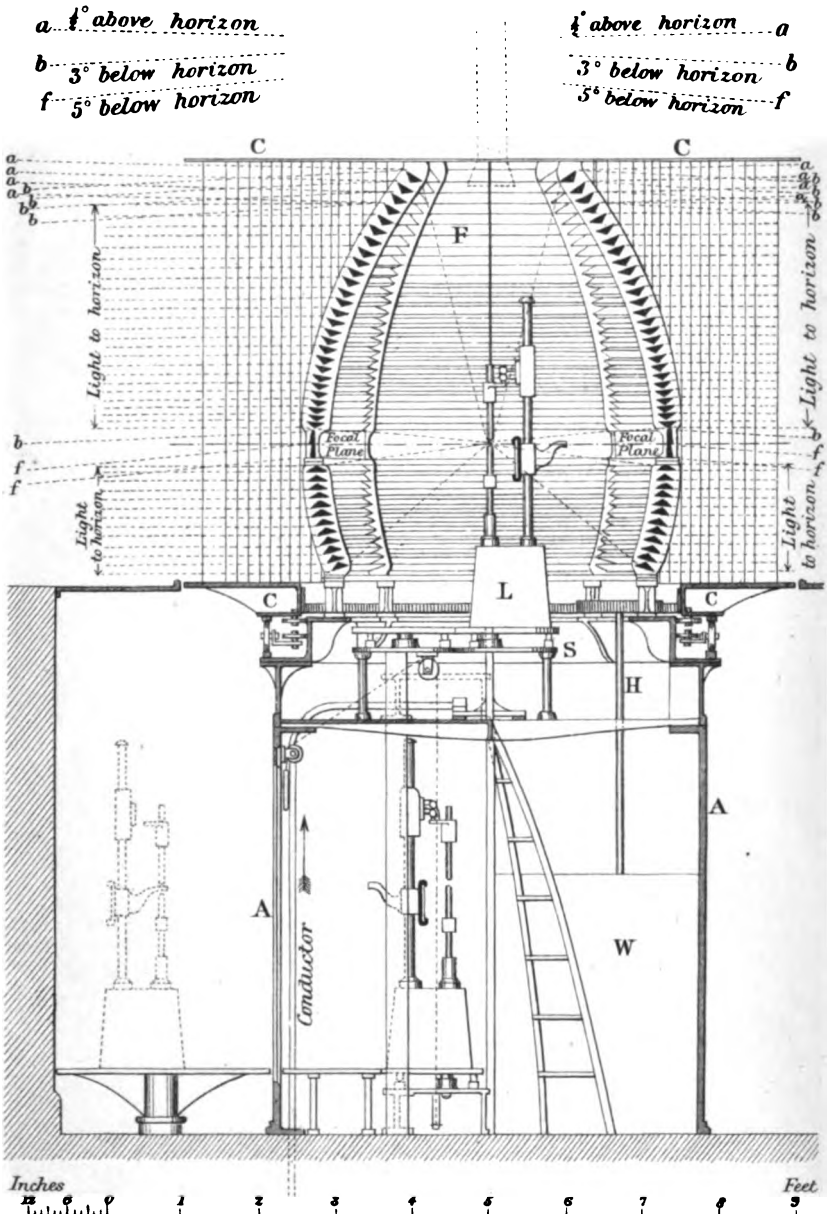
ELECTRIC LIGHTHOUSE. *Plate 64.*

Dioptric Apparatus.

Fig. 8. *Vertical Section.*



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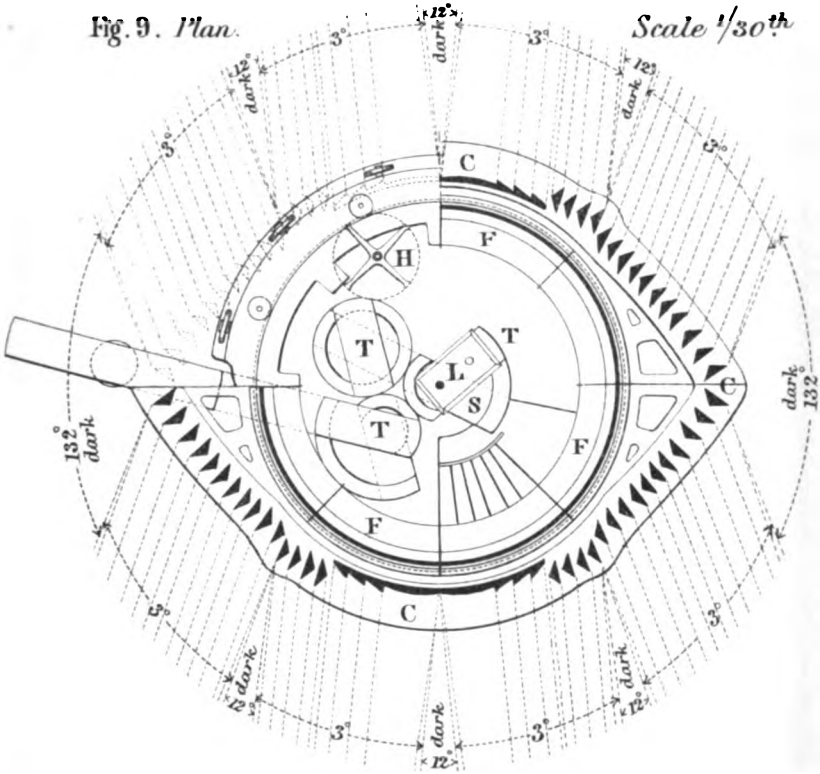
Dioptric Apparatus.

Fig. 9. *Plan.* *Scale 1/30th.*



Wall carrying Copper Conductors.

Fig. 10. *Side Elevation.*

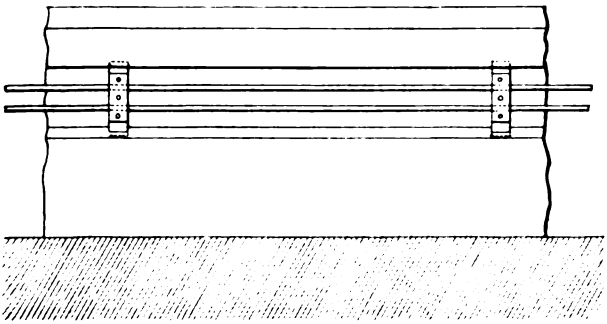
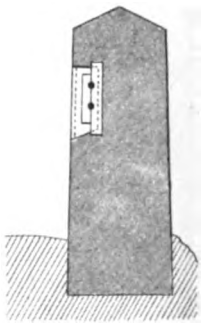


Fig. 11. *Transverse Section.*



Inches 12 6 0 1 2 3 4 5 6 7 8 9 *Feet*

(*Proceedings Inst. M.E. 1887.*) *Scale 1/30th.*

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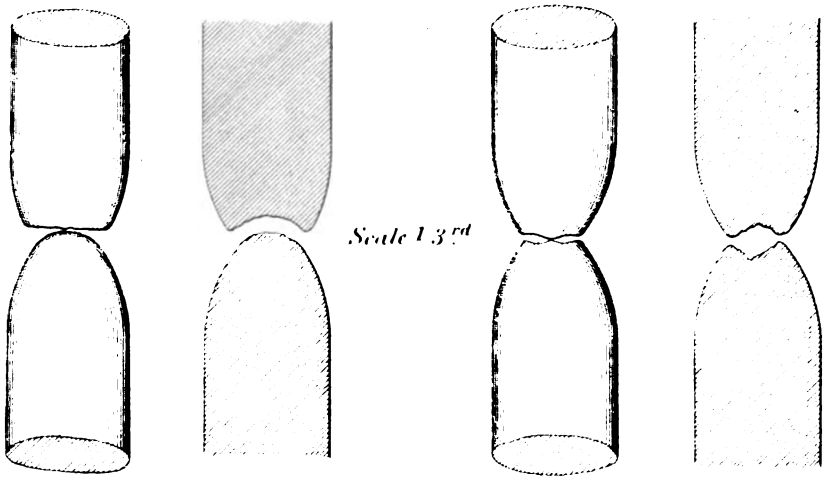
Carbons for Arc Light.

Cylindrical Carbons 50 m m. diameter.

Continuous Current. *Alternating Current.*

Fig. 12. *Elevation.* Fig. 13. *Vertical Section.* Fig. 14. *Elevation.* Fig. 15. *Vertical Section.*



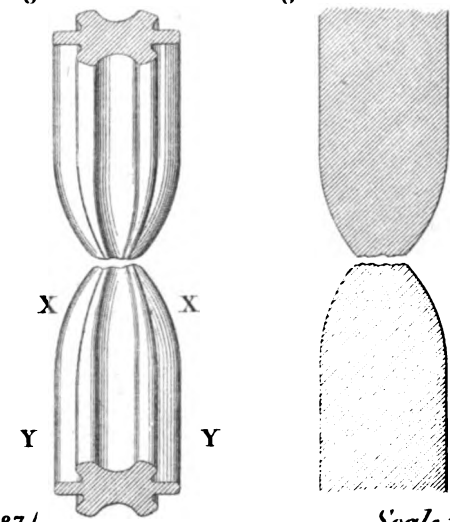
Fluted Carbons 50 m m. diameter.

Alternating Current.

Fig. 18. *Transverse Section at XX.*

Fig. 19. *Transverse Section at YY.*

Fig. 16. *Elevation.* Fig. 17. *Vertical Section.*



Scale 1/3rd

(Proceedings Inst. M.E. 1887.)

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TAY VIADUCT.

Plate 67.

Fig. 1. *Elevation of Viaduct.*

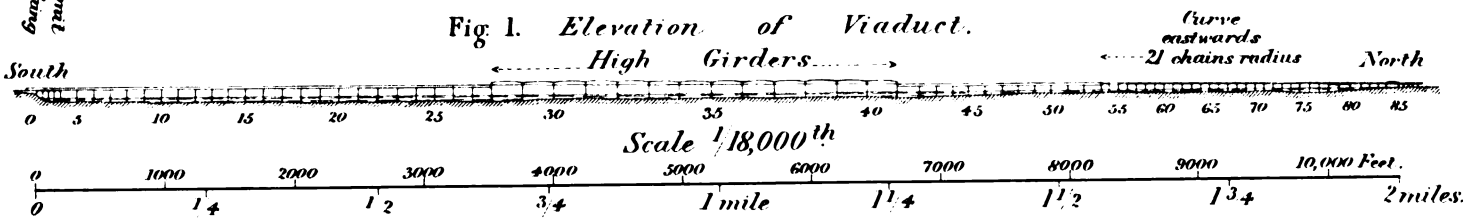


Fig. 2. *Side Elevation of Spans 41 and 42.*

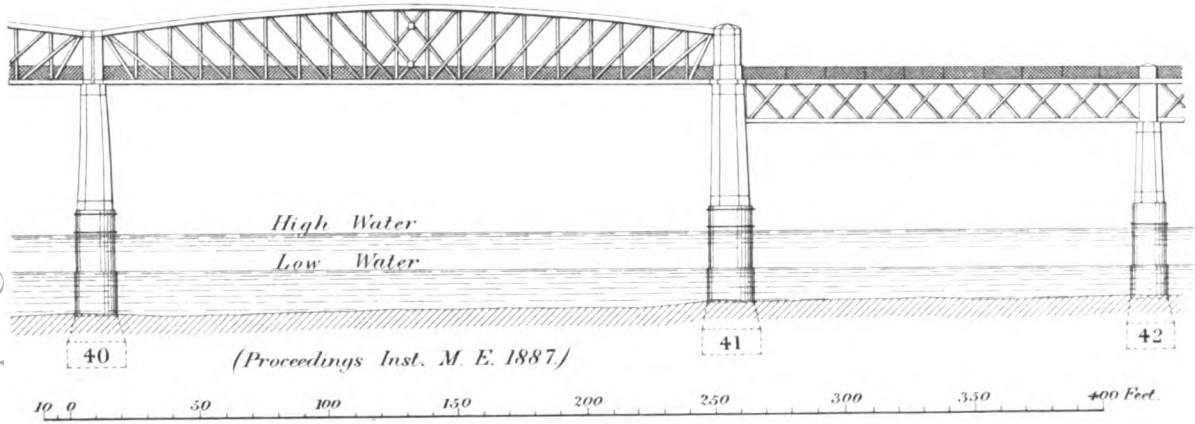
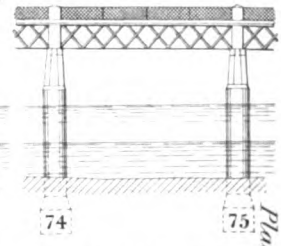


Fig. 3.
Side Elevation of Span 75.



Scale 1/900th

Plate 67.

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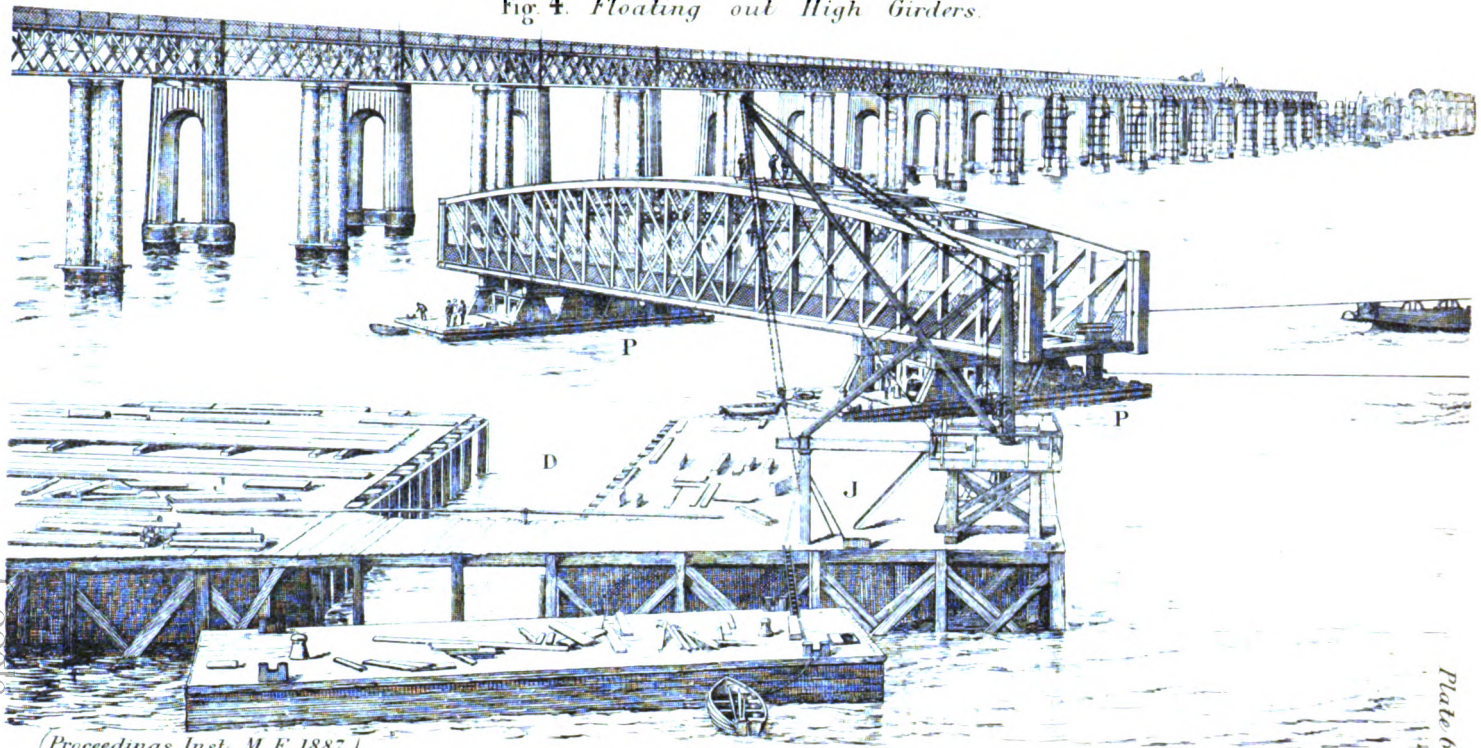
TAY VIADUCT.

Fig. 4. *Floating out High Girders.*



(Proceedings Inst. M. E. 1887.)

Plate 68.

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TAY VIADUCT.

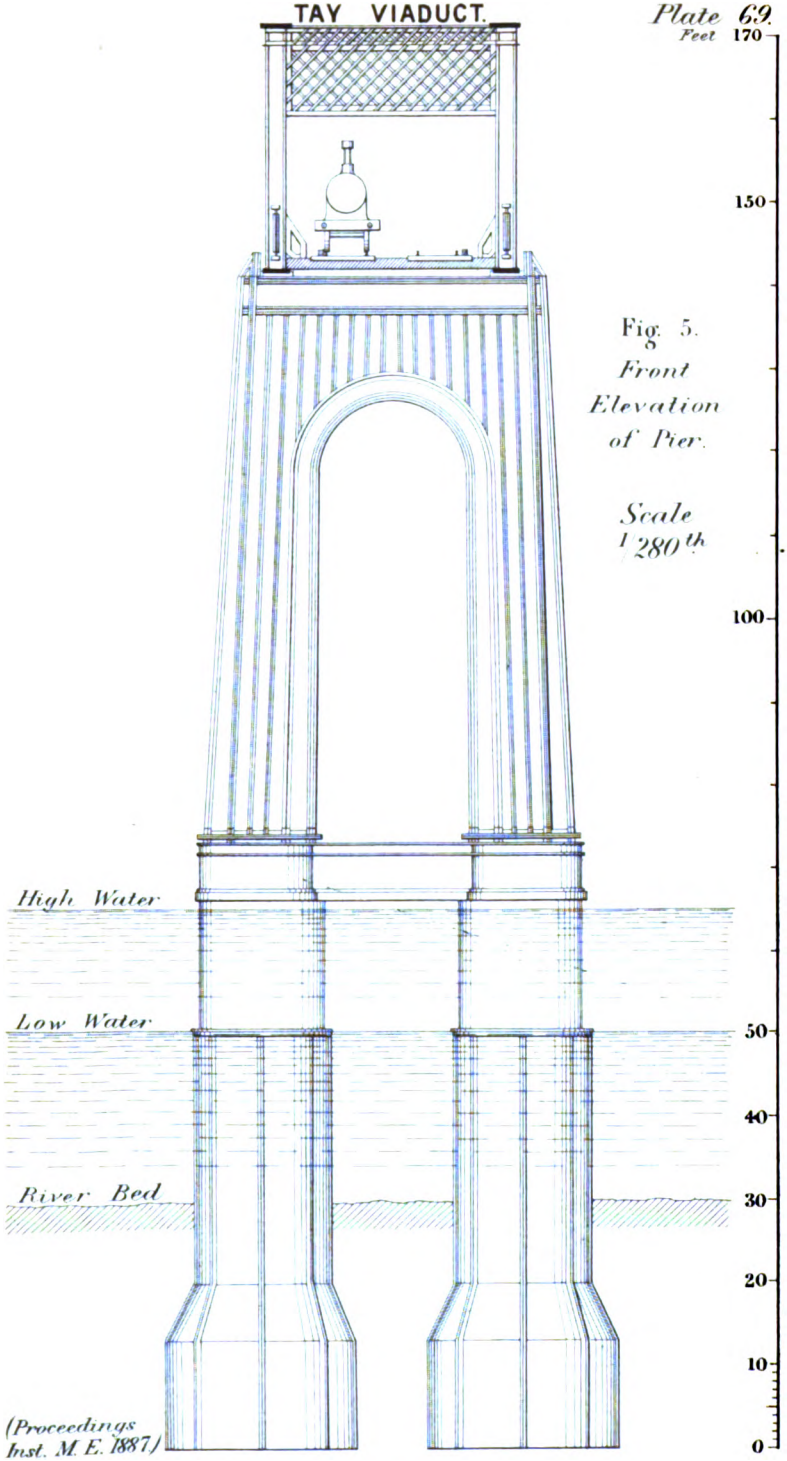

Fig. 5.
Front Elevation of Pier.

Scale 1/280th

(Proceedings Inst. M. E. 1887)

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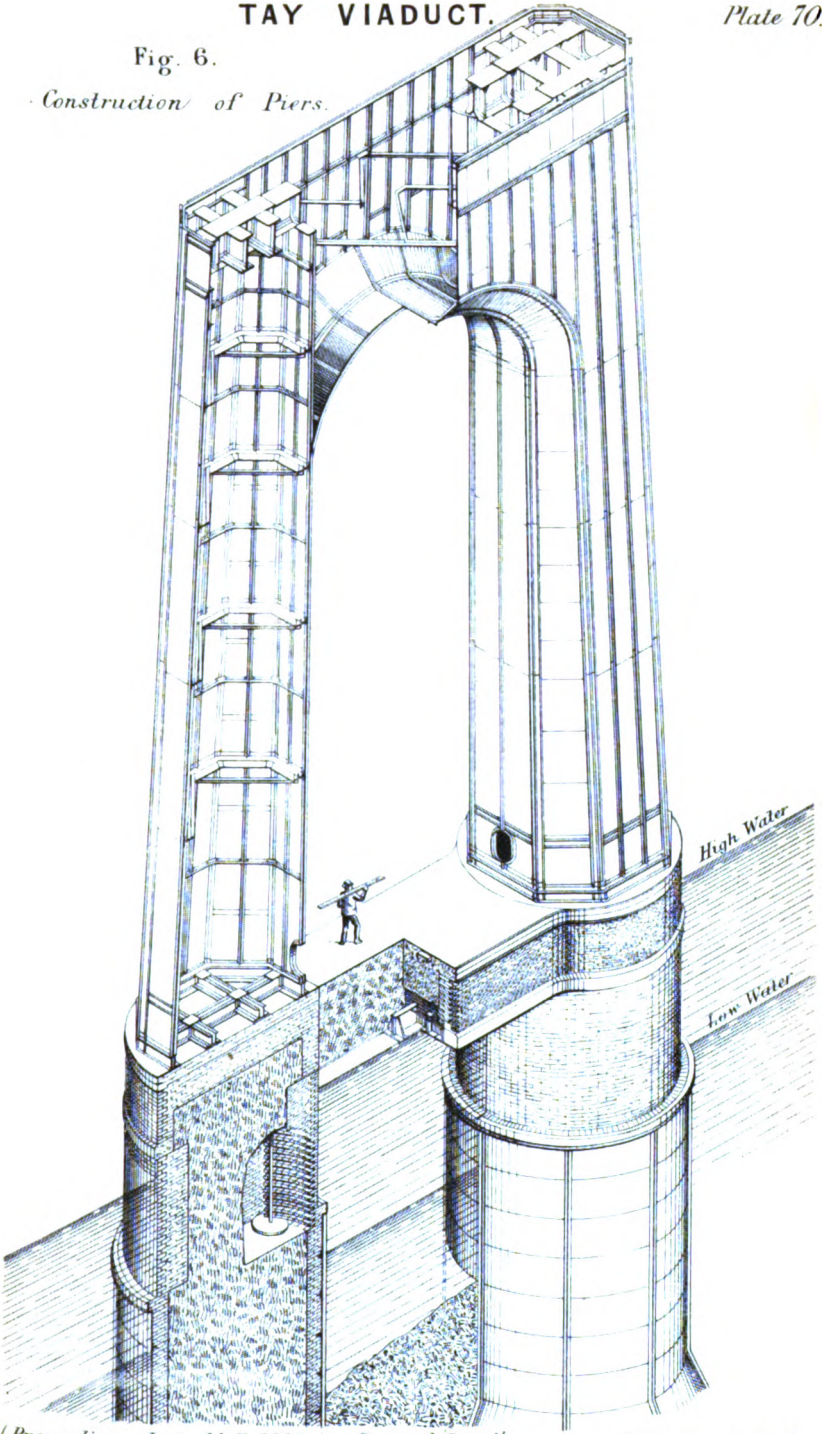
Fig. 6.

Construction of Piers.



(Proceedings Inst. M.E. 1887.) Scale 1/200th 16 feet per inch.

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TAY VIADUCT.

Pontoon for sinking Cylinders.

Plate 71.

Fig. 7. *Plan.*

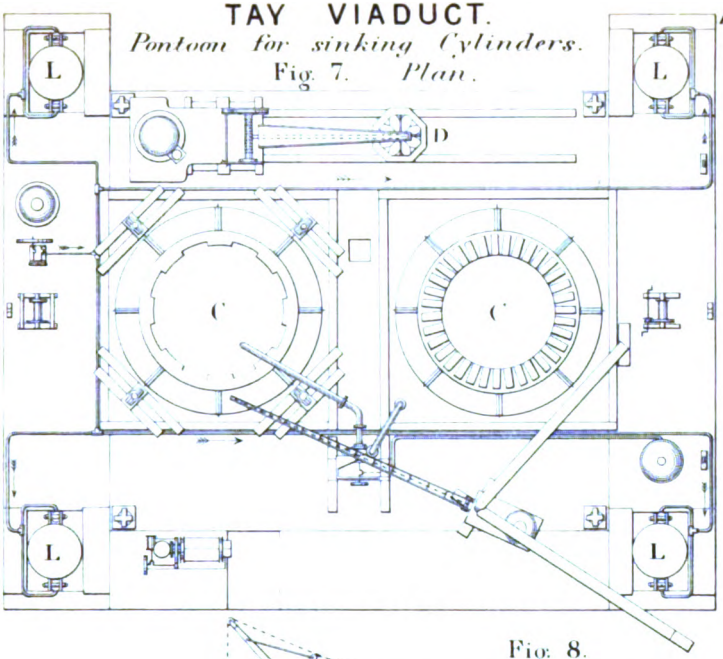
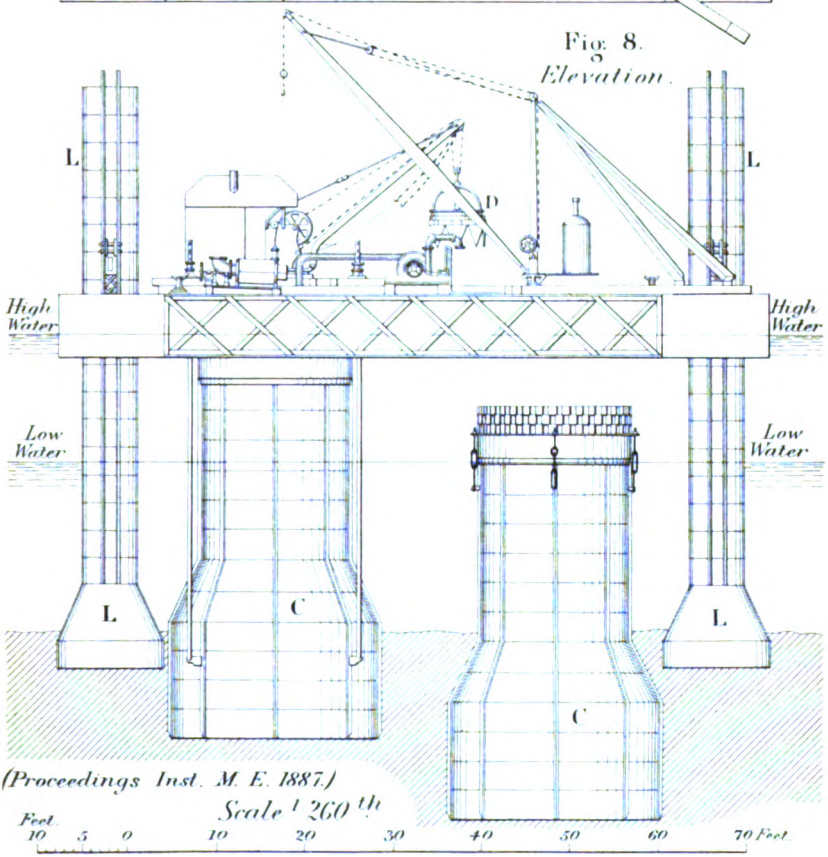


Fig. 8. *Elevation.*



(Proceedings Inst. M. E. 1887.)

Scale 1/260th

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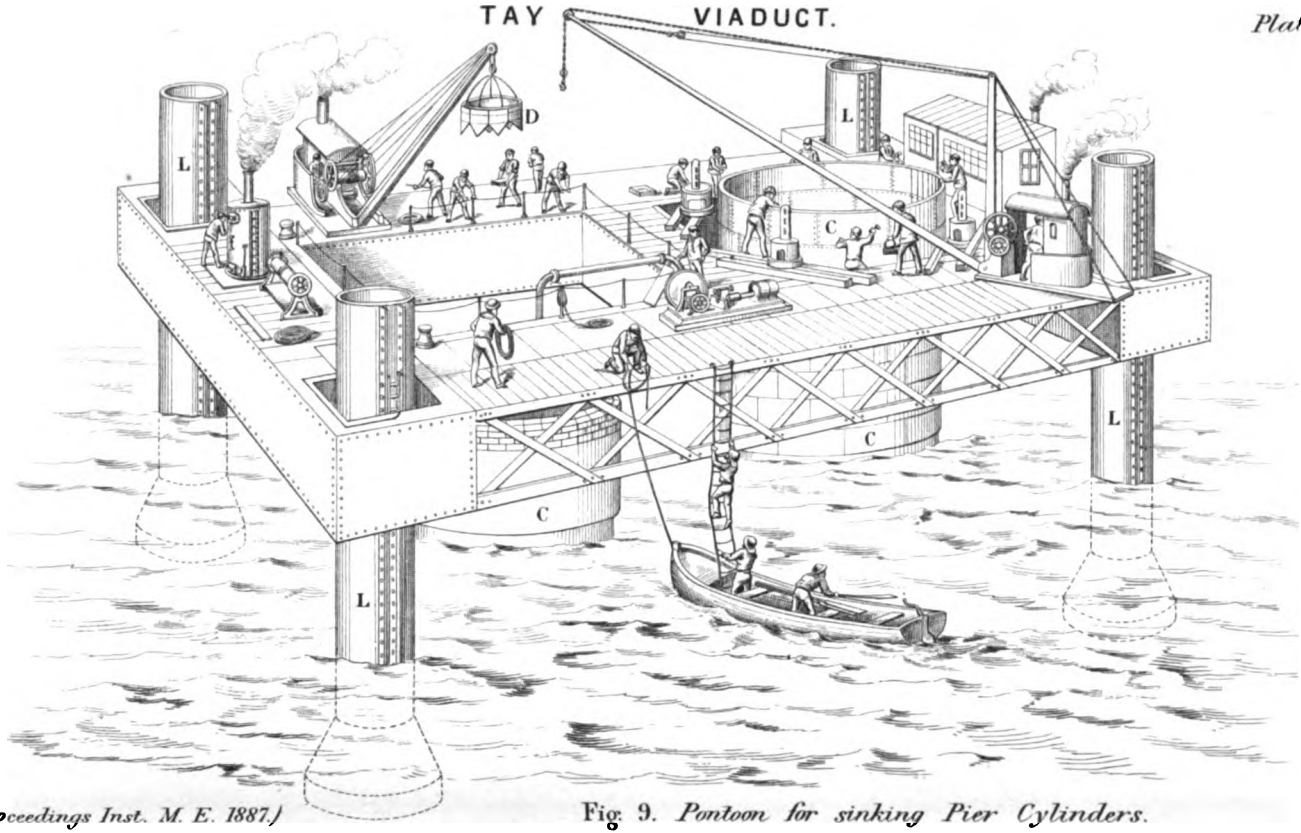

(Proceedings Inst. M. E. 1887.)

Fig. 9. *Pontoon for sinking Pier Cylinders.*

Plate 72.

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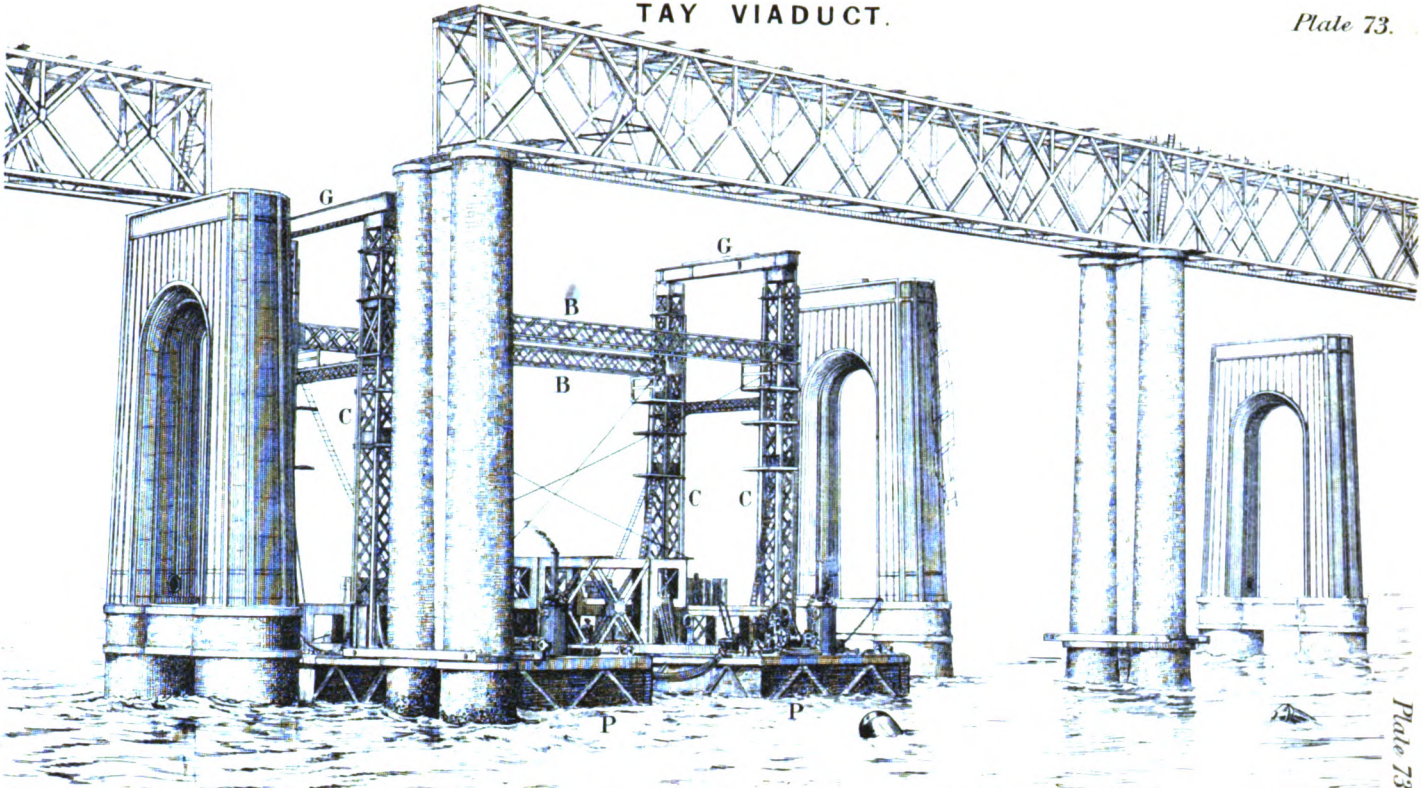

(Proceedings Inst. M.E. 1887.)

Fig 10. *Transferring Girders from Old to New Viaduct.*

Plate 73.

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TAY VIADUCT.

Fig. 11. *Running out New Girders on roadway formed by Old Girders.*

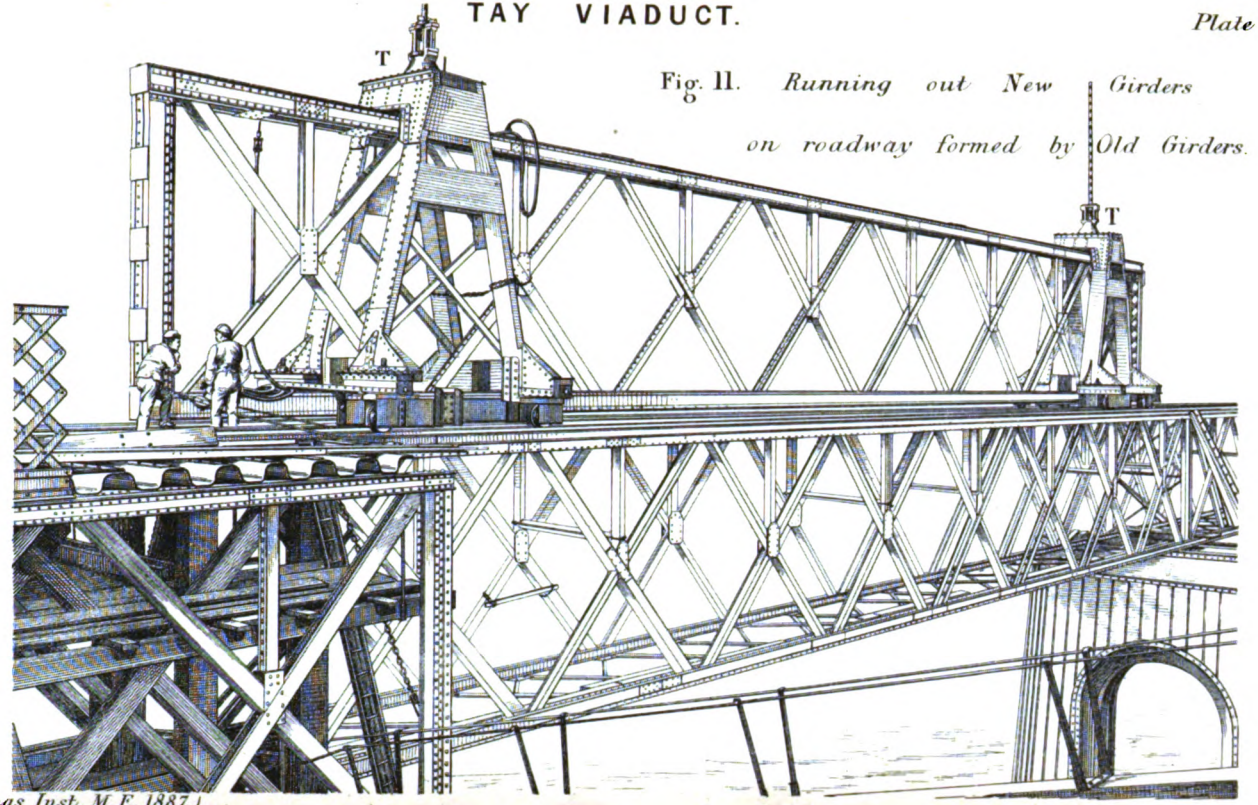

Plate 74.

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DREDGING CLYDE ESTUARY.

Fig. 1. *Plan of Lower Estuary of Clyde.*

Scale 1/43,200th

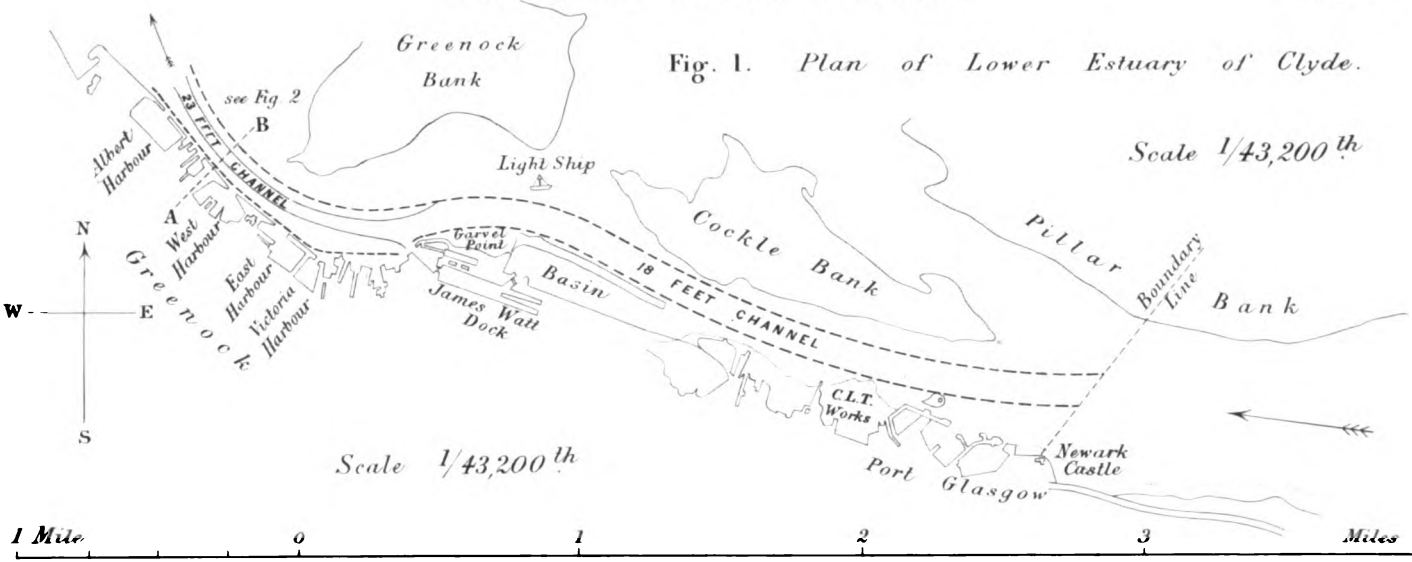
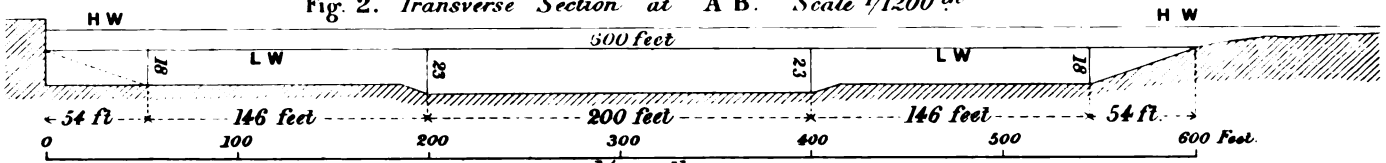


Fig. 2. *Transverse Section at A B. Scale 1/1200th*



(Proceedings Inst. M.E. 1887.)

Scale 1/1200th = 100 feet per inch.

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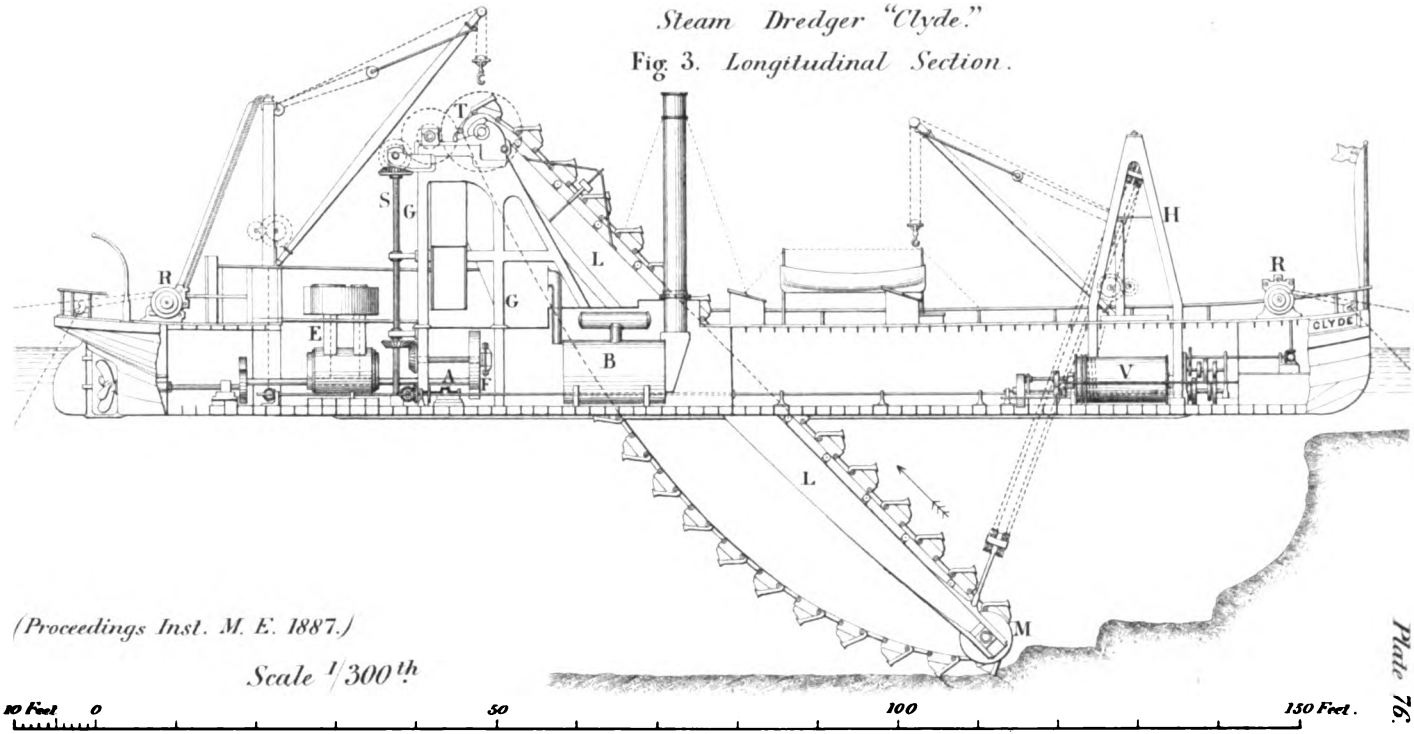
DREDGING CLYDE ESTUARY.

Steam Dredger "Clyde."

Fig. 3. *Longitudinal Section.*



(Proceedings Inst. M. E. 1887.)

Scale 1/300th

Plate 76.

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DREDGING CLYDE ESTUARY.

Steam Dredger "Clyde". Fig. 4. *Plan.*

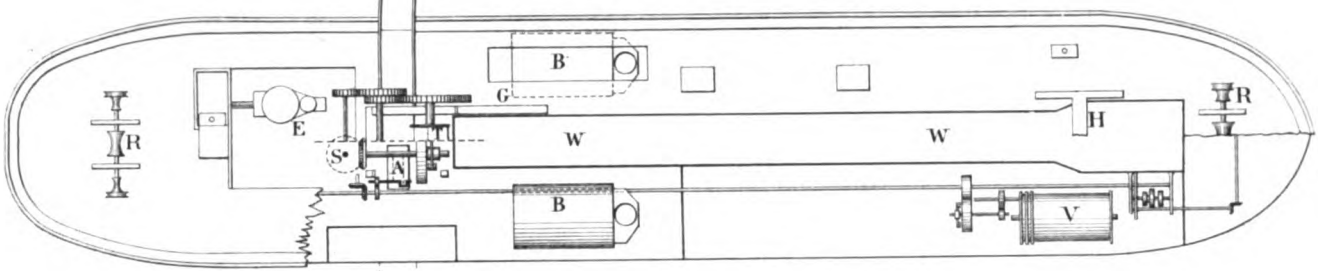


Fig. 5.

Transverse Section at Shoots.

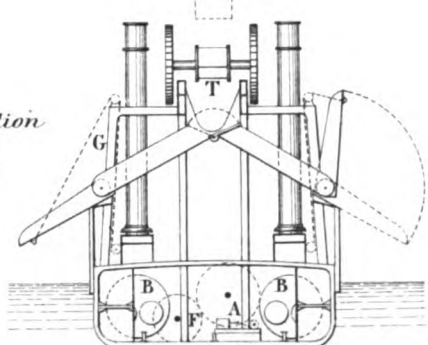
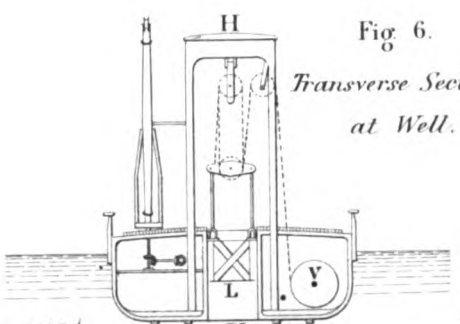


Fig. 6.

Transverse Section at Well.



Scale 1/300th

(Proceedings Inst. M. E. 1887.)

10 Feet 0 50 100 150 Feet.

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DREDGING CLYDE ESTUARY.

Hopper Barges
"Cloch," "Cumbrae," and "Toward."
Scale 1/300th

Fig. 7. *Transverse Section through Hopper.*

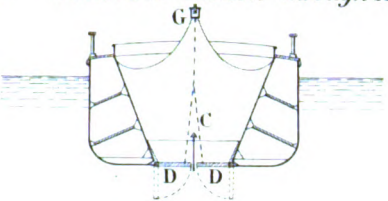


Fig. 8. *Longitudinal Section.*

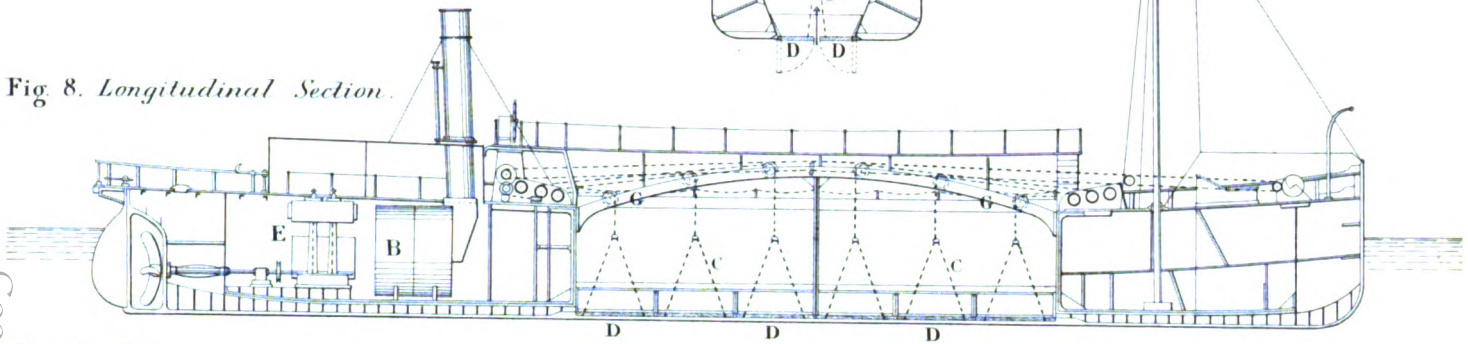
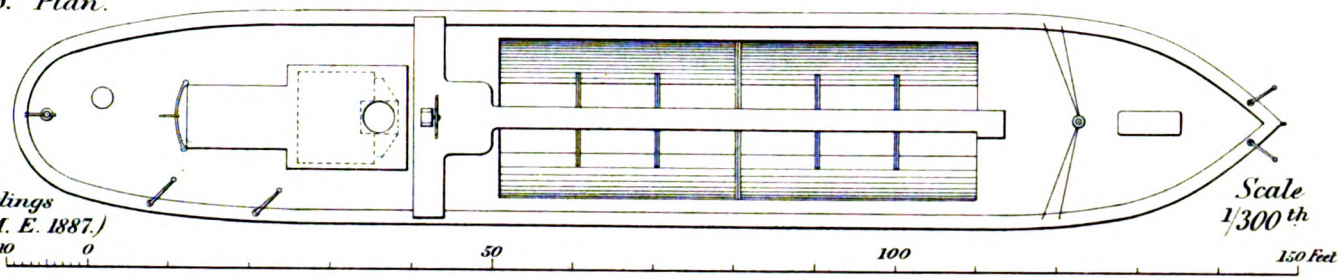


Fig. 9. *Plan.*



(*Proceedings Inst. M. E. 1887.*)

Plate 78.

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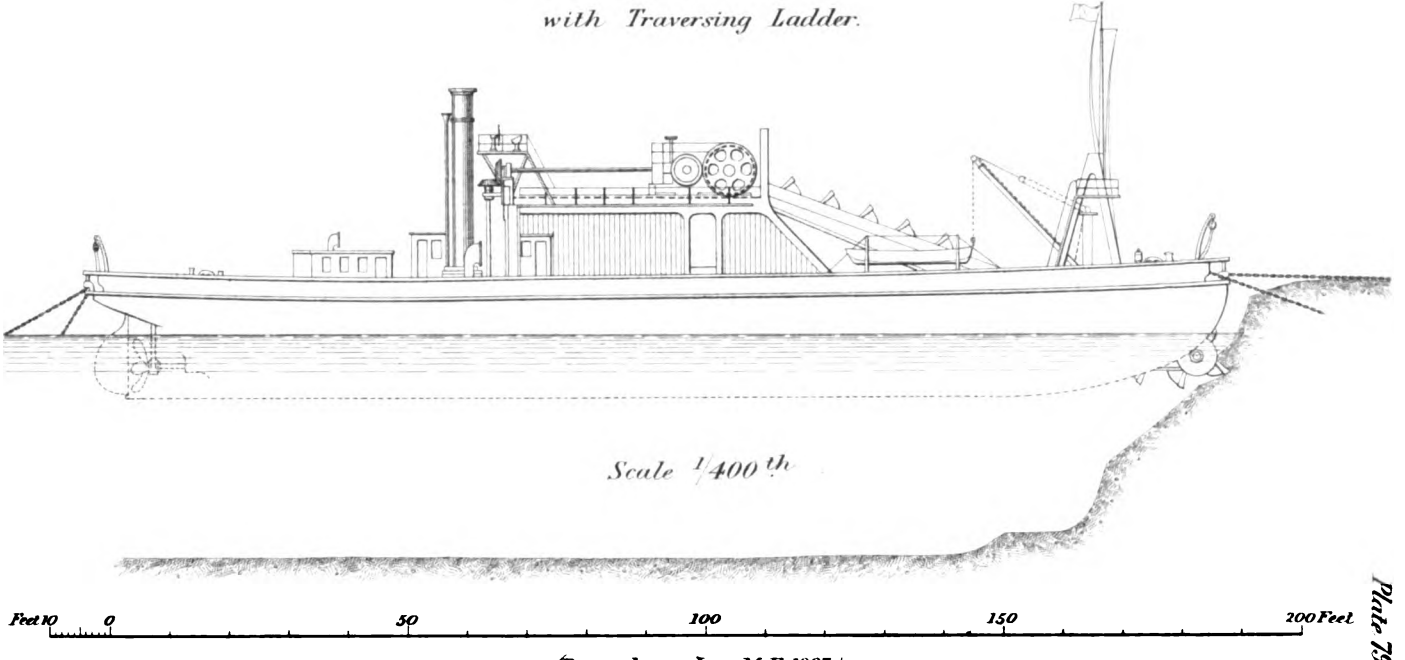
DREDGING BELFAST LOUGH.

850 – *Ton Hopper Dredger*

with Traversing Ladder.



(Proceedings Inst. M.E. 1887.)

Plate 79.

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SHIP WAVES.

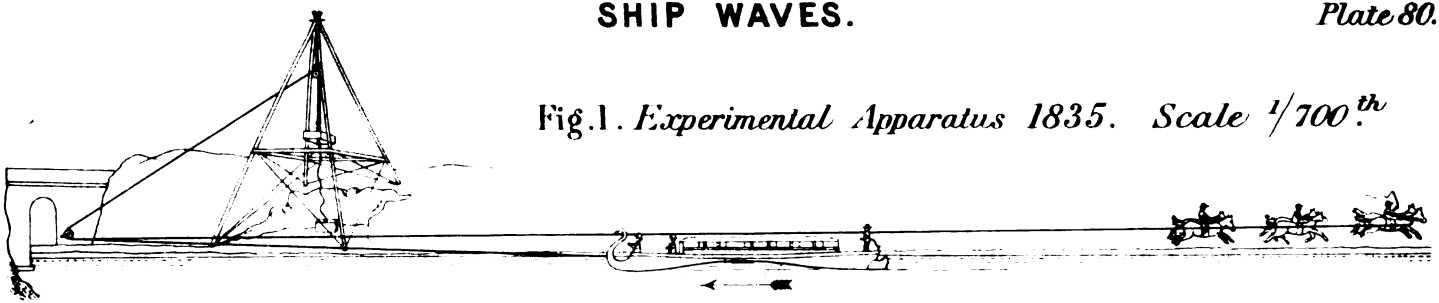

Fig. 1. *Experimental Apparatus 1835. Scale 1/700th.*

Fig. 2. *Boat behind the wave.*

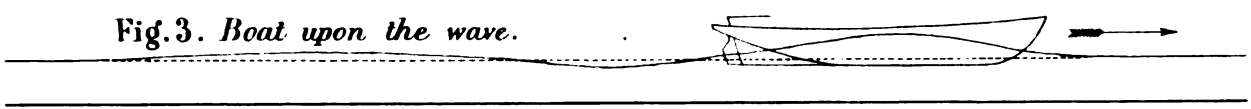

Fig. 3. *Boat upon the wave.*

Section of Waves in wake of 83 feet Launch.

Vertical Scale 1/48th.
4 feet per inch.

Horizontal Scale 1/960th.
80 feet per inch.

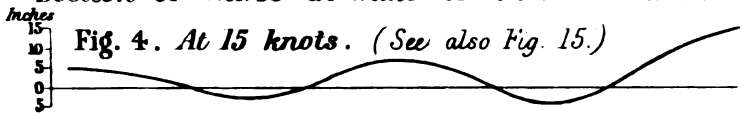

Fig. 4. *At 15 knots.* (*See also Fig. 15.*)

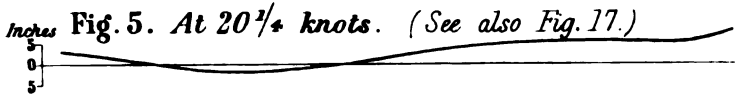

Fig. 5. *At 20¼ knots.* (*See also Fig. 17.*)

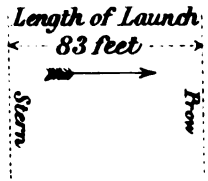

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Fig. 6. *Wave Profile, H.M.S. "Curlew."*

Length of Ship 195 *feet.*
Breadth 28 *feet.*
Displacement 780 *tons.*

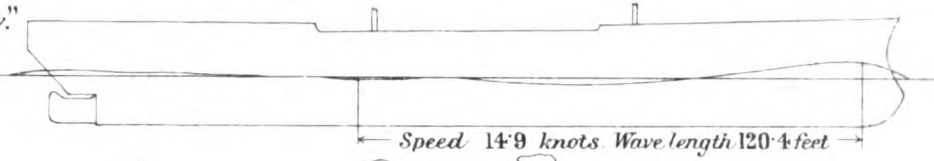


Fig. 7. *Wave Profiles.*

Length of Ship 250 *feet.*
Breadth 37 *feet.*
Displacement 2000 *tons.*

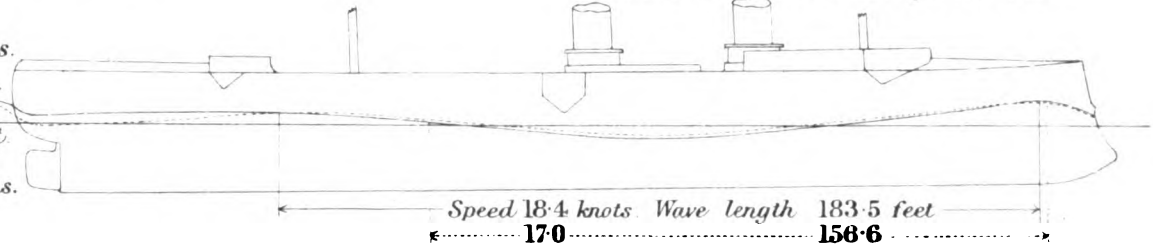
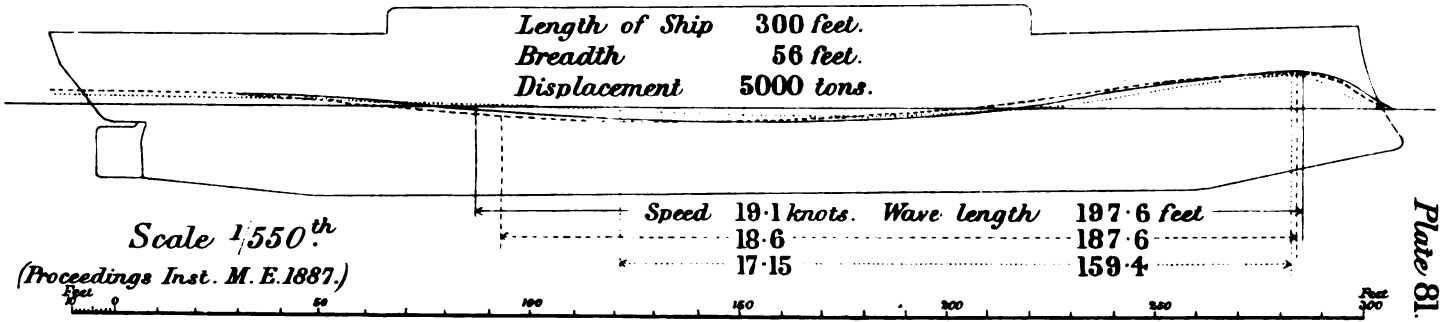


Fig. 8. *Wave Profiles, H.M.S. "Orlando."*



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SHIP WAVES.

Wave Pattern.

Fig. 9.

Plan of Curves of Echelon Waves.

$$x = \sqrt{\frac{1 \pm w}{(3 \pm w)^3}}$$

$$\frac{y}{x} = \sqrt{\frac{1}{8}(1 - w^2)}$$

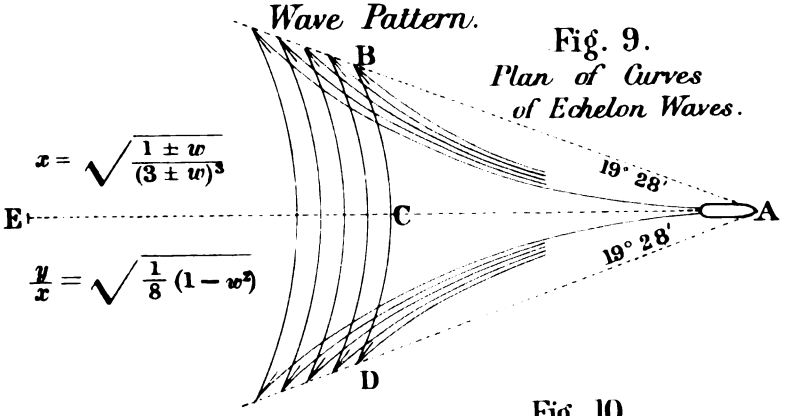


Fig. 11.

Perspective view of Model.

Fig. 10.

Plan of Model of Echelon Waves.

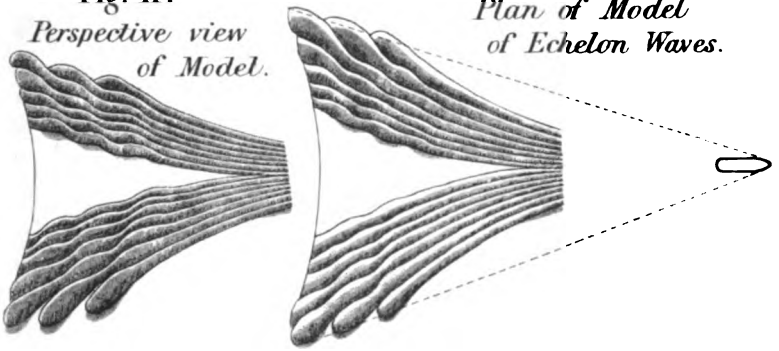
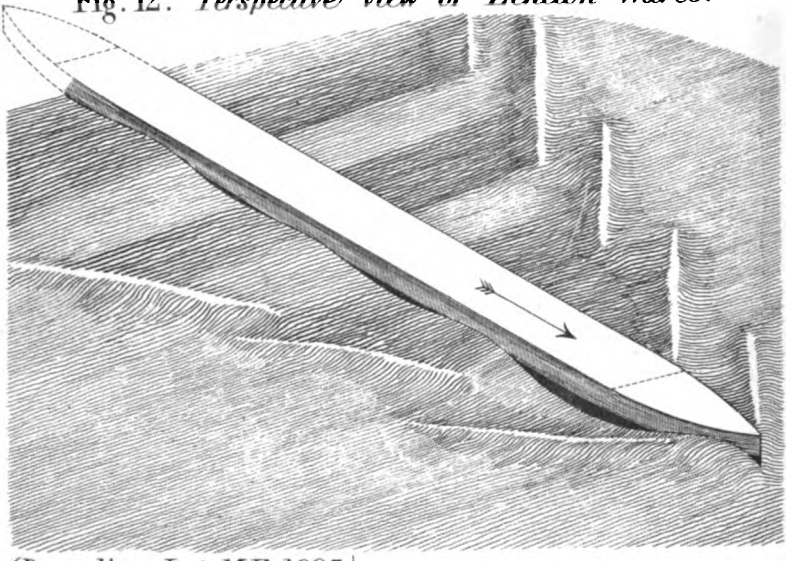


Fig. 12. *Perspective view of Echelon Waves.*



(Proceedings Inst. M.E. 1887.)

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Plan of Wave System made by 83 feet Launch at various speeds.

The positions of the Wave crests are indicated by the transverse shading; they were accurately measured for a distance of only about two and a half boat's lengths clear of the stern.

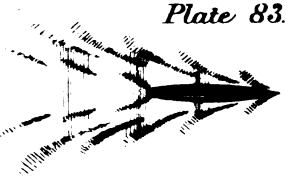

Fig. 13.
At 9 knots.

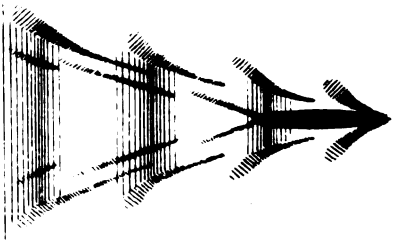

Fig. 14.
At 12 knots.

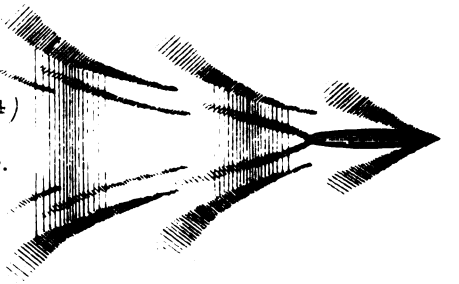

Fig. 15.
(See also Fig 4)
At 15 knots.

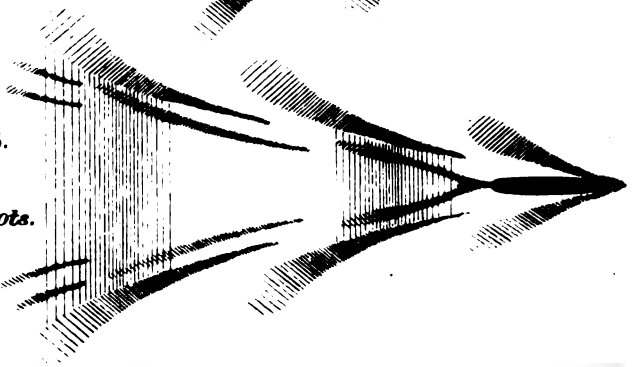

Fig. 16.
At 18 knots.

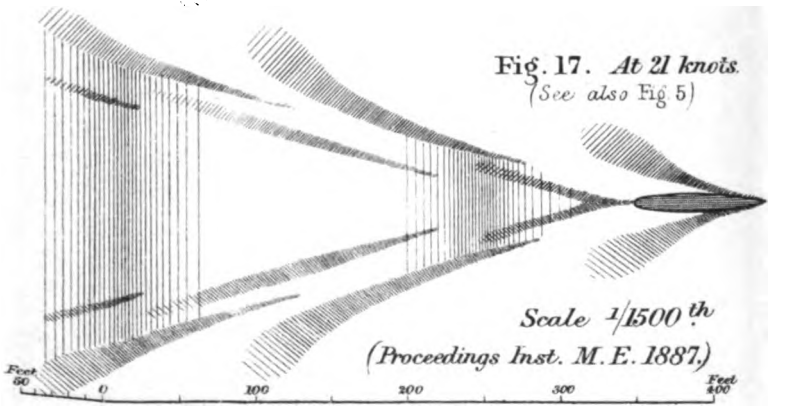

Fig. 17. *At 21 knots.*
(See also Fig 5)

Scale 1/1500th
(Proceedings Inst. M.E. 1887.)

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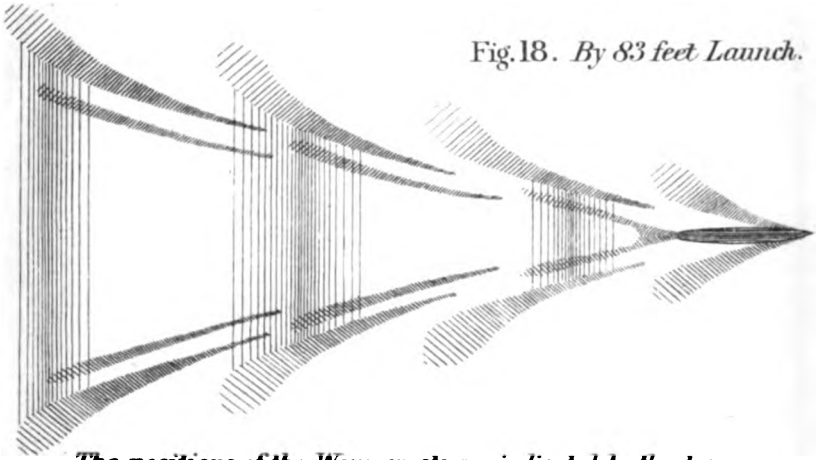
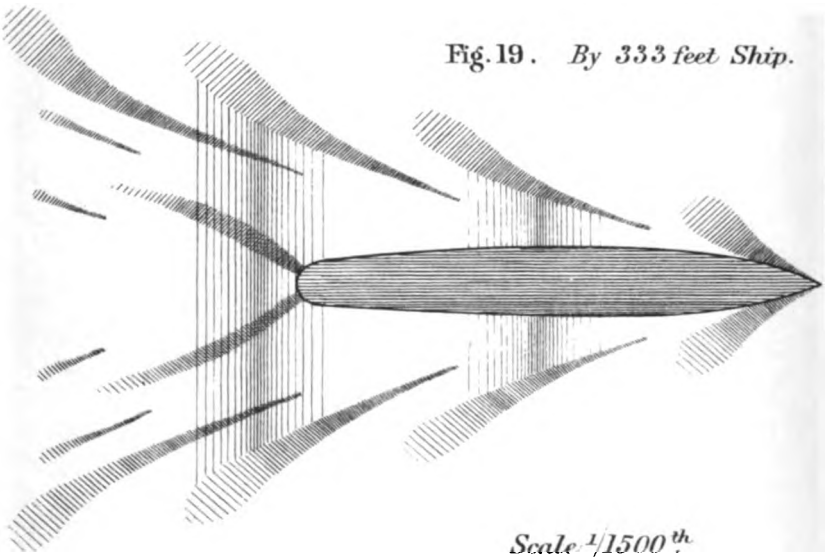
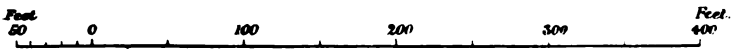
Plans of Wave Systems made by 83 feet Launch and 333 feet Ship at speed of 18 knots.



The positions of the Wave-crests are indicated by the transverse shading; they were accurately measured for a distance of only about two and a half boat's lengths clear of the stern.





(Proceedings Inst. M.E. 1887.)

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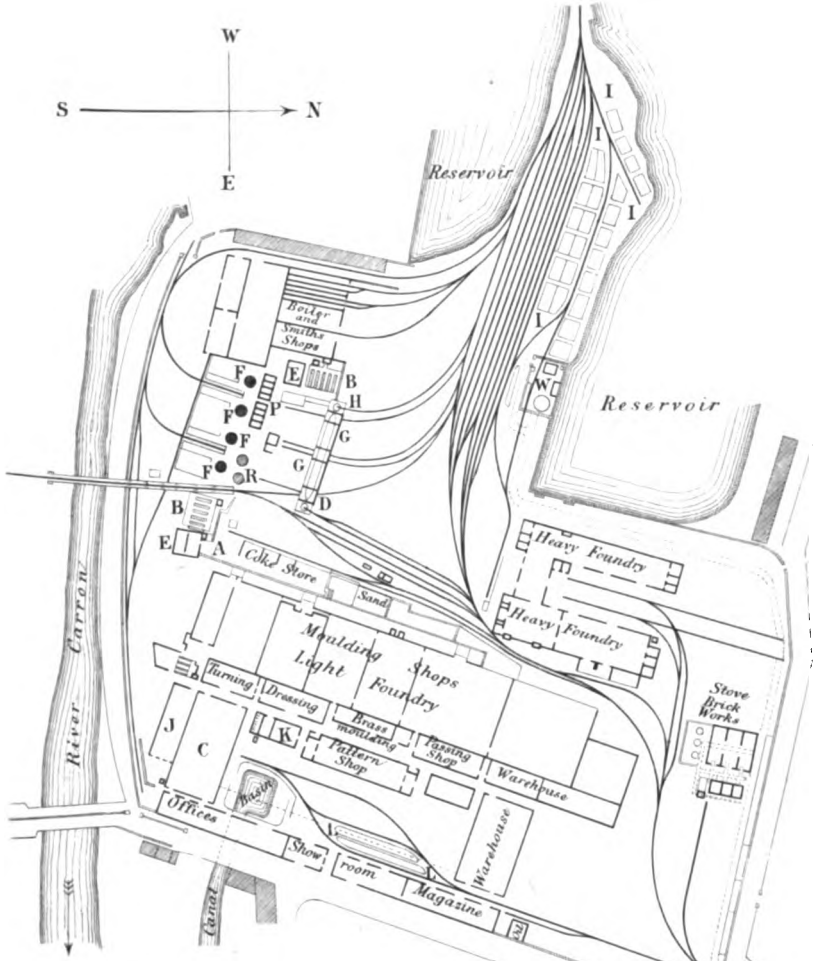
CARRON IRON WORKS.

Plate 85.



F	*Blast-Furnaces*		
P	*Hot-Blast Pipe Stoves*		
R	*Regenerative Hot-Blast Stoves*		
G	*Gantry*	I	*Pig Iron stocking ground*
H	*Hydraulic Hoist*	W	*Gas work*
D	*Hydraulic Drop*	J	*Grinding shop*
E	*Blowing Engines*	C	*Fitting shops*
B	*Boilers*	K	*Berlin blacking shop*
A	*Hydraulic Engines &c*	L	*Loading platform*

0 — 500 — 1000 Feet.

0 — 1/8 Mile — Mile 1/4

(Proceedings Inst. M.E. 1887.)

Scale 1/4000th = 333 feet per inch.

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EDINBURGH WATERWORKS. *Plate 86.*

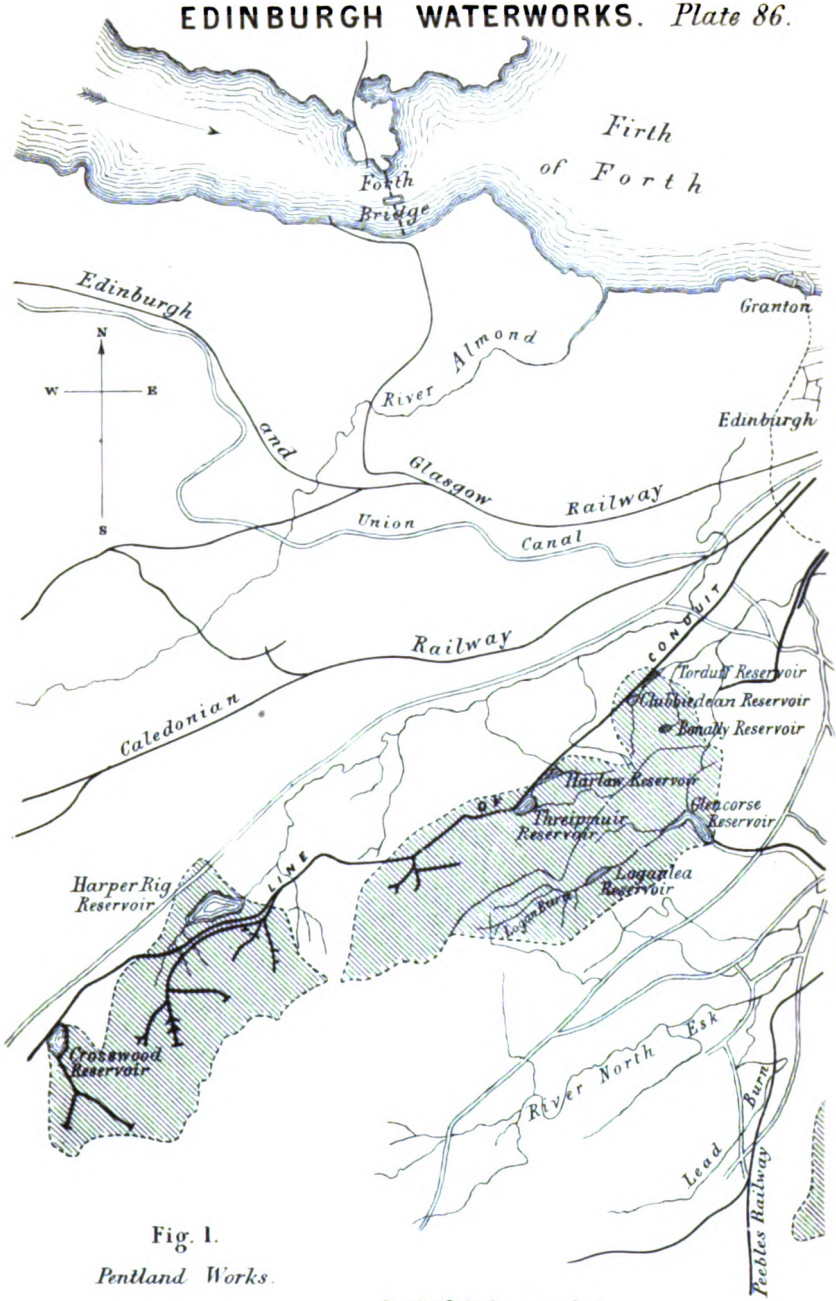

Fig. 1.

Pentland Works.

Scale 3 Miles to an Inch.

Mile 1 — 0 — 5 — Miles 10

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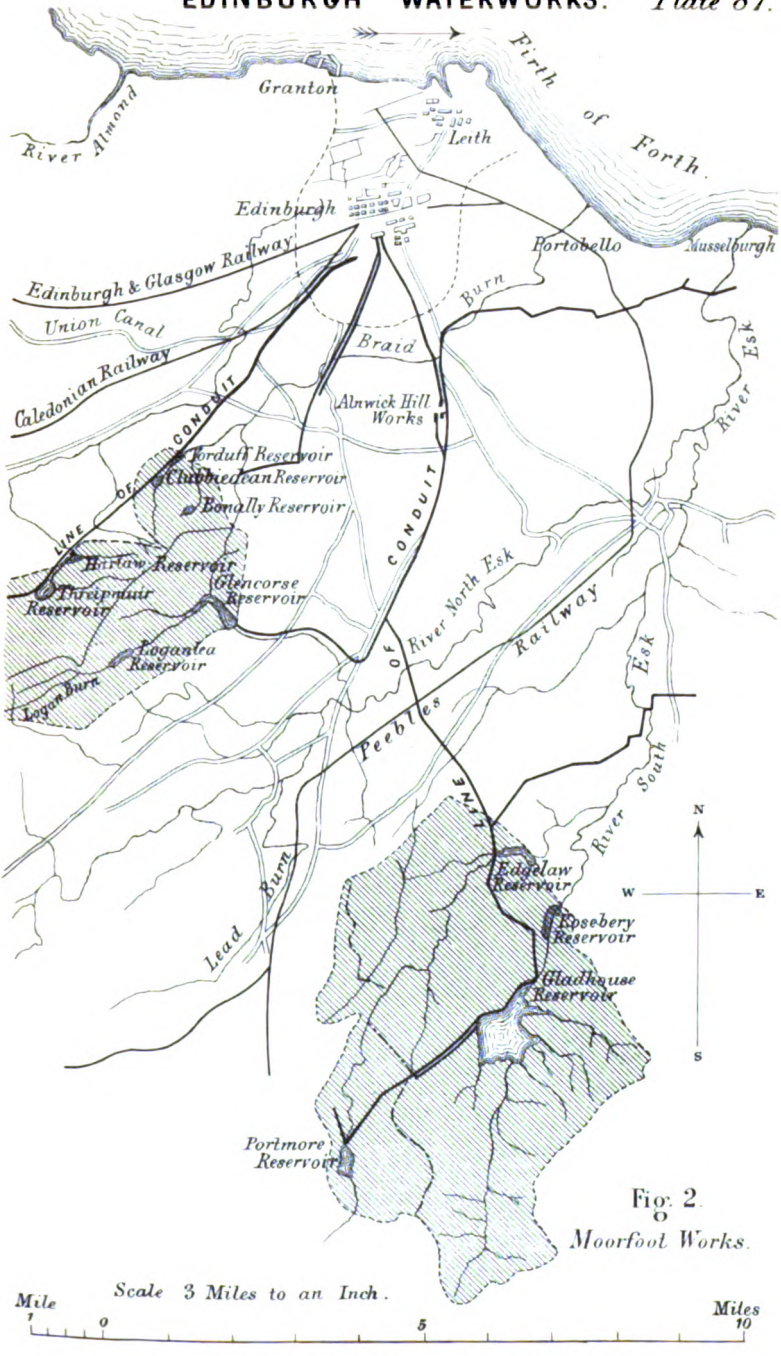

Fig. 2.
Moorfoot Works.

(Proceedings Inst. M. E. 1887.)

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Fig. 1. *Indicator Diagrams taken 8 Nov. 1886. Steam-pipe Jacketed.*

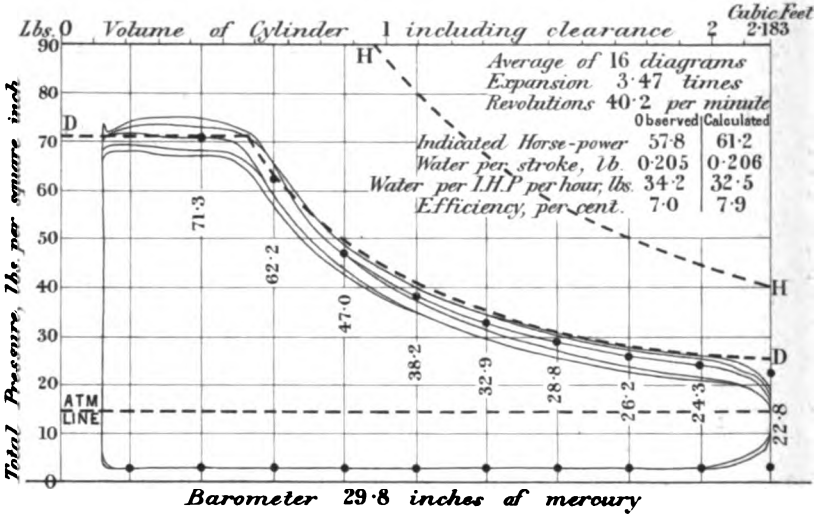

Fig. 2 *Distribution of Heat.*

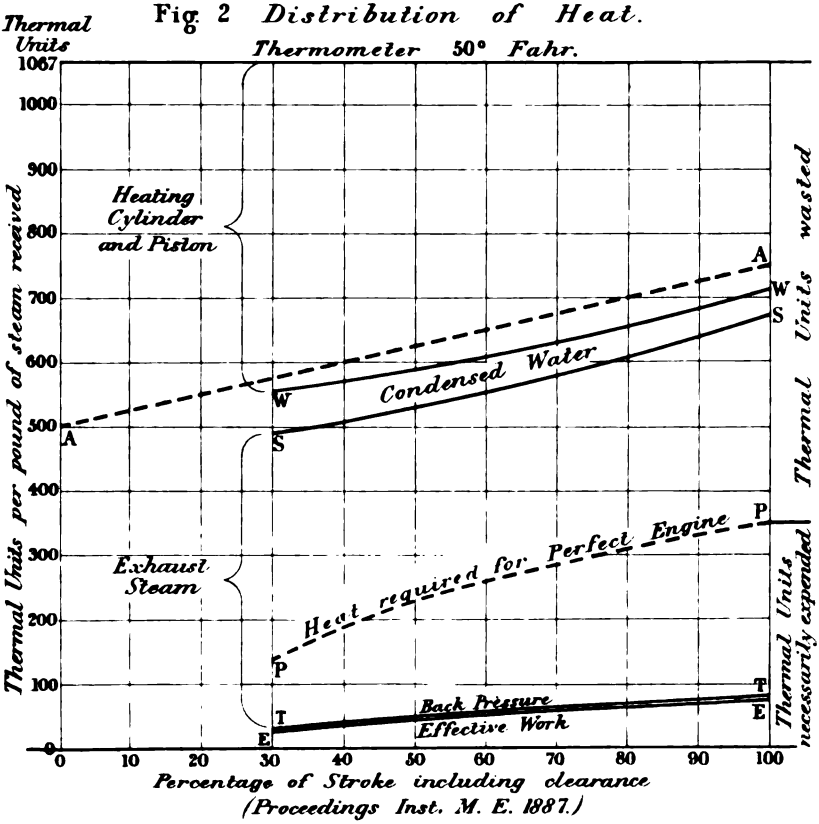

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Fig. 3. *Indicator Diagrams taken 4 Nov. 1886.*

Steam-pipe not Jacketed.

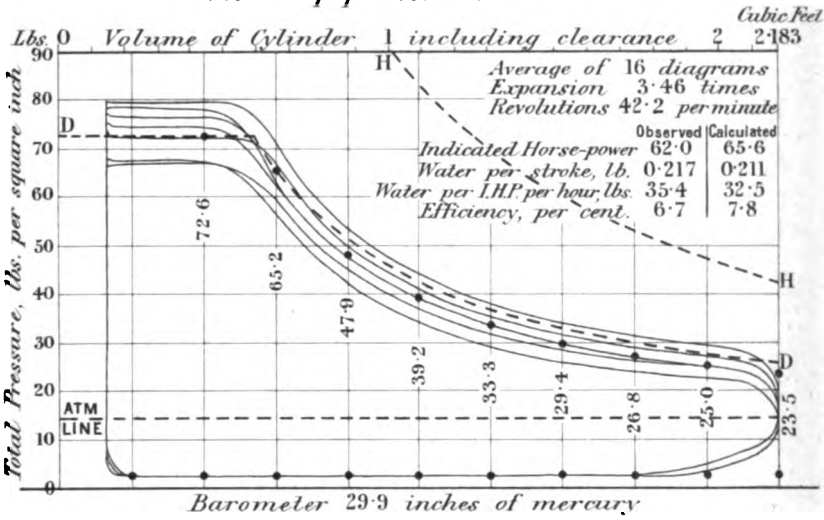

Fig. 4. *Distribution of Heat.*

Thermometer 57° Fahr.

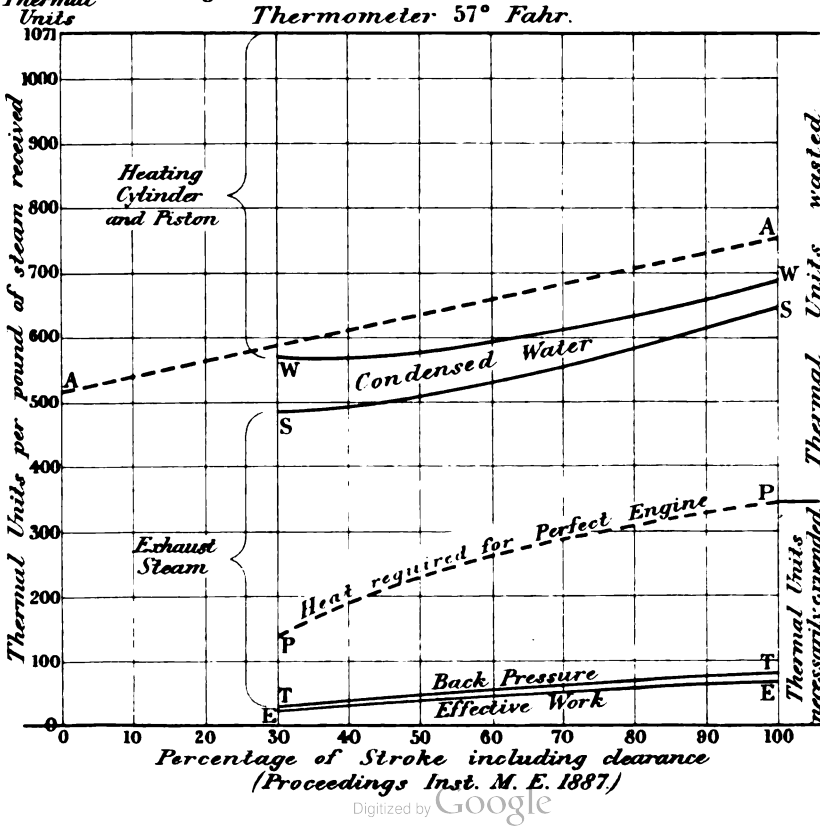

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Fig. 5. *Indicator Diagrams taken 2 Dec. 1886.*
Steam-pipe Jacketed.

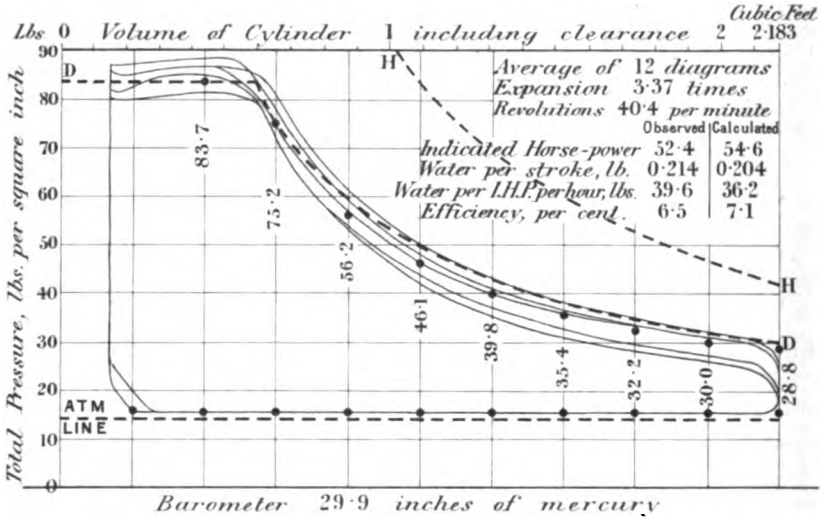
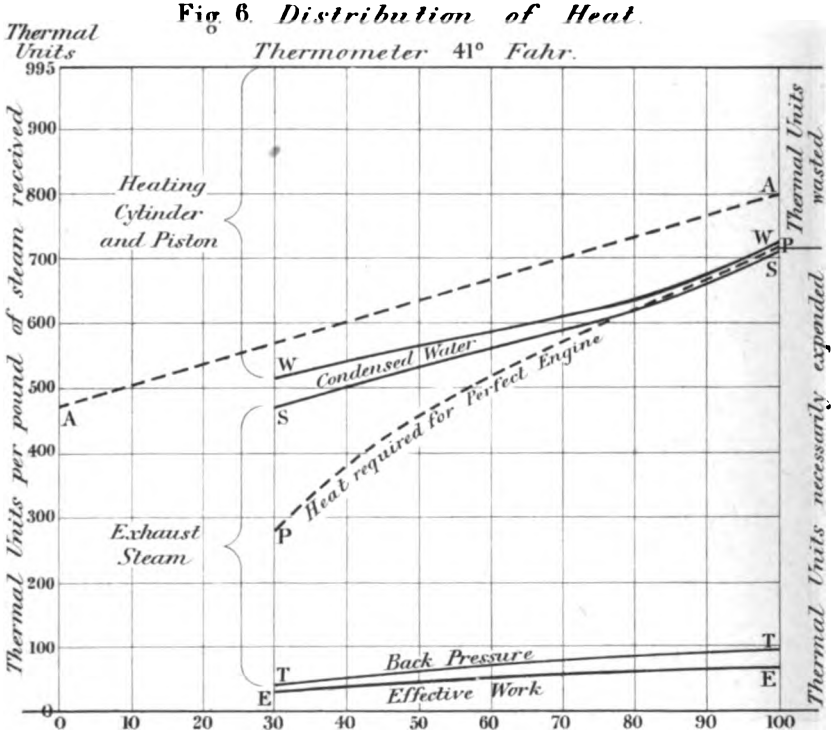


Fig. 6. *Distribution of Heat.*



Percentage of Stroke including clearance
(Proceedings Inst. M. E. 1887.)

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Fig. 7. *Indicator Diagrams taken 2 Dec. 1886.*
Steam-pipe not Jacketed.

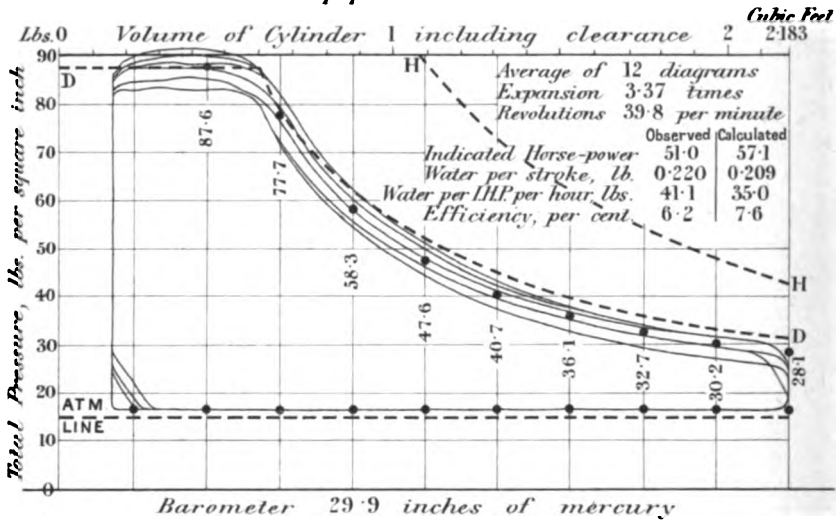
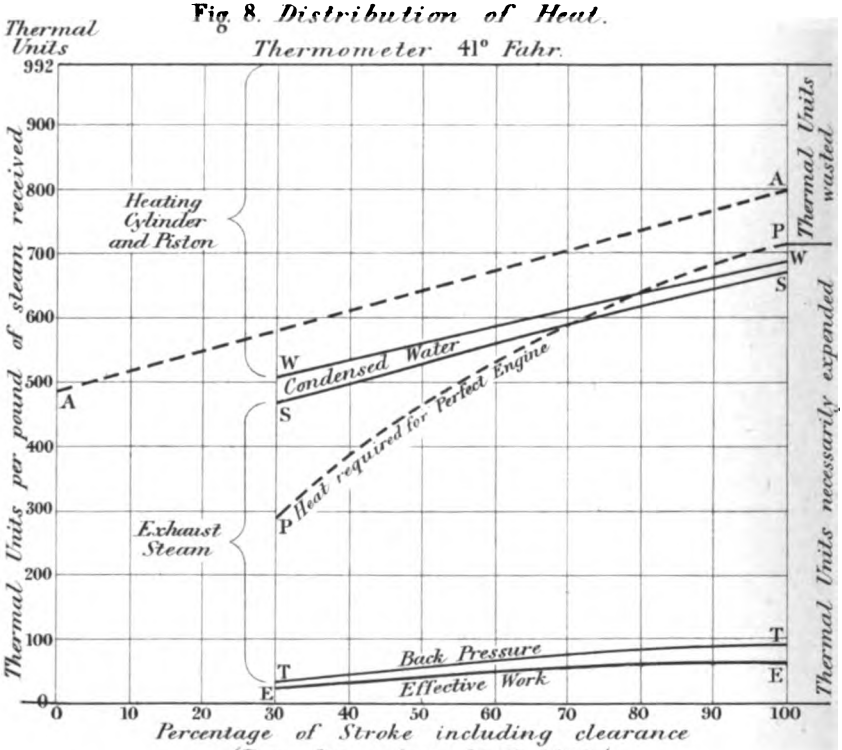


Fig. 8. *Distribution of Heat.*



(Proceedings Inst. M. E. 1887.)

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Fig. 9. *Indicator Diagrams taken 6 Dec. 1886.*

Steam-pipe Jacketed.

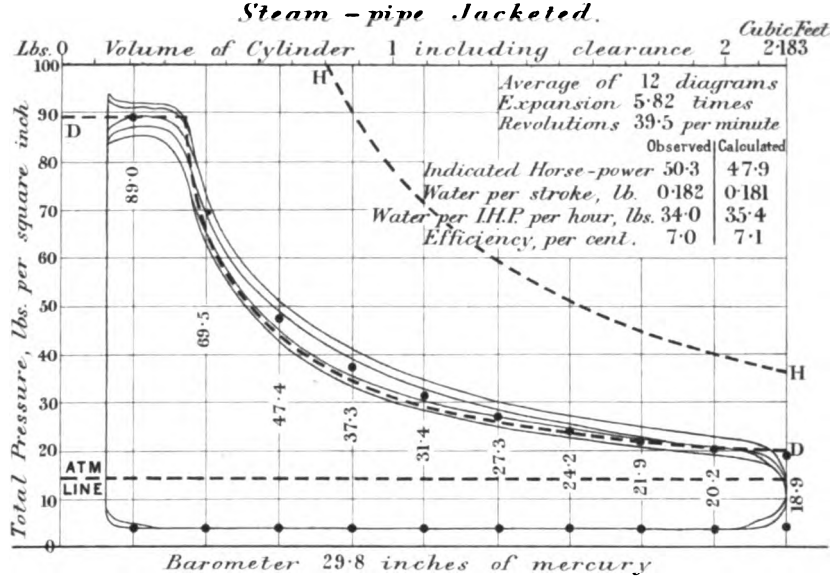
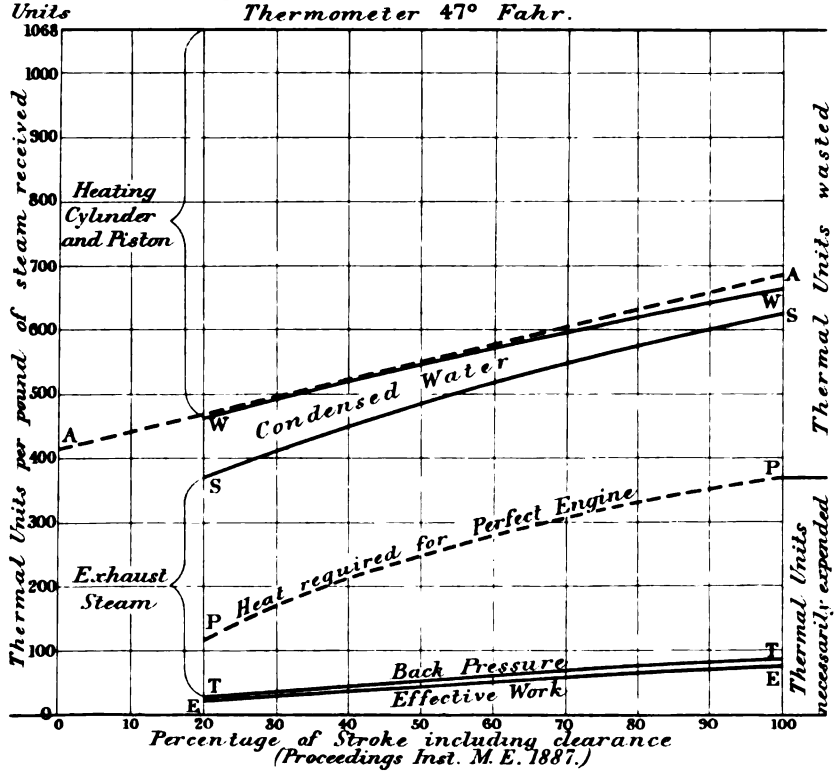


Fig. 10. *Distribution of Heat.*

Thermometer 47° Fahr.



(Proceedings Inst. M. E. 1887.)

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Fig 11. *Indicator Diagrams taken 11 Dec. 1886.*
Steam-pipe Jacketed.

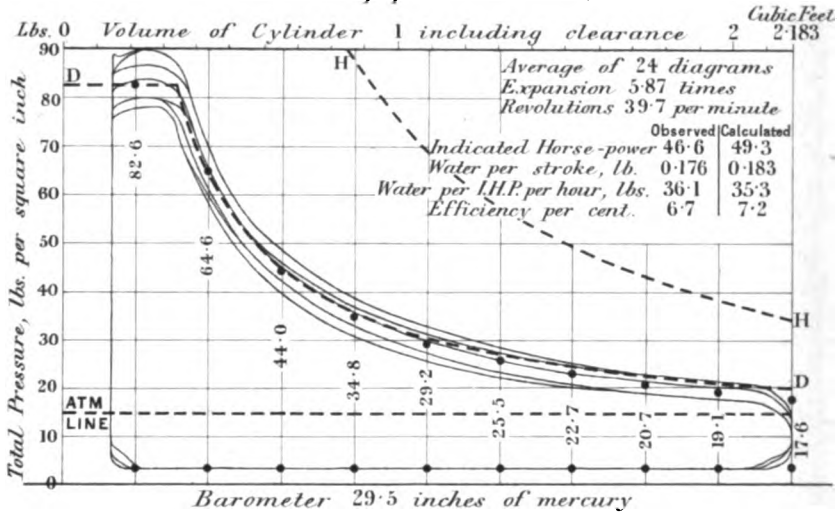
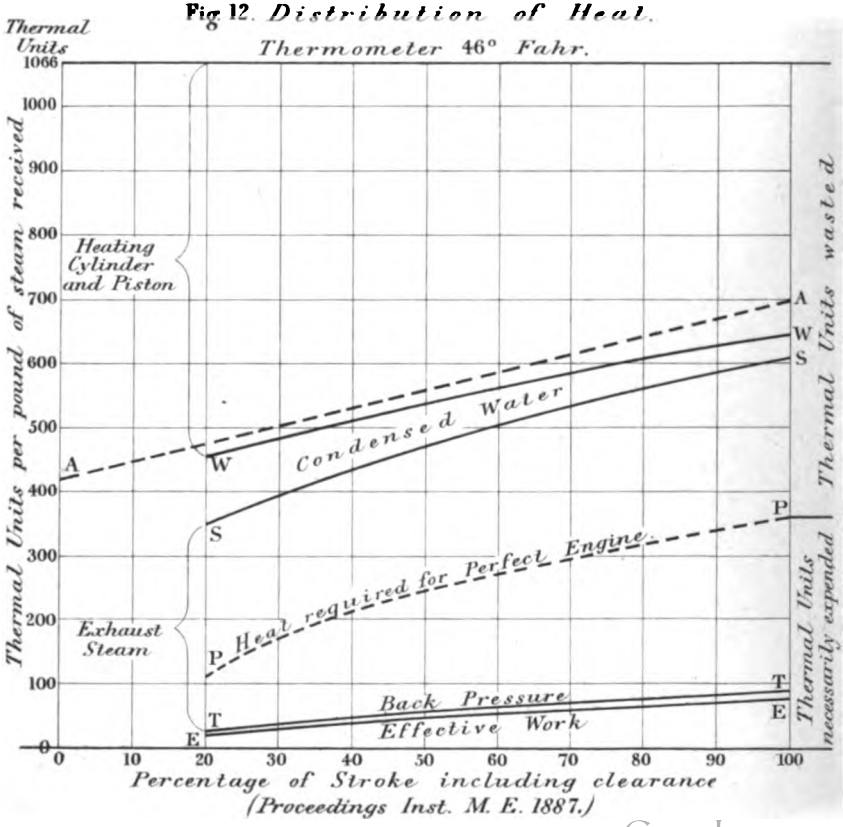


Fig 12. *Distribution of Heat.*



(Proceedings Inst. M. E. 1887.)

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Fig. 13. *Indicator Diagrams taken 1 Nov. 1886.*

Steam-pipe Jacketed.

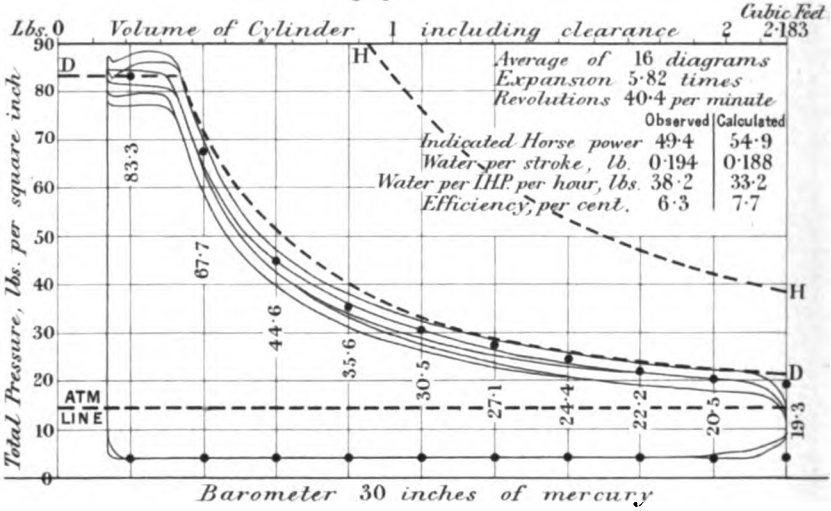
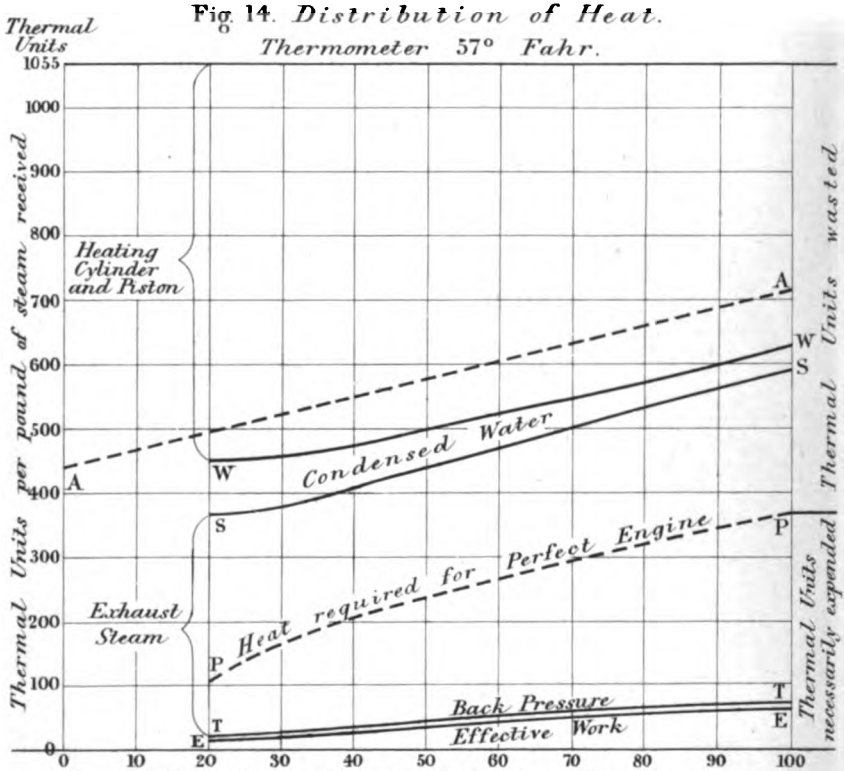


Fig. 14. *Distribution of Heat.*



(*Proceedings Inst. M. E. 1887.*)

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Fig. 15. *Indicator Diagrams taken 19 Nov. 1886.*
Steam-pipe not Jacketed.

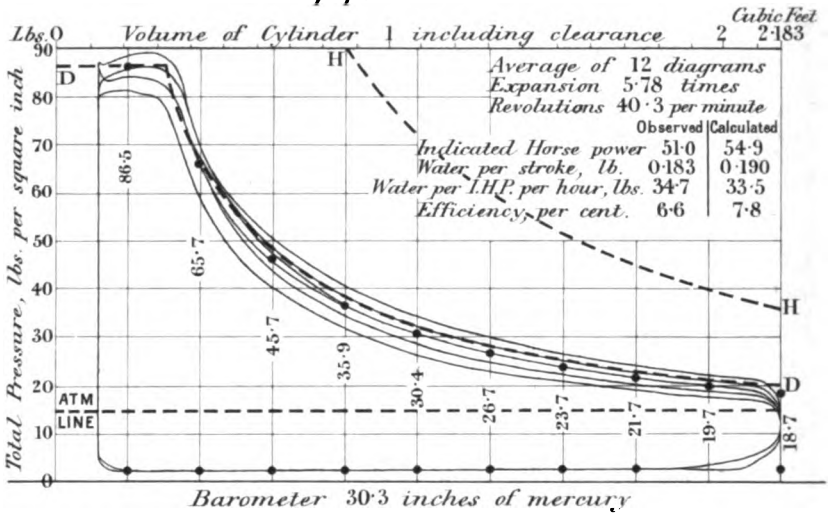
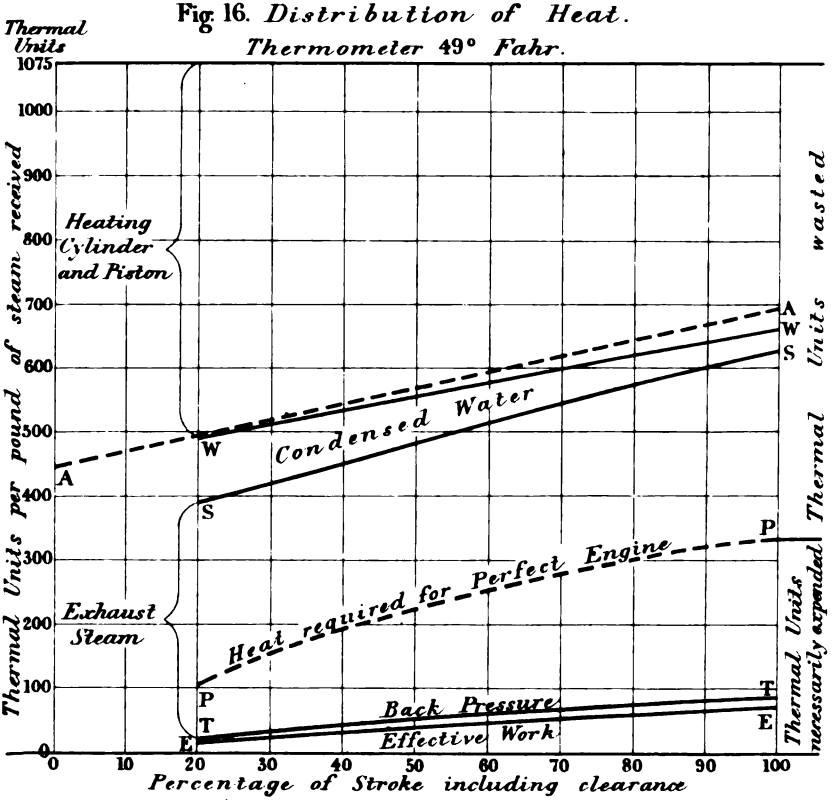


Fig. 16. *Distribution of Heat.*



(Proceedings Inst. M. E. 1887.)

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Fig. 17. *Indicator Diagrams taken 11 Dec. 1886.*
Steam-pipe not Jacketed.

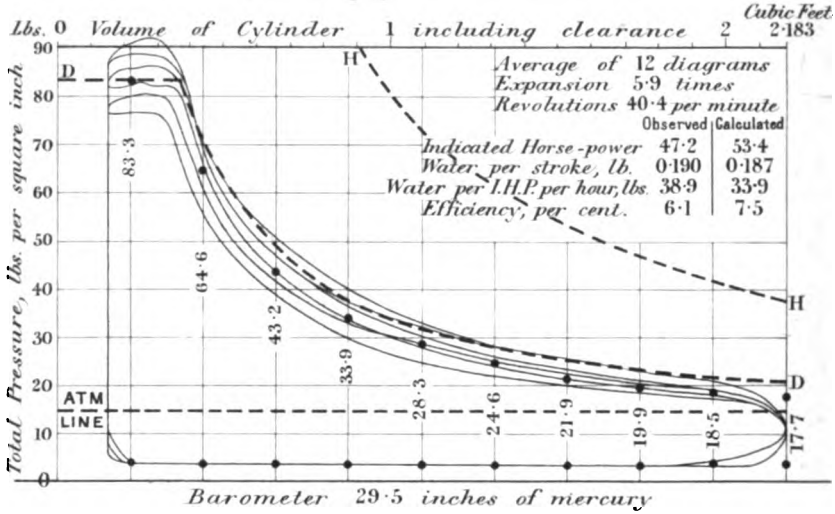
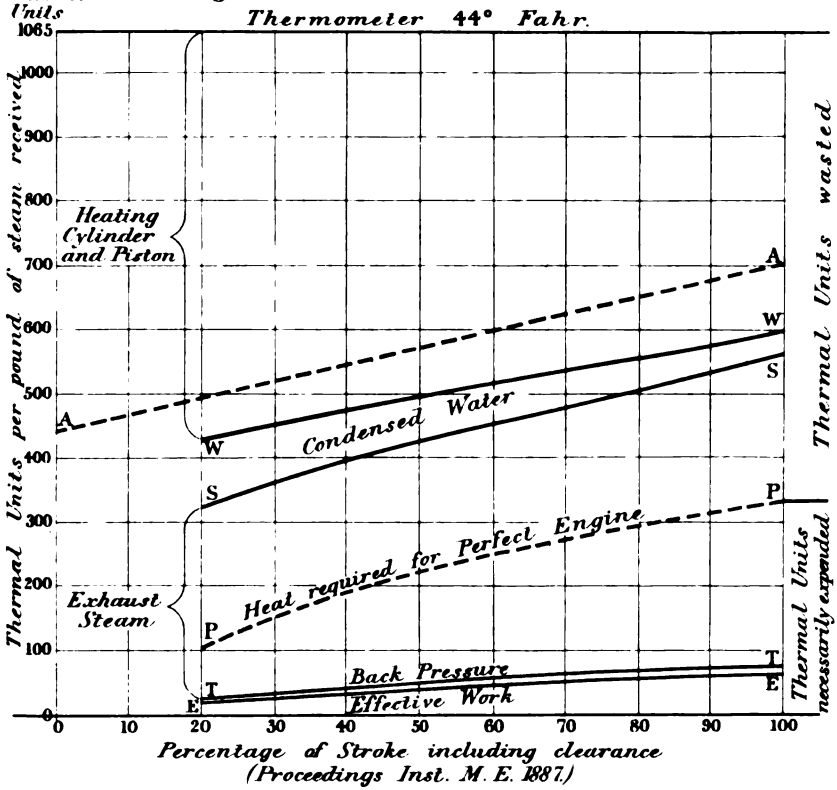


Fig. 18. *Distribution of Heat.*



(Proceedings Inst. M. E. 1887.)

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Fig. 19. *Indicator Diagrams taken 29 Nov. 1886.*

Steam-pipe Jacketed.

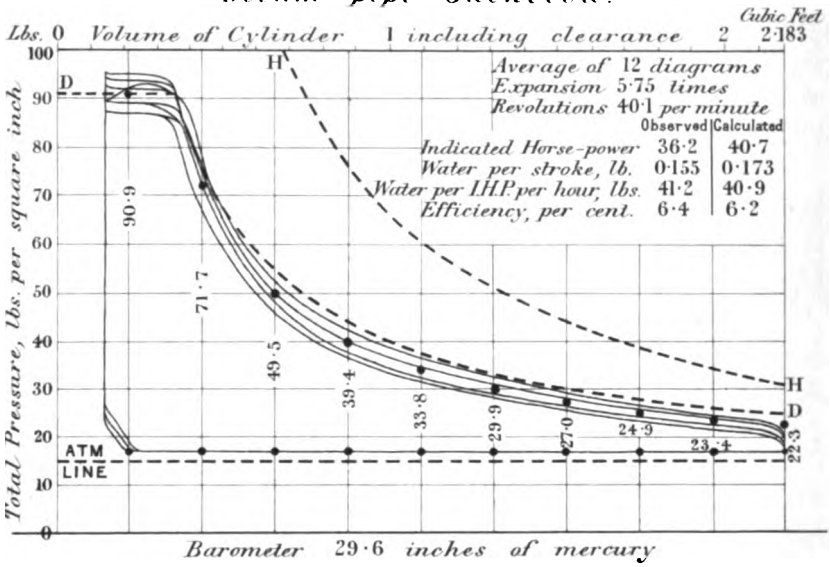
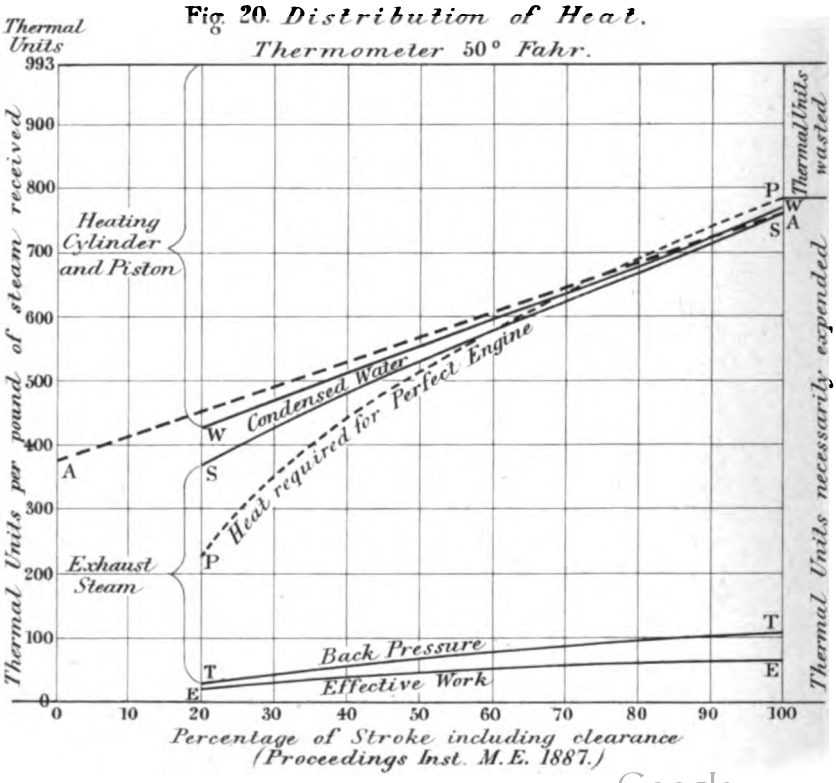


Fig. 20. *Distribution of Heat.*



(Proceedings Inst. M.E. 1887.)

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Fig. 21. *Indicator Diagrams taken 26 Nov. 1886.*
Steam-pipe not Jacketed.

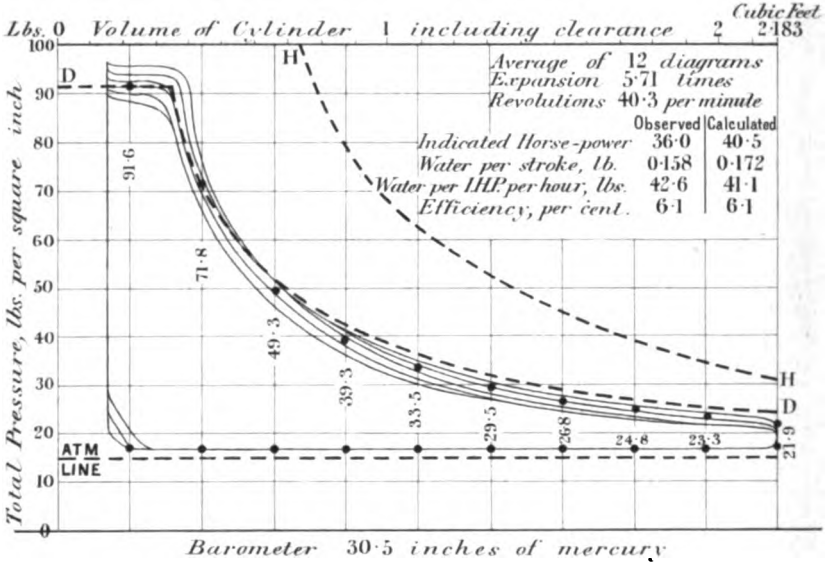

Fig. 22. *Distribution of Heat.*

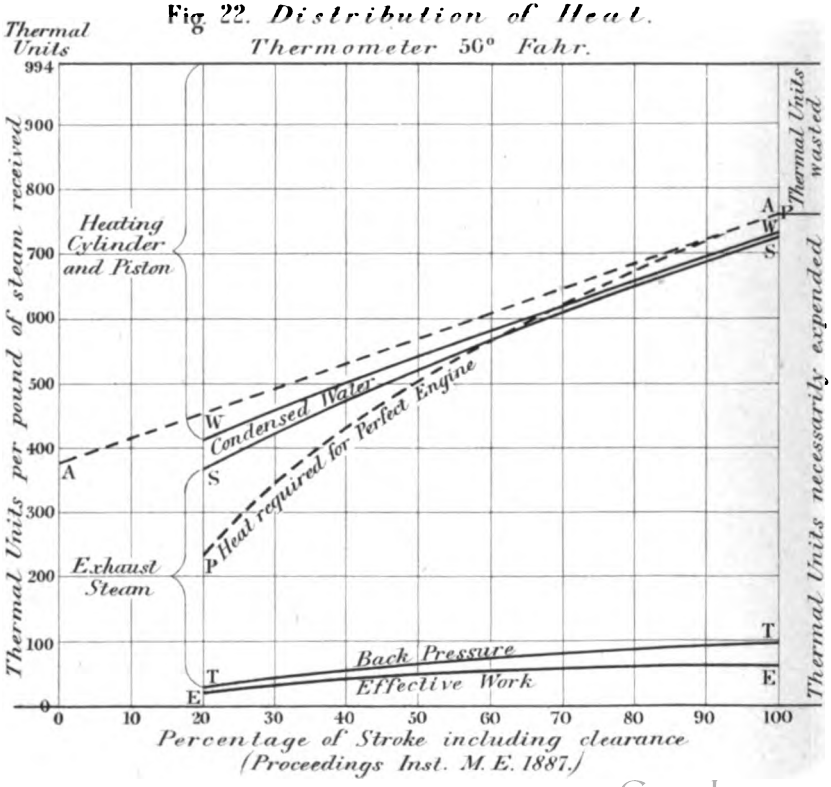

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Fig. 23. *Indicator Diagrams taken 18 Nov. 1886.*
Steam-pipe Jacketed

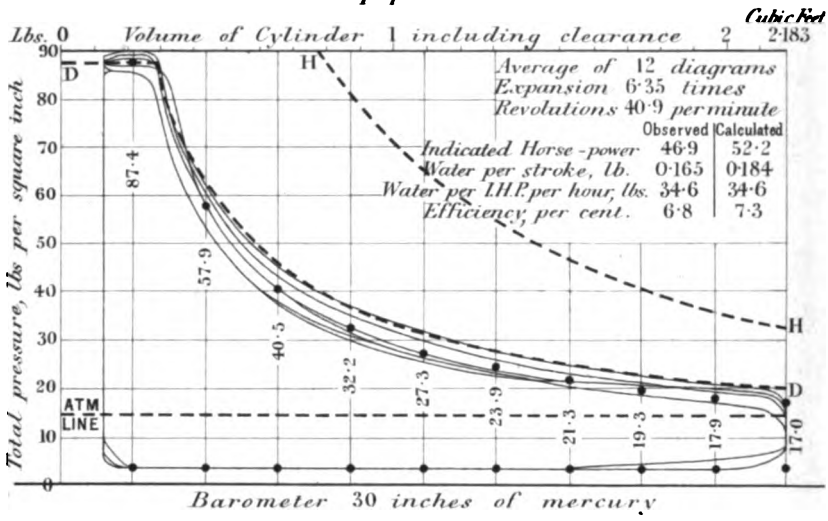
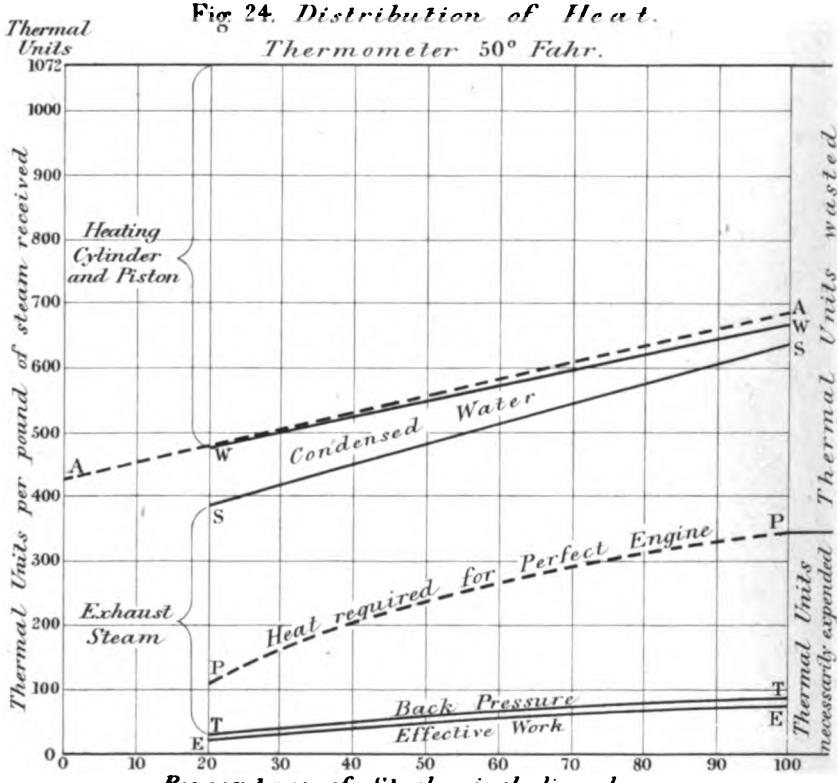


Fig. 24. *Distribution of Heat.*



(Proceedings Inst. M.E. 1887.)

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Fig. 25. *Indicator Diagrams taken 18 Nov. 1886.*

Steam-pipe not Jacketed.

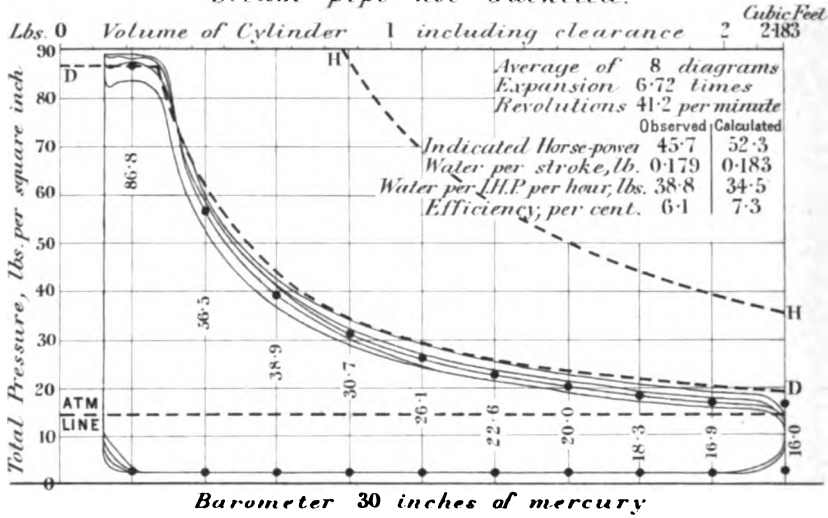

Fig. 26. *Distribution of Heat.*

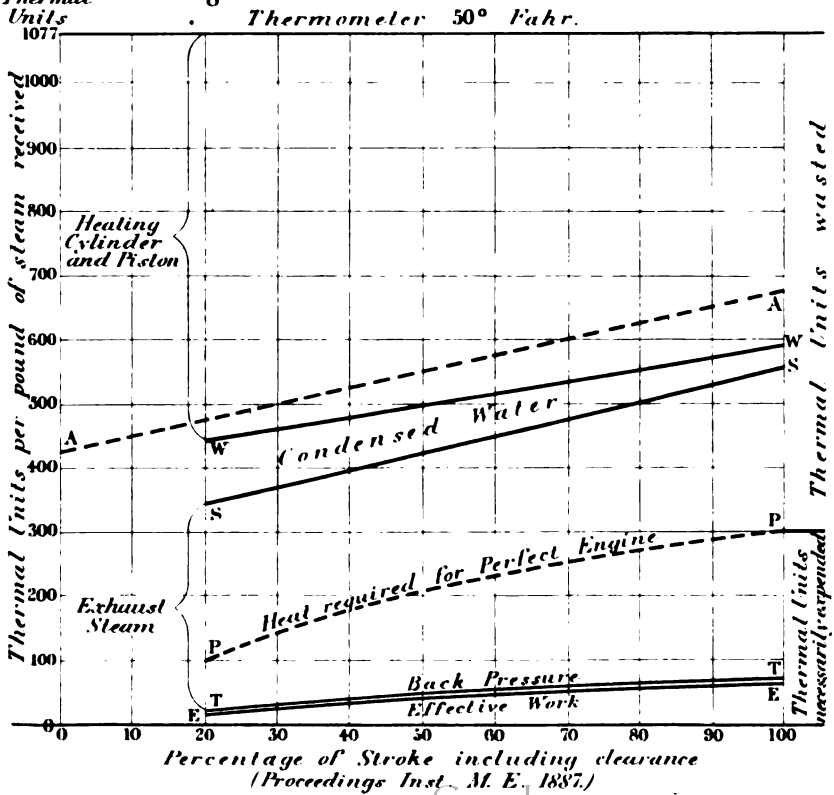

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Fig. 27. *Indicator Diagrams taken 29 Nov. 1886.*
Steam-pipe Jacketed.

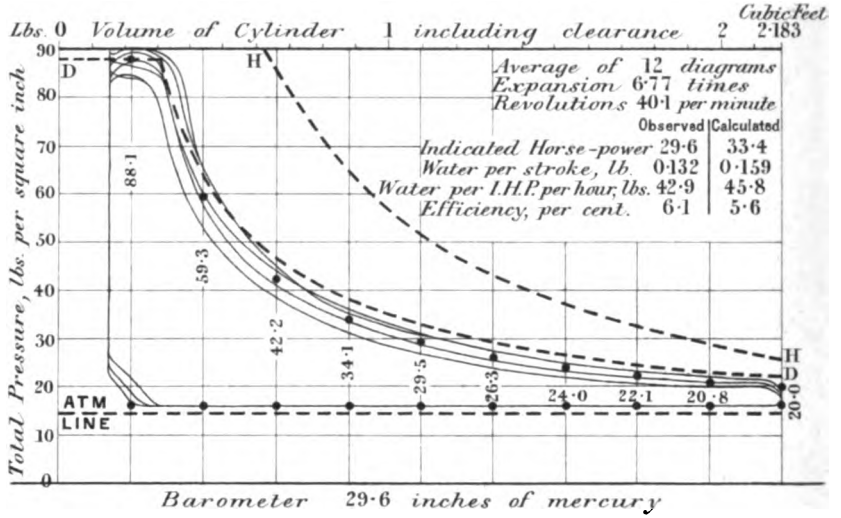

Fig. 28. *Distribution of Heat.*

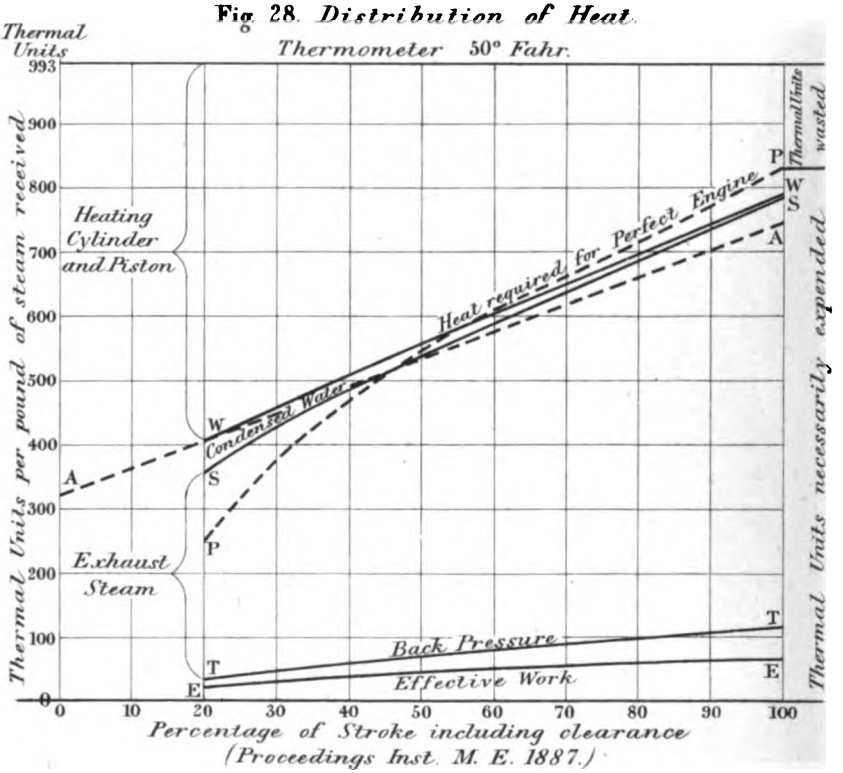

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Fig. 29. *Indicator Diagrams taken 13 Dec. 1886.*
Steam-pipe Jacketed.

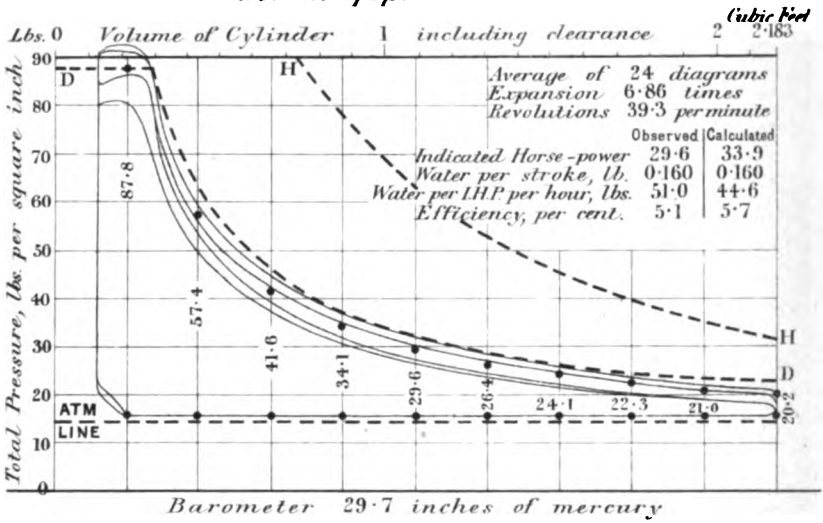

Fig. 30. *Distribution of Heat.*
Thermometer 46° Fahr.

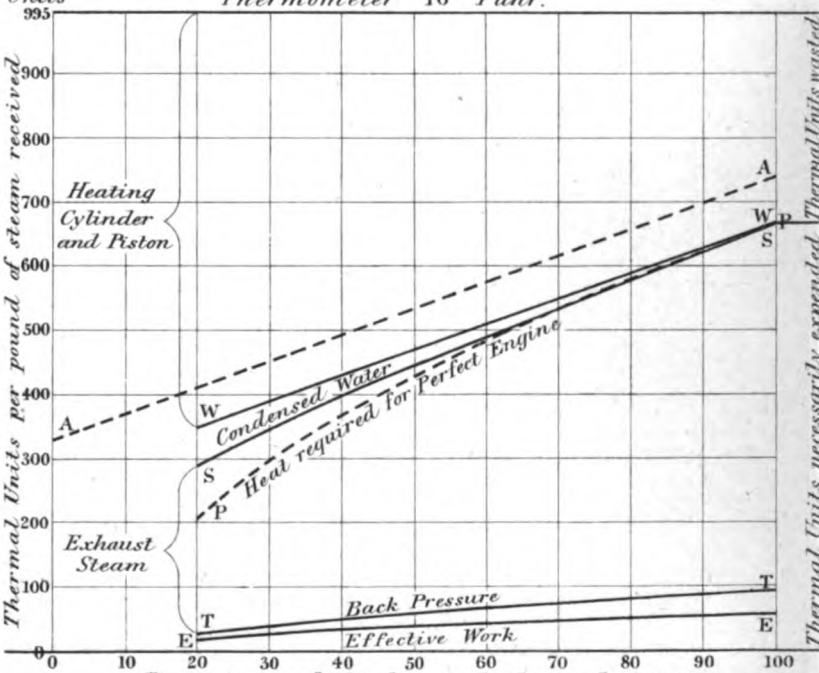

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Fig. 31. *Indicator Diagrams taken 13 Dec. 1886.*

Steam-pipe not Jacketed.

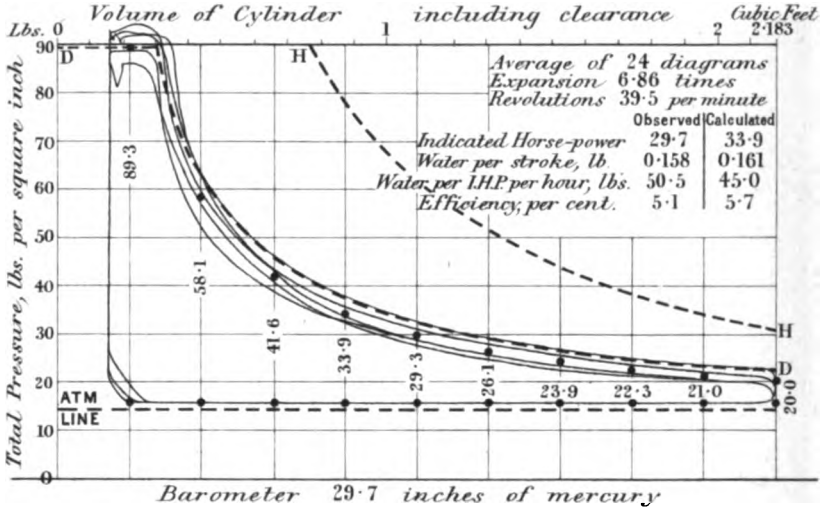
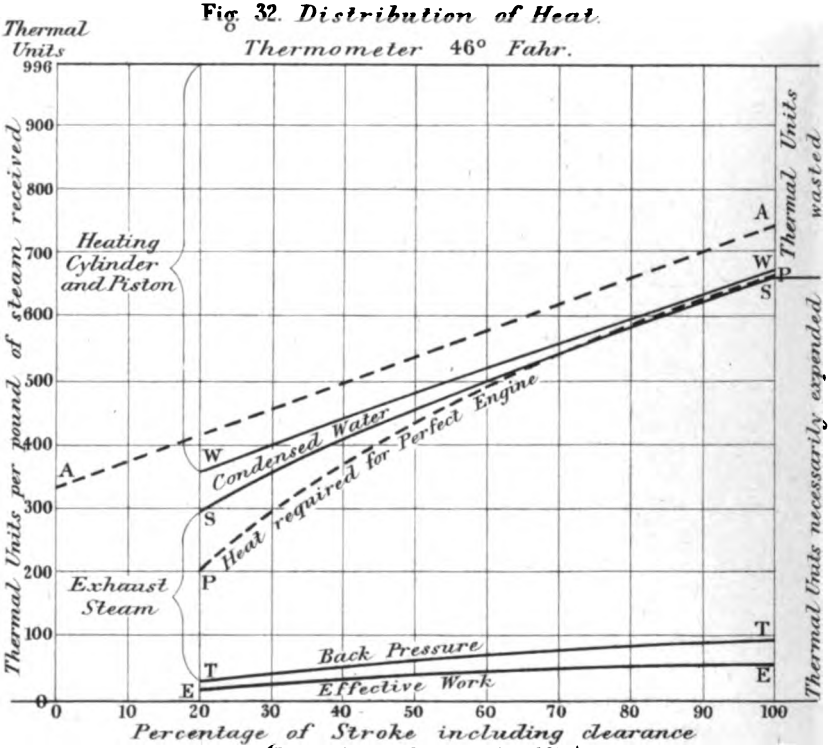


Fig. 32. *Distribution of Heat.*



(*Proceedings Inst. M. E. 1887.*)

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Fig. 33. *Initial Condensation and Re-evaporation.*

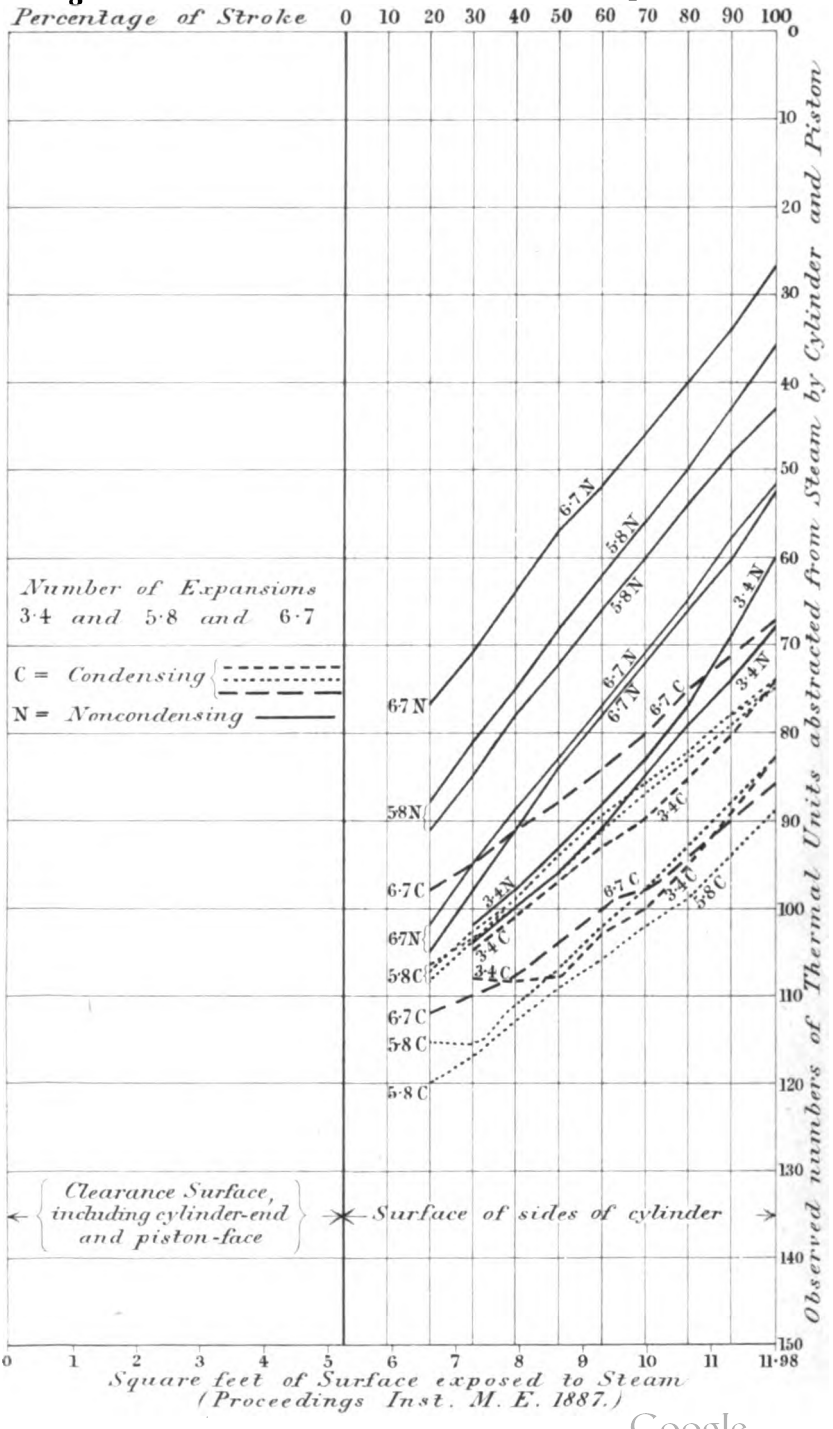

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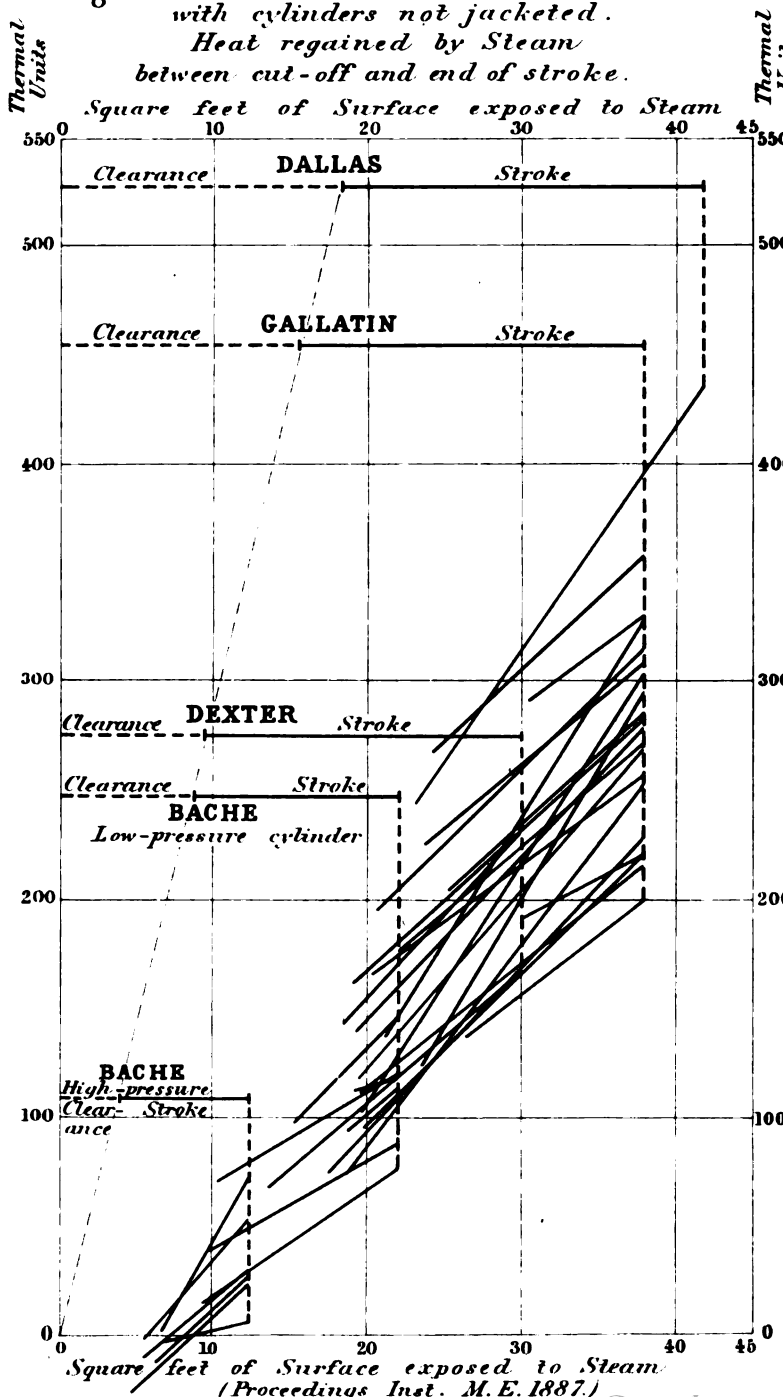
Fig. 34. *U.S. Marine-Engine Trials 1874 with cylinders not jacketed. Heat regained by Steam between cut-off and end of stroke.*



(Proceedings Inst. M.E. 1887.)

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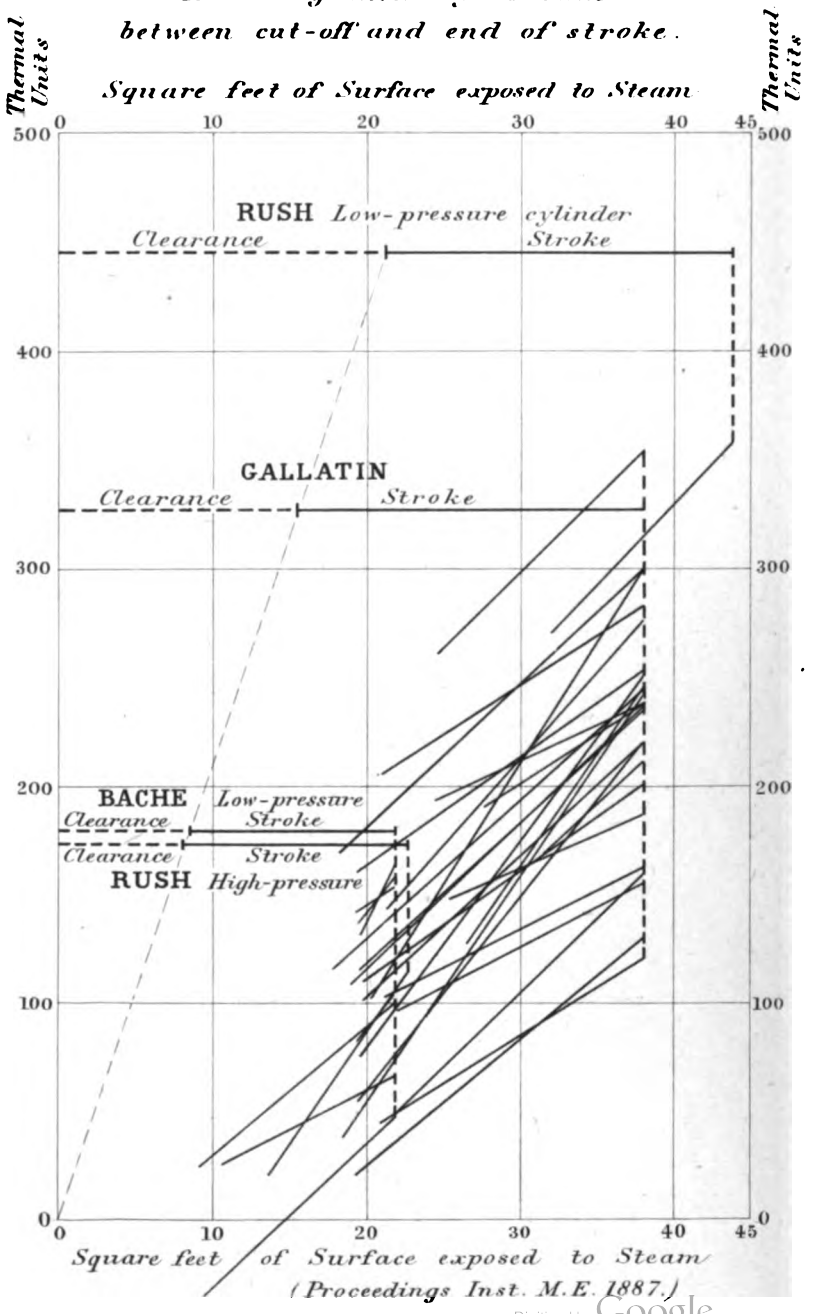
Fig. 35. *U.S. Marine-Engine Trials 1874 with cylinders jacketed.*

Heat regained by Steam between cut-off and end of stroke.



(Proceedings Inst. M.E. 1887.)

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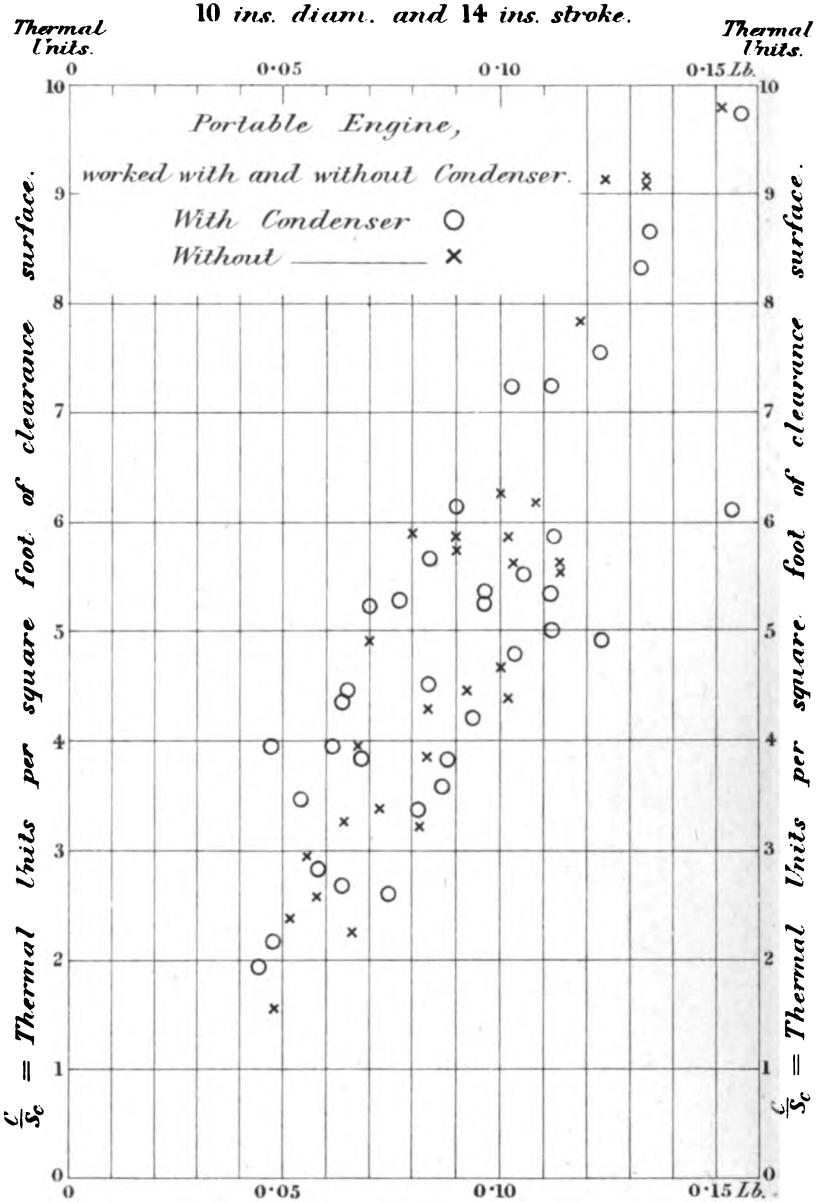
Fig. 36. *Net Initial Condensation by Clearance Surface in jacketed Cylinder, 10 ins. diam. and 14 ins. stroke.*



Initial Density of Steam, lb. per cubic foot, divided by square root of revolutions per second.

(Proceedings Inst. M. E. 1887.)

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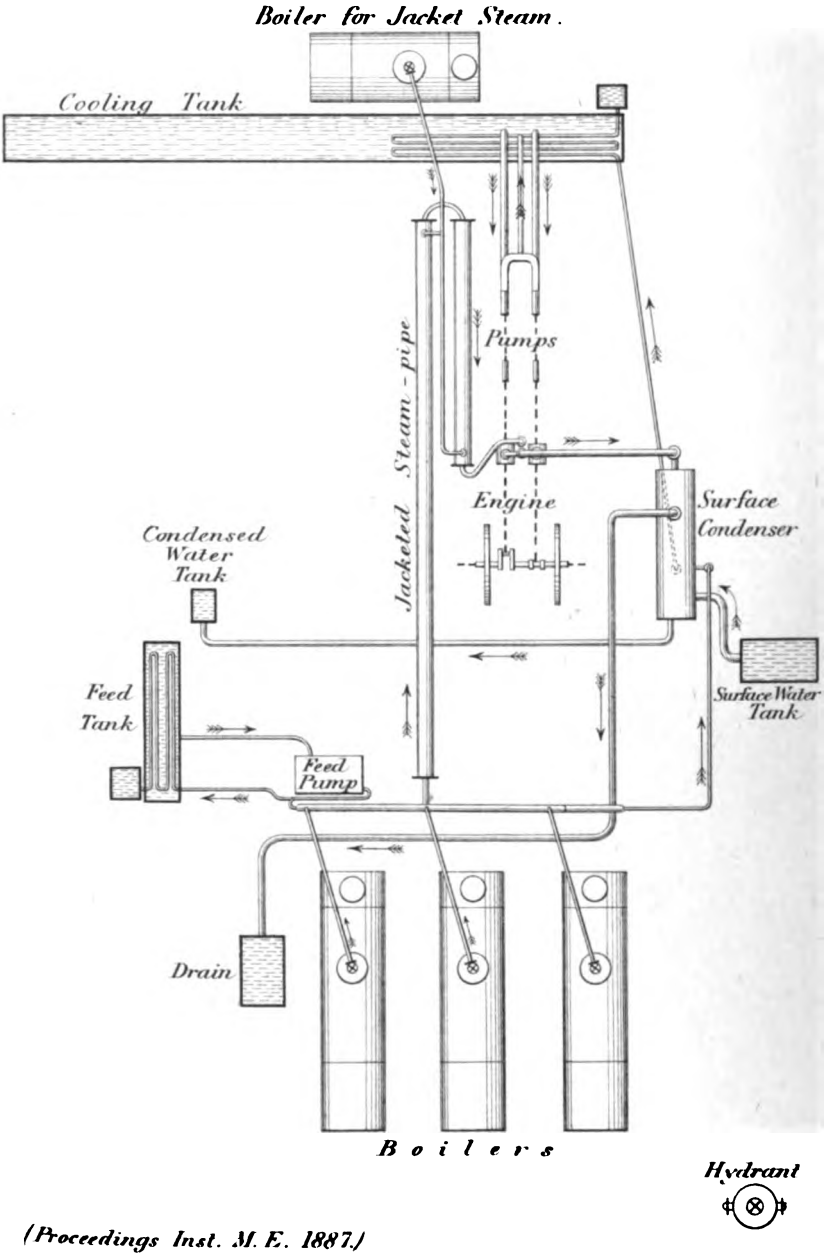
Fig. 37.

Arrangement of Experimental Apparatus.



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STEAM - ENGINE HEAT.

Valve Gear.

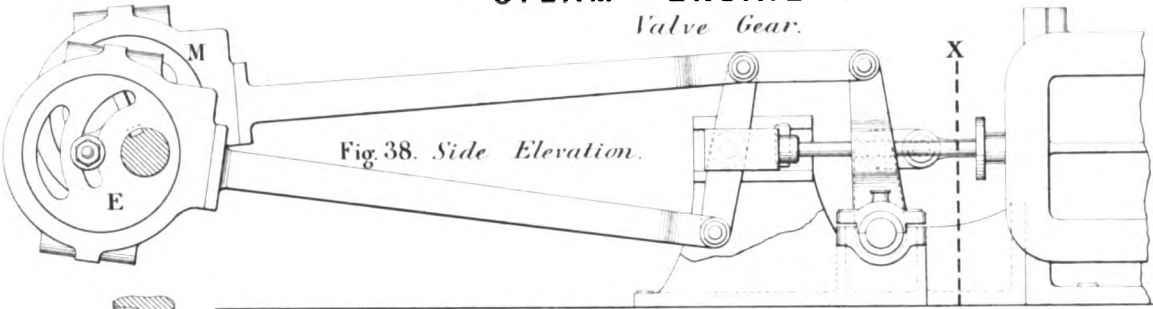

Fig. 38. *Side Elevation.*

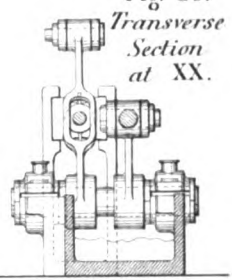

Fig. 39. *Transverse Section at XX.*

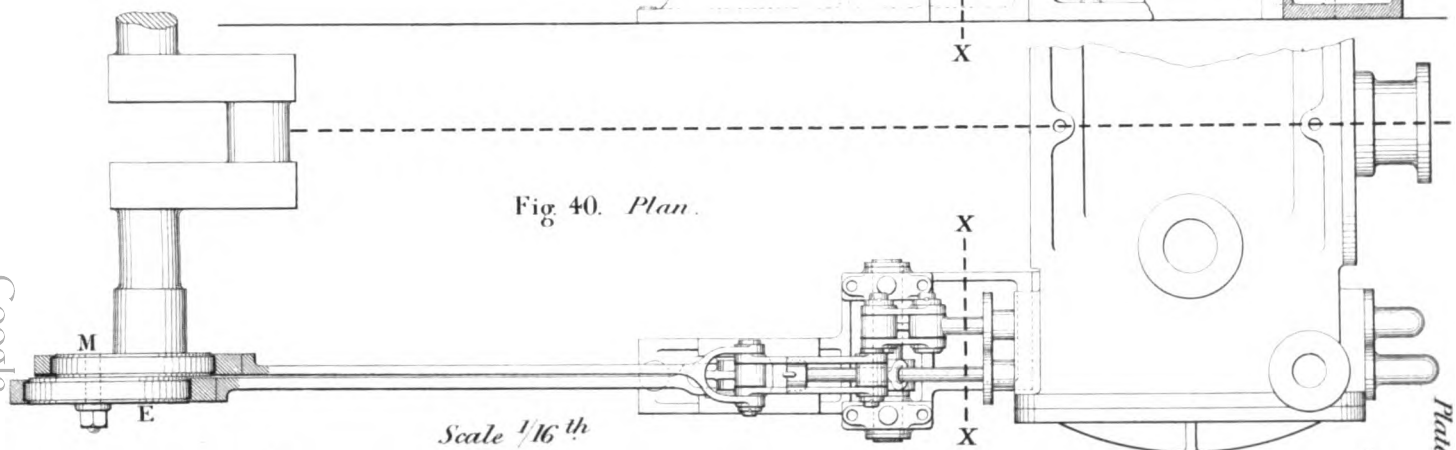

Fig. 40. *Plan.*

Scale 1/16th

Ins. 12 6 0 1 2 3 4 5 6 Feet.

(Proceedings Inst. M. E. 1887.)

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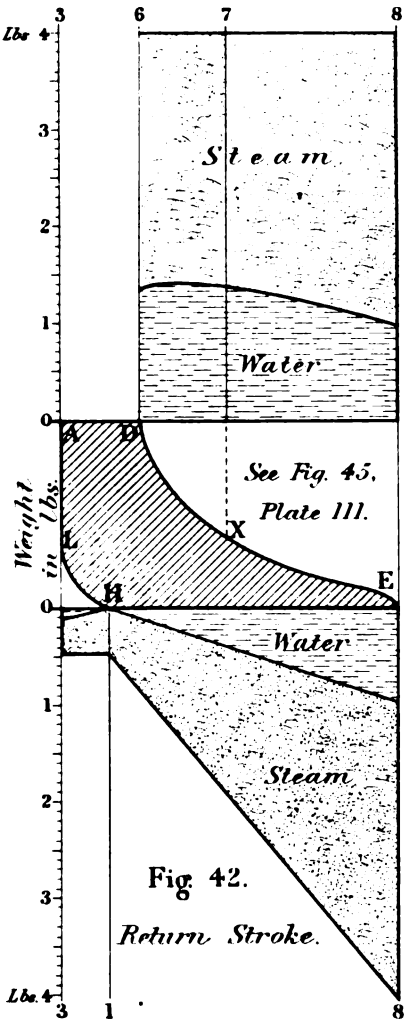
Non-Condensing Cylinder, not Jacketed.

Condensation and Re-evaporation.

Fig. 41. *Forward Stroke.*

For ordinates see Table 5.

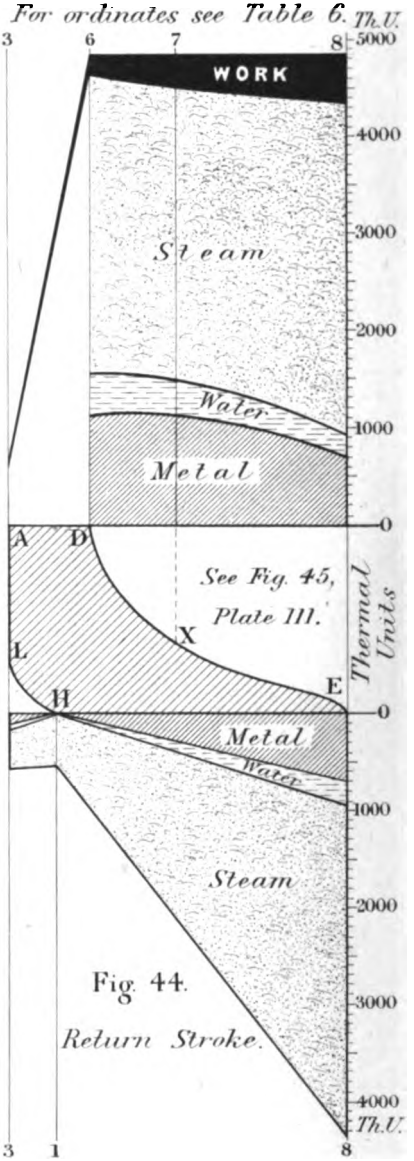


For ordinates see Table 5.

Distribution of Heat.

Fig. 43. *Forward Stroke.*

For ordinates see Table 6.



For ordinates see Table 6.

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Fig. 45. *Indicator Diagram*

from Non-Condensing Cylinder, not Jacketed.

See Plate 110.

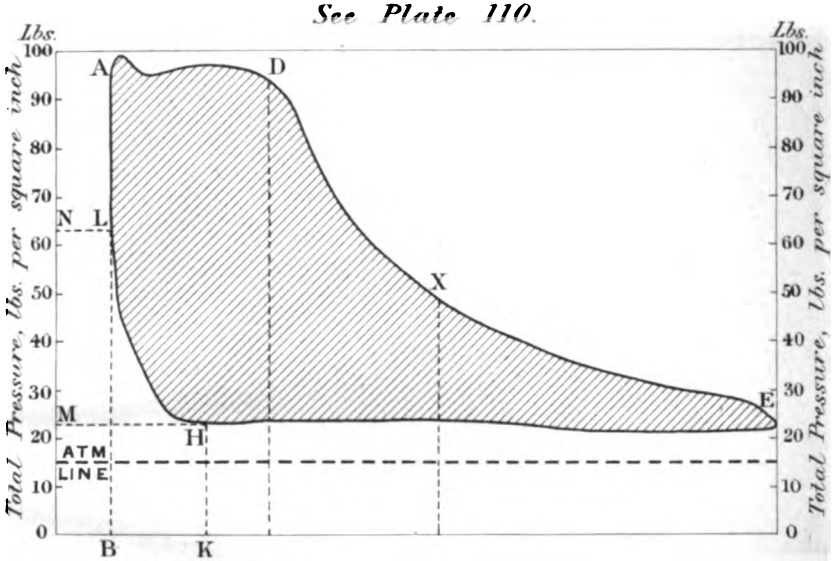
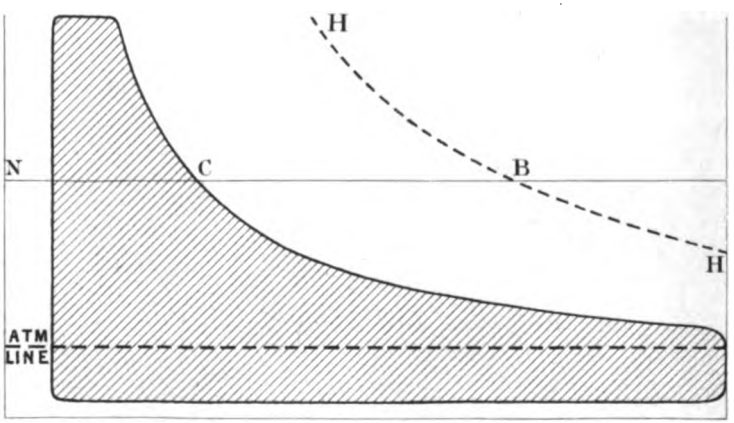


Fig. 46.



(Proceedings Inst. M. E. 1887.)

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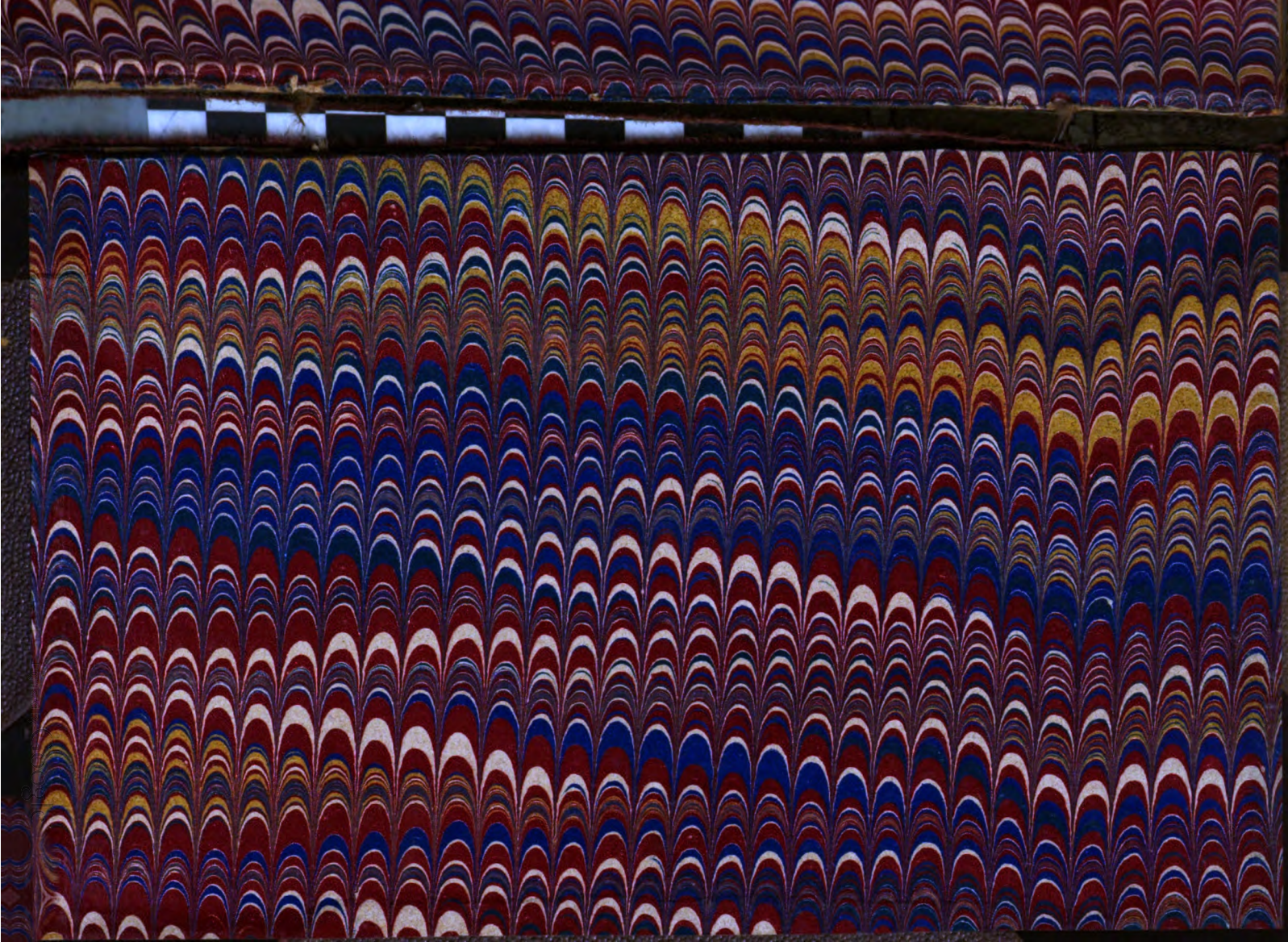

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