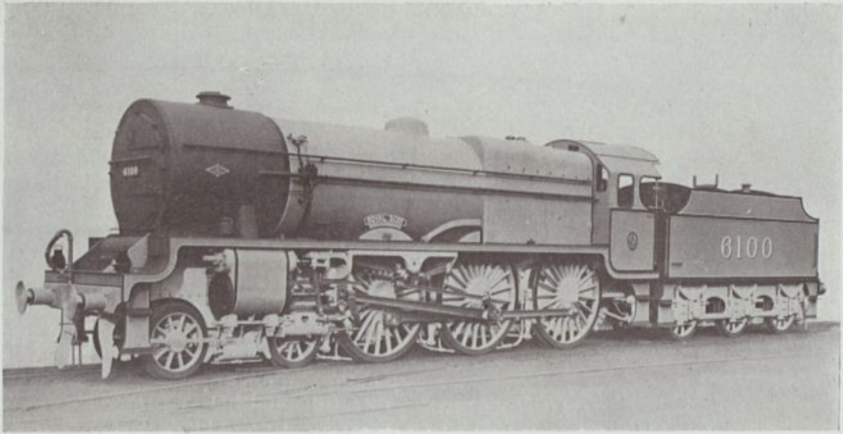
LOCOMOTIVE ENGINEERS' POCKET BOOK

1928.



4-6-0 3-CYLINDER SIMPLE EXPRESS LOCOMOTIVE.
LONDON, MIDLAND & SCOTTISH RAILWAY.

Designed by Sir Henry Fowler, K.B.E., Chief Mechanical Engineer.
Built by The North British Locomotive Co. Ltd., Glasgow.

LOCOMOTIVE ENGINEERS' POCKET BOOK

1928.

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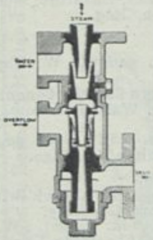

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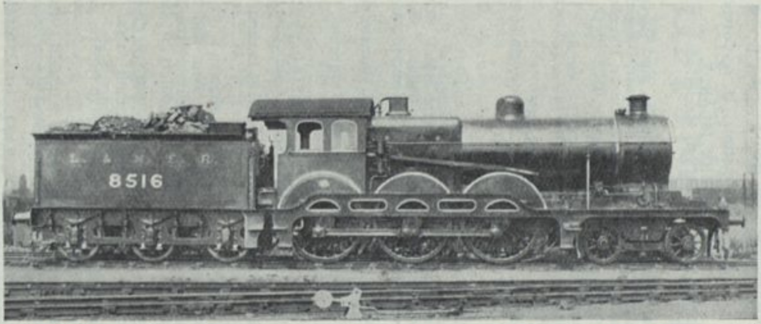

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South African Railways. (3 ft. 6 in. and 2 ft.) F. R. Collins, D.S.O., Chief Mechanical Engineer, Pretoria.
Advisory Engineer in London: G. G. Elliott, Trafalgar Square.

Cape Copper Railway. (2 ft. 6 in. gauge). W. F. Kitto, Ookiep.

New Cape Central. (3 ft. 6 in.) F. Dawson, General Manager Robertson Station, Cape Colony.

AUSTRALASIA.

New South Wales Government Railways. (4 ft. 8½ in.) E. E. Lucy, Chief Mechanical Engineer, Redfern, Sydney. A. D. J. Forster, Assistant C.M.E.

Commonwealth Railways, Trans-Australian. (4 ft. 8½ in.) G. A. Gahan, Chief Mechanical Engineer, Port Augusta. Consulting Engineer, W. H. Woolnough, Victoria St., S.W.1.

Queensland Government. (3 ft. 6 in.) R. J. Chalmers, Ipswich.

Silverton Tramway. New South Wales. F. L. Rushton, Broken Hill, N.S.W.

South Australian Government. (5 ft. 3 in. and 3 ft. 6 in.) F. J. Shea, Islington, nr. Adelaide.

Tasmanian Government. (3 ft. 6 in. and 2 ft.) H. B. Bennett, Chief Mechanical Engineer, Launceston.

Emu Bay Railway, Tasmania. (3 ft. 6 in.) A. Richardson, Chief Mechanical Engineer, Burnie.

Mount Lyell Mining Railway. (3 ft. 6 in.) G. W. Wright, Chief Mechanical Engineer, Queenstown.

Victorian Government. (5 ft. 3 in.) A. E. Smith, Chief Mechanical Engineer, Melbourne. Consulting Engineers, John Coates & Co., Ltd., Victoria House, Melbourne Place, W.C.2.

West Australian Government. (3 ft. 6 in.) E. A. Evans, Chief Mechanical Engineer, Midland Junction, W.A.

Midland of Western Australia. W. Wilson, Midland Junction, W.A.

New Zealand Government Railways. (3 ft. 6 in. gauge). G. S. Lynde, Chief Mechanical Engineer, Wellington, N.3. Consulting Engineer, Rendle Harvey, 34, Victoria St., S.W.1.

CANADA.

Algoma Central & Hudson Bay. (4 ft. 8½ in.) C. D. Rafferty, Master Mechanic, Sault Ste Marie.

Algoma Eastern.

Canadian National Railways. (4 ft. 8½ in.) C. E. Brooks, Chief of Motive Power, Montreal.
G. E. Smart, Chief of Car Equipment, Montreal.
C. B. Brown, Chief Engineer (Operating Dept.), Montreal.

Canadian Pacific. (4 ft. 8½ in.) C. H. Temple, Supt. of Motive Power. Montreal.

Quebec Central. (4 ft. 8½ in.) G. M. Robins, Master Mechanic. Sherbrooke, Quebec.
Temiscouta. (4 ft. 8½ in.) W. J. Walsh, Master Mechanic, Riviere du Loup, Quebec.
Temiskaming & Northern Ontario. S. B. Clement, Chief Engineer.
Toronto, Hamilton & Buffalo. (4 ft. 8½ in.) W. T. Kuhn, Supt. of Motive Power, Hamilton, Ont.
Newfoundland. (3 ft. 6 in.) J. H. Folmor, Supt. of Motive Power, St. Johns, Newfoundland.
Dominion Atlantic. (Nova Scotia). (4 ft. 8½ in.) D. L. Derrom, Master Mechanic, Kentville.

MEXICO.

El Oro Mining & Railway. (3 ft.) A. F. Main, Manager, El Oro, Mexico.
Mexican. (4 ft. 8½ in., 3 ft., 2 ft. 6 in., and 2 ft.) F. Smethurst, Supt. of Motive Power, Orizaba, Mex.
National Railways of Mexico. (4 ft. 8½ in. and 3 ft.) J. M. Santos, Loco. Supt., Mexico City.

BRITISH HONDURAS.

Stann Creek. (3 ft.) G. W. E. Francis.

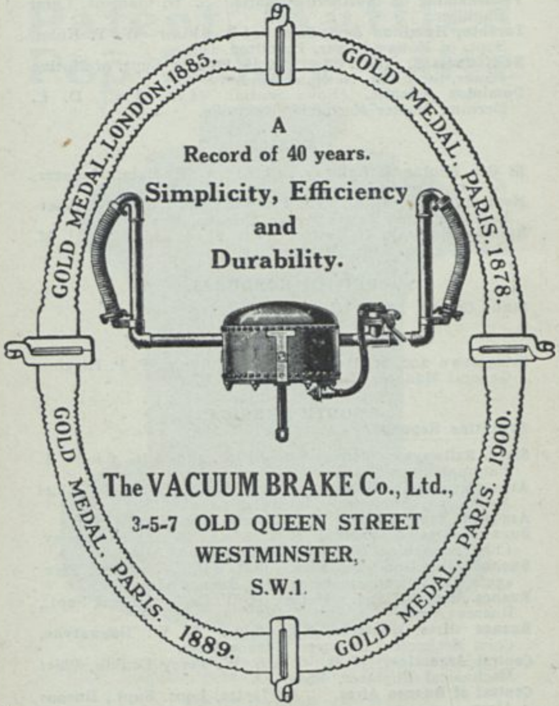
BARBADOS.

Bridgetown and St. Andrews. (2 ft. 6 in.) P. P. Higgins, General Manager, Bridgetown.

SOUTH AMERICA.

Argentine Republic.

State Railways. (Metre, 4 ft. 8½ in. and 5 ft. 6 in.) A. Pasquini, Peru 672, Buenos Aires.
Argentine North Eastern. (4 ft. 8½ in.) E. Noble, Chief Mechanical Engineer, Concordia.
Argentine Transandine. P. Fishwick, Loco. Supt.
Buenos Aires & Pacific. (5 ft. 6 in.) R. C. Kimberley, Chief Mechanical Engineer, Junin, Buenos Aires.
Buenos Aires Great Southern. (5 ft. 6 in.) Pedro C. Saccaggio, Chief Mechanical Engineer, Buenos Aires.
Buenos Aires Midland. (Metre). P. W. Dobson, Loco. Supt., Buenos Aires.
Buenos Aires Western. (5 ft. 6 in.) A. W. Bannatyne, Chief Mechanical Engineer, Buenos Aires.
Central Argentine. (5 ft. 6 in.) W. Percy Deakin, Chief Mechanical Engineer, Rosario.
Central of Buenos Aires. O. Jaette, Loco. Supt., Buenos Aires.
Cordoba Central. (Metre). L. S. Simpson, C.B.E., D.S.O., Chief Mechanical Engineer, Cordoba.
Entre Rios. (4 ft. 8½ in.) E. Noble, Concordia.
Province of Santa Fé. (Metre). A. Jonesca, Buenos Aires.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Brazil.

Araraquara. (Metre). E. Bittencourt, Araraquara, State of S. Paulo.

Brazil Great Southern. (Metre). F. V. Lander, General Manager, Uruguayana.

Central of Brazil. (5 ft. 6 in. and Metre). J. de A. Ribeiro, Loco. Supt., Rio de Janeiro.

Great Western of Brazil. (Metre). Snr. Pelagio R. dos Santos, Loco. Supt., Pernambuco.

Leopoldina. (Metre). R. C. Crocker, Loco. Supt., Rio de Janeiro.

Mogyana. (Metre and 2 ft. 0 in.) Dr. H. A. Da Costa, Campinas.

Paulista. (5 ft. 6 in. Metre and 2 ft 0 in.) J. Cintra, Loco. Supt., Jundiahy.

San Paulo. (5 ft. 6 in. and Metre). H. E. Dalzell, C.M.E., Saõ Paulo.

Sorocobana. (Metre gauge). A. G. R. da Luz, General Manager, Saõ Paulo

Western of Minas. (Metre and 2 ft. 6 in.) F D. Paes Leme, Bello Horizonte, Minas Geraes.

British Guiana.

Government Railways. (4 ft. 8½ in. and 3 ft. 6 in.) A. H. July, Loco. Supt., Georgetown.

Chili.

Agua-Santo. (2 ft. 6 in.) J. Elliott, Culeta-Buena.

Arica-La Paz. (Metre). M. Araya, Arica.

Anglo-Chilian Nitrate. (3 ft. 6 in.). Owned by the Anglo-Chilean Nitrate Corporation, Ltd., 120, Broadway, New York, U.S.A.

Antofagasta & Bolivia. (Metre and 2 ft. 6 in.) H. R. Hood. Mejillones.
F. Fraitag, Uyuni.

Arica & Tacna. (4 ft. 8½ in.) M. E. Yorke Eliot, Tacna.

Carrizal & Carro Blanco. (4 ft. 2 in.) J. King, Engineer, Carrizal.

Chilian Northern. (Metre). H. R. Hood, Antofagasta.

Chilian Transandine. (Metre). P. L. Fishwick, Los Andes.

Junin. (2 ft. 6 in.) P. Clarke, General Manager, Iquique.

Nitrate. (4 ft. 8½ in.) T. Jefferson, Iquique.

Taltal. (3 ft. 6 in.) W. H. Revill, Taltal.

Colombia.

Amaga. (3 ft.) Salvador, Master Mechanic, Medellin.
Ambalema-Ibague. (3 ft.) ———, Master Mechanic, Ambalema.
Antioquia. (3 ft.) H. Anderson, Locmotive Superintendent, Bello.
Barrancabermeja. (Metre.) Goodwin, Master Mechanic, El Centro-Barranca.
Barranquilla. (3 ft. 6 in.) C. Fryer, Locomotive Superintendent, Barranquilla.
Caldas. (3 ft.) C. Bazurto, Master Mechanic, Pereira.
Carare. (Metre.) P. C. Dewhurst, C.M.E., Bogotá. (Works at Tunja.)
Cartagena. (3 ft.) R. Boyd, Master Mechanic, Cartagena.
Central Bolivar. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá. (Works at Cartagena.)
Central Northern (Div. 1). (Metre.) P. C. Dewhurst, C.M.E., Bogotá; (Works at La Gomez.)
Central Northern (Div. 2). (Metre.) P. C. Dewhurst, C.M.E., Bogotá; F. Newbold, Division Locomotive Superintendent. (Works at Bogotá.)
Cucuta. (Metre.) J. J. Porras, Master Mechanic, San Jose de Cucuta.
Cucuta-Pamplona. (Metre.) P. C. Dewhurst, C.M.E., Bogotá; J. J. Porras, Master Mechanic. (Works at San Jose de Cucuta.)
Cundinamarca. (Metre & 3 ft.) R. Perez, Master Mechanic, Bogotá; P. C. Dewhurst, Advisory Mechanical Engineer, Bogotá.
Dorada. (3 ft.). R. G. R. Melrose, Locomotive Superintendent, Mariquita.
Girardot. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá; S. R. Phelps, Div. Loco. Supt. Works at Girardot.
Nacederos-Armenia. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá. C. Bazurto, Master Mechanic. (Works at Pereira.)
Narino. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá. (Works at Tumaco.)
North Eastern. (Metre.) G. Melo, Master Mechanic, Bogotá.
Pacific. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá; ———, Division Locomotive Superintendent. (Works at Dagua.)
Santa Marta. (3 ft.) J. Oberle, Locomotive Superintendent, Santa Marta.
Santander-Timba. (3 ft.) ———, Master Mechanic, Santander, Cauca.
Southern. (Metre.) P. C. Dewhurst, C.M.E., Bogotá; F. Newbold, Division Locomotive Superintendent. (Works at Bogotá.)
Tolima. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá; S. R. Phelps, Divisional Locomotive Superintendent. (Works at Flandes.)
Western Trunk. (3 ft.) P. C. Dewhurst, C.M.E., Bogotá; (Works at Bolombolo.)
Western of Bogota (Metre.) ———, Master Mechanic, Bogotá.

Ecuador.

Guayaquil & Quito. (3 ft. 6 in.) W. C. Simmons, Huigra, Ecuador.

Paraguay.

Central. (4 ft. 8½ in.) E. Thomas, Chief Mechanical Engineer, Sapucay, Asuncion.

Peru.

Cayalti. (0·60m.) F. W. Main.
Central of Peru. (4 ft. 8½ in.) R. D. Deacon, Supt. of Motive Power, Callao.
Eten. (4 ft. 8½ in.) E. Vargas, Engineer, Eten.
Pacasmayo & Guadalupe. (4 ft. 8½ in.) A. S. Cooper, C.B., Lima.
Southern. (4 ft. 8½ in.) H. W. O'Hagan, Arequipa.
Trujillo. (3 ft.) H. E. Dawson, Trujillo.

Uruguay.

Central. (4 ft. 8½ in.) P. Sedgefield, Montevideo.
Midland. (4 ft. 8½ in.) J. Wavrunek, Paysandu.
Northern. (4 ft. 8½ in.) ,, ,,
North Western. (4 ft. 8½ in.) ,, ,,

Venezuela.

Bolivar. (2 ft.) C. H. Carstens, Aroa.
La Guaira & Caracas. (3 ft.) A. C. Clarke, General Manager, Caracas.
Puerto Cabello & Valencia. (3 ft. 6 in.) B. Hewitt, Valencia.

CUBA.

United Railways of the Havana & Regla Warehouses. (4 ft. 8½ in. and 3 ft.) T. E. Keyworth, Chief Mechanical Engineer, Cienaga, Havana.
Northern. A. Jiminez, Loco. Supt., Morón.

GUATEMALA.

International Railways of Central America. Chief Engineer: C. Chandler, Guatemala, C.A.

JAMAICA.

Jamaica Government Railway. (4 ft. 8½ in.) P. M. McKay, Loco. Supt., Kingston, Jamaica, B.W.I.

SAN DOMINGO.

Govt. Railway. L. A. Baldwin, San Domingo.
Samana-Santiago Railway of San Domingo. (3 ft. 6 in.) J. F. Laing, Sanchez, San Domingo.

TRINIDAD.

Trinidad Government Railways. (4 ft. 8½ in.) Capt. E. H. Wainwright, Port of Spain

INDUSTRIAL WORKS OWNING LOCOMOTIVES.

Standard 4 ft. 8½ in. gauge unless otherwise stated.

Abram Coal Co. Abram Collieries, Bickershaw, near Wigan. 2 locos. Thos. Molyneux, Engineer.

Ackton Hall Colliery Co., Featherstone, near Pontefract. 4 locos. W. H. Scholes, Engineer.

Edgar Allen & Co., Ltd., Sheffield. 1 loco. T. W. Barley, Engineer.

Samuel Allsopp & Sons, Ltd., Burton-on-Trent. 4 locos. L. C. Smith. Engineer.

Anglo-Scottish Beet Sugar Corporation, Colwick. 2 locos.

Ashington Coal Co., Ltd., Newcastle-on-Tyne. 17 locos (4 ft. 8½ in. and 2 ft. gauges). John Eskdale, Engineer.

Associated Portland Cement Co., Ltd., Swanscombe, Kent. 30 locos. (3 ft. 5½ in. gauge). N. S. Wellstead, Engineer.

Astley & Tyldesley Collieries, Ltd., Tyldesley, near Manchester. 5 locos. D. C. Smith, General Manager.

Backworth Colliery Co., West Cramlington, near Newcastle. 6 locos.

Barrow Hæmatite Steel Co., Ltd., Barrow-in-Furness. 24 locos., 1 crane loco., 5 locos. (2 ft. 10 in. gauge), 2 electric locos. W. F. Clement, Engineer.

Bass, Ratcliff & Gretton, Ltd., Burton on-Trent. 7 locos.

Beckerstaffe Coal Co., Ltd., Ormskirk. 1 loco. J. Diggle, Engineer.

Bold Venture Lime Co., Ltd., Chatburn, near Clitheroe. 1 loco.

John Bowes & Partners, Milburn House, Newcastle-on-Tyne. Works at Marley Hill, Pontop, Dipton, Springwell, etc. 15 locos. J. English, Engineer.

City of Birmingham Gas Dept., Gas Works, Saltley, Birmingham. 13 locos (5 works). J. Foster, Engineer in Chief.

Birtley Iron Co., Birtley, Co. Durham. 2 locos.

Blaina Colliery, Swansea. 2 locos. Rhys Hughes, Engineer.

British Copper Manufacturers, Ltd., Swansea. 10 locos.

Richard Briggs & Sons, Ltd., Quarry Owners, Clitheroe. 1 steam, 2 internal combustion locos.

John Brown & Co., Ltd., Atlas Steel & Iron Works, Sheffield. 12 locos.

Brown, Bayley's Steel Works, Sheffield. 4 locos. F. G. Bell, Engineer.

Butterley Co., Ltd., Butterley Ironworks, Derby. 21 locos. G. F. Wright, Director and Manager.

Buxton Lime Firms Co., Ltd., Royal Exchange, Buxton. 10 steam and 4 internal combustion (4 ft. 8½ in.), 9 internal combustion (2 ft.).

Cadbury Bros, Ltd., Bournville, Birmingham. 5 locos. L. Barrow, Engineer.

Cannock & Rugeley Collieries, Hednesford. 8 locos. — Taylor, Chief Engineer.

Cargo Fleet Iron Co., Ltd., Cargo Fleet, Middlesbrough. 10 locos.

J. & J. Charlesworth, Ltd., Milnes House, Wakefield. 9 locos. W. B. Lodge, Engineer.

Chatterley Whitfield Collieries, Ltd., Whitfield Colliery, Norton in the Moors, Stoke-on-Trent. 10 locos.

Charing Cross & City Electricity Supply Co., London. 2 locos.

Cleeves' Western Valleys Anthracite Collieries, Ltd., Ammanford. 4 locos. G. Veater, Engineer.

Cleveland Bridge & Engineering Co., Ltd., Darlington. 1 loco. 10 loco. cranes, 8 petrol locos (2 ft. gauge).

Clifton Colliery Co., Ltd., Nottingham. 3 locos. G. W. Lawson, Engineer.

Cochrane & Co., Ltd., Ormesby Iron Works, Middlesbrough-on-Tees. 15 locos. W. R. Trusson, Engineer.

Cory Brothers & Co., Ltd., Coryton, Essex. 2 locos. J. H. Freeman, Engineer.

Cramlington Coal Co., Cramlington, Northumberland. 16 locos.

Crosfield Iron Co., Whitehaven. 2 locos.

Dalton Main Collieries, Silverwood Colliery, Thrybergh, nr. Rotherham. J. Clark, Engineer. 4 locos and 3 travelling cranes.

J. H. Dennis, Nocton, Lincs. 1 loco.

Dinorwic Slate Quarries, Port Dinorwic, N. Wales. 3 locos., 4 ft. gauge; 20 locos., 1 ft. 11½ in. gauge. Vaughan, Williams, Manager.

Dorking Greystone Lime & Cement Co., Betchworth, Surrey. 4 locos. E. W. Taylerson, Managing Director.

Dorman Long & Co., Ltd., Britannia Works, Middlesbrough. 22 locos. John A. Thornton, Works Manager.
Acklam Iron & Steel Works, Middlesbrough. 12 steam locos., 2 internal combustion locos. A. H. Taylor, Engineer,
Carlton Iron Works. 9 locos.
Warrenby & Coatham Ironworks. 15 locos.

Duffryn Aberdare Coal Co., Hirwain, Glam. 2 locos. William Jenkins, Engineer.

Earl Fitzwilliam's New Stubbin Colliery, Rawmarsh, Rotherham, 5 locos. H. Ward, Engineer.

Ebbw Vale Steel, Iron & Coal Co., Ltd. 26 locos. W. J. Cole, Engineer.

Emlyn Anthracite Colliery, Swansea. 3 locos. J. D. Morgan, Engineer.

Exhall Colliery & Brickworks, Ltd., Bedworth, near Nuneaton. 4 locos. John Staley, Engineer.

Falmouth Docks & Engineering Co., Ltd. 3 locos. H. W. Bartlett, Engineer.

Samuel Fox & Co., Ltd., Stocksbridge Works, near Sheffield. 12 locos. W. H Robinson, Engineer.

Gas, Light & Coke Co., Horseferry Road, Westminster. 58 locos., 4 ft. 8½ in. gauge; 3 locos., 2 ft. 9 in. gauge; 6 locos., 2 ft. 0 in. gauge. T. Hardie, Chief Engineer.

Glasbrook Bros., Ltd., Swansea. 6 locos. A. James, Engineer.

Glasgow Corporation Gas Department, Glasgow. 13 locos. (4 ft. 8½ in. gauge), 27 locos. (2 ft. gauge), 7 locos. (2 ft. 6 in. gauge), 2 electric locos (2 ft. 6 in. gauge). J. W. McLusky, Engineer.

Glasgow Iron & Steel Co., Ltd., Wishaw. 13 locos. A. Pomphrey, Engineer.

Greaves, Bull & Lakin, Ltd., Harbury, Leamington. 5 locos., 3 ft. gauge. W. Minto, Loco. Eng.

Arthur Guiness Sons & Co., Ltd., St. James' Gate Brewery, Dublin. 22 locos., 1 ft. 10 in. gauge; 2 locos., 5 ft. 3 in. gauge. T. N. Mulligan, Engineer.

Gjers, Mills & Co., Ayresome Ironworks, Middlesbrough. 6 locos.

William Harrison Ltd., Brownhills Collieries, near Walsall. 3 locos. John Walton, Engineer.

Harton Coal Co., Ltd., South Shields. 3 locos. (steam), also several electric.

Richard Heath & Low Moor Ltd. Biddulph Valley Coal and Iron Works, Stoke-on-Trent. 16 locos. R. Smith, Engineer.

Alfred Hickman Ltd., Spring Vale Furnaces, Wolverhampton. At Steel Works: 23 locos. (4 ft. 8½ in. gauge). 1 loco. (2 ft. gauge).
At Mines: 4 locos. (2 ft. gauge). J. Featonby, Engineer.

Huntley & Palmers, Ltd., Biscuit Factory, Reading. 4 locos. A. W. Blackmore, Engineer.

Imperial Paper Mills Ltd., Bycliffes, Gravesend, Kent. 3 locos (fireless). W. H. Salmon, M.I.M.E., Engineer.

Ind. Coope & Co., Ltd, Burton-on-Trent. 2 locos. H. Dolman, Engineer.

John Knowles & Co., Woodville, Burton-on-Trent. 5 locos.

James Joicey & Co., Ltd., Harperley Hall, Tantobie, S. O., Co. Durham. 9 locos. F. Short, Engineer, Beamish S. O., Co. Durham.

Lambton & Hetton Collieries Ltd., Silksworth Colliery, Sunderland. 1 loco. Thos. Charlton, Engineer.

City of Leeds Gas Dept., Market Hall, Leeds. 4 locos. C. S. Shapley, Engineer.

Lever Bros. Ltd., Port Sunlight. 12 steam and 1 Fireless loco. (4 ft. 8½ in. gauge). 4 steam (2 ft. gauge). W. L. Hargreaves, Engineer.

The Lilleshall Company, Ltd., Shifnal. 11 locos. H. Hilton, Engineer.

Littleton Collieries. — Hall, Engineer. 5 locos.

Edward Lloyd, Ltd., Paper Mills, Sittingbourne, Kent. 5 steam locos., 2 fireless locos., 1 battery loco. (2 ft. 6 in. gauge). A. A. Richards, M.I.M.E. Engineer.

Londonderry Port and Harbour Commissioners, Derry. 2 locos.

Lothian Coal Co. Ltd., Newbattle Collieries, Newtongrange, Midlothian.

J. Lyons & Co., Ltd., Cadby Hall, Kensington. 1 loco. Greenford Works. E. Price Jones, Chief Engineer.

Manvers Main Collieries, Ltd., Rotherham. 10 locos.

Middleton Estate and Colliery Co., Ltd., Leeds. 5 locos. Jas. Robinson, Engineer.

Midland Coal & Iron Co., Ltd., Newcastle, Staffs. — Cork, Chief Engineer, 12 locos.

Mitchell Main Colliery Co., Ltd., Barnsley. 2 locos. J. R. Brittain, Engineer.

Metropolitan Water Board, Rosebery Avenue, Clerkenwell. 3 locos. (2 ft. 6 in. gauge), 1 loco. (4 ft. 8½ in. gauge). H. W. Stilgoe, M.I.C.E., Chief Engineer.

Normanby Ironworks, Middlesbrough. 8 locos.

North Bitchburn Coal Co., Ltd. 9 locos.

North Lonsdale Iron & Steel Co., Ltd., Ulverston. 4 locos. H. J. Macklin, Engineer.

North's Navigation Collieries, Maesteg, Glam. W. McPherson, Engineer.

Parkgate Iron & Steel Co., Ltd., Rotherham. 15 locos., 5 locos. (3 ft. gauge). C. B. Capon, Engineer.

Partridge, Jones & John Paton, Ltd., Abersychan, Mon. 4 locos. T. B. Cryer, Engineer.

Pease & Partners, Ltd., Tees Iron Works, Middlesbrough. 8 locos.

Skinningrove Ironworks, Saltburn-by-the-Sea. 17 locos. W. P. Richmond, Engineer.

Lord Penrhyn's Quarries, Bethesda, North Wales. 20 locos. (narrow gauge). J. Jack, Engineer.

Pelaw Main Collieries, Birtley. 13 locos. G. W. N. Harrison.

Penrikyber Navigation Colliery Co., Ltd., Penrhiwceiber, Glam. 2 locos. T. E. Phillips, Engineer.

Platt Bros. & Co., Ltd., Oldham. 9 locos. (4 ft. 8½ in. gauge), 3 electric locos (2 ft. 6 in. gauge).

Powell Duffryn Steam Coal Co., Aberaman, near Aberdare. 16 locos. Ivor Williams, Engineer, Bargoed.

Priestman Collieries, Ltd., Millburn House, Newcastle-on-Tyne. 14 locos.

River Wear Commissioners, Sunderland. 7 locos. A. Crombie, Engineer.

Rother Vale Collieries, Treeton, near Rotherham. 8 locos. F. M. Castleman. Engineer.

Seaham Harbour & Dock Co. Seaham Harbour. 9 locos.

Seaton Burn Coal Co., Forest Hall, Northumberland. 13 locos.

Seaton Delaval Coal Co., Seaton Delaval, Northumberland. 12 locos.

Sheffield Gas Co., Commercial St., Sheffield. 2 locos. R. Halkett, General Manager.

Shelton Iron & Steel Co., Stoke-on-Trent. — Lake, Chief Engineer, 19 locos.

Ship Canal Portland Cement Manufacturers, Ltd., Ellesmere Port. 4 locos. W. Hodgson, Manager.

Shotts' Iron Co., Ltd., Shotts' Iron Works, Shotts, N.B. 14 locos. A. B. Allison, Works Manager.

Silvertown Lubricants, Ltd., Silvertown. 1 loco.

South Hetton Colliery Co., South Hetton, Co. Durham. 10 locos.

South Suburban Gas Co., Lower Sydenham. 3 locos.

South Metropolitan Gas Co., East Greenwich. 24 locos., 2 sentinels, at E. Greenwich. 3 locos (3 ft. gauge) at Vauxhall. 2 locos at Old Kent Road.

Stella Coal Co., Ltd., Cathedral Buildings, Dean St., Newcastle-on-Tyne. 8 locos. E. B. Forster, Engineer.

The Staveley Coal & Iron Co., Ltd., near Chesterfield. 19 locos., 3 locos. (3 ft. gauge). T. Smales, Engineer.

Swansea Improvements & Tramways Co., Ltd. 5 locos.

Tinsley Park Colliery Co., Ltd., Tinsley, Sheffield. 3 locos. O. Crowther, Engineer.

Topham, Jones & Railton (1926) Ltd., Swansea. 3 locos., 1 petrol loco. (2 ft. gauge).

Tredegar Iron & Coal Co., Ltd., Tredegar. 6 locos. F. Stuart Hall, Works Manager.

Trimsaran Co., Ltd., Kidwelly, Carmarthenshire. 3 locos. A. D. Jones, Engineer.

Tyne Improvement Commission. 17 locos. R. F. Hindmarsh, M.I.C.E., Chief Engineer, Newcastle-on-Tyne.

Tyne & Tees Shipping Co., Ltd., Stockton & Middlesbrough. 9 locos.

United Alkali Co., Ltd., Gateshead. (Allhusen's Chemical Works). 6 locos.

United Collieries Ltd., 109, Hope Street, Glasgow. 17 locos. David McQueen, Engineer.

Victoria Coal and Coke Co., Ltd., Wakefield. 2 locos. J. Derbyshire, Engineer.

Vivian & Sons, Ltd., Swansea. 10 locos. T. Hill, Engineer.

Wath Main Colliery Co., Ltd., Wath-on-Dearne, Rotherham. 4 locos.

Wearmouth Coal Co., Ltd., Sunderland. 10 locos. C. Almond, Engineer.

West Cannock Colliery Co. 5 locos. Raithwaite, Engineer.

Whitehaven Colliery Co., Ltd. 13 locos. J. W. Parker, Engineer.

Williams & Co., Linthorpe Ironworks, Middlesbrough. 6 locos.

William Whitwell & Co., Ltd., Thornaby Iron Works, Stockton-on-Tees. 7 locos. Wm. Little, Engineer.

Worthington & Co., Ltd., The Brewery, Burton-on-Trent. 6 locos. Alfred Hill, Engineer.

Exors of Sir Hedworth Williamson, Fulwell Lime Quarries. 8 locos.

BRITISH LOCOMOTIVE BUILDERS.

Andrew Barclay Sons & Co., Ltd., Caledonia Works, Kilmarnock ; 53, Victoria Street, S.W.1.

Atkinson Walker Wagons Ltd., Preston; 83 Pall Mall, London.

Avonside Engine Co., Ltd., Bristol.

W. G. Bagnall, Ltd., Stafford ; 32, Victoria Street, S.W.1.

Baguley (Engineers), Ltd., Burton-on-Trent.

William Beardmore & Co., Ltd., Parkhead Steel Foundry, Glasgow ; 36 Victoria Street, S.W.1.

Beyer, Peacock & Co., Ltd., Gorton Foundry, Manchester; Abbey House, S.W.1.

Drewry Car Co., Ltd., Burton-on-Trent ; 13, South Place, E.C.

John Fowler & Co. (Leeds), Ltd., Leeds ; 113, Cannon Street, E.C.

R. & W. Hawthorn, Leslie & Co., Ltd., Forth Banks Loco. Works, Newcastle-on-Tyne ; 54, Victoria Street, S.W.1.

F. C. Hibberd & Co., Ltd., 98, Great Tower Street, E.C.3.

J. &. F. Howard, Ltd., Bedford ; Aldwych House, W.C.2.

Hudswell, Clarke & Co., Ltd., Railway Foundry, Leeds.

Hunslet Engine Co., Ltd., Leeds ; 1, Broad Street Place, E.C.

Kerr, Stuart & Co., Ltd., Stoke-on-Trent ; 5, Broad Street Place, E.C.

Kilmarnock Engineering Co., Ltd., Kilmarnock ; 28, Kingsway, W.C.2.

Kitson & Co., Ltd., Airedale Foundry, Leeds ; 3, Victoria Street, S.W.1.

Motor Rail & Tramcar Co., Ltd., Simplex Works, Bedford.

Nasmyth, Wilson & Co., Ltd., Patricroft, Near Manchester ; 38, Parliament Street, S.W.1.

North British Loco. Co., Ltd., Glasgow ; 13, Victoria Street, S.W.1.

Peckett & Sons, Ltd., Atlas Loco. Works, Bristol ; 9, Victoria Street, S.W.1.

Robert Stephenson & Co., Ltd., Darlington ; 25, Victoria Street, S.W.1.

Sir W. G. Armstrong, Whitworth & Co., Ltd., Elswick Works, Newcastle-on-Tyne ; Kinnaird House, Pall Mall, S.W.1.

" Sentinel " Wagon Works, Ltd., Iddesleigh House, S.W.1.

Vulcan Foundry Co., Ltd., Newton-le-Willows, Lancs. ; 33, Tothill Street, S.W.1.

Yorkshire Engine Co., Ltd., Sheffield 83, Buckingham Palace Road, S.W.1.

LOCOMOTIVE ENGINEERING.

I. GENERAL CONDITIONS.

The selection of the proper **Design** for a Locomotive Engine and conversely, the criticism of the **Performance** of a Locomotive Engine must be based, as in all other machines, upon a full knowledge of the **conditions** under which the engine has to do its work, and of the **nature of the work** which it has to do. The following is a specification of such conditions as they occur in general practice, *viz*:—

Conditions imposed by Nature.

Climate. This has to be taken into account chiefly as to its dryness or humidity as affecting the state of the rails, and consequently the adhesion of the driving wheels therewith. It has further to be considered in relation to the protection of the enginemen from the direct sun, the rains and the sand storms of the tropics or from the ice and snow of the northern regions.

Water. The impurities carried in solution in the water supply must be taken into account, and if bad water must be used extra facilities must be provided for thorough "wash-outs" of the boiler. The distance between water supply stations defines the necessary storage to be provided, *i.e.*, "tank capacity," and consequently whether a Tank-engine or an Engine and Tender is necessary.

Fuel. The fuel of the country is a matter of primary importance. Coal, wood, oil, etc., have each their respective and varying characteristics to be taken into account in the construction and equipment of the furnace. Here also the distance between supply stations as affecting "bunker capacity" has to be taken into account.

Conditions imposed by the Railway Engineer.

Railway Gauges. The Rail-Gauge or distance between the rails varies on different railways from 2 ft. on light railways or "feeder lines," to 5 ft. 6 in. The gauge exercises a very great influence on the design of the engine. In actual working the narrower gauges have the effect of limiting the speed at which trains may be run, but not the tractive force, which on many engines on the 3 ft. 6 in. gauge, for example, is higher than exists in modern British railways of the 4 ft. 8½ in. gauge. A table giving the principal gauges in use in the world is given on another page.

The **Gauge of Maximum Moving Dimensions** defines at various points the maximum widths and heights of the engine. It is, on British railways, with reference to this gauge more than to the Rail-Gauge that difficulties are now being experienced

Permanent Way and Bridges. The maximum weights of the locomotive as supported by the rails at the wheels are determined by the strength of this substructure—the permanent way, bridges, etc. In ordinary practice the weight of rail in pounds per yard is usually taken as the index of this strength. Also as an empirical rule, the weight of rail, in pounds per yard, divided by 5, gives the approximate limiting axle load in tons.

Inclines. Uphill work is, as regards the loads to be hauled, the important factor of resistance with which an engine has to contend and the "rate" of the grade, varying in main line practice up to 1 in 40, and in special practice to 1 in 12½, determines the value of this factor. The length of the "up" grade and its occurrence relative to easier up grades, level or "down" grade approach has also to be taken into account in considering the steaming capacity of the boiler, and consequently chiefly the speed at which the work can be done. A profile of the line is most useful in this connection. It is also important to observe in cases of combined incline and curve if the rate of the incline has been reduced to compensate for the additional resistance. On grades of maximum rate "compensation for curvature" is usually given and an uncompensated curve may entail an additional resistance of 20% to the normal grade resistance.

Curves. The minimum radius of curves determines the maximum "Rigid wheel base" that can be adopted—this base being the distance between the centres of any group of axles on which the wheels have only the usual lateral movement between tyre flange and rail. "Main line" curves are specially to be considered, as they have to be traversed at a certain speed; "Siding curves" which are traversed at very slow speeds, and which are usually of a sharper radius than the main line minimum, may admit the use of a wheel base as determined for the latter but careful attention must be given to make sure that such is the case or a shorter base adopted. Further, special care has to be taken, especially in the case of flexible wheel base engines, *i.e.*, engines fitted with a bogie, radial-box, pony-truck or axle-boxes otherwise arranged for lateral movement, in which the buffer-beam has a considerable overhang that the correspondent movement is also allowed for in the case of the buffers and draw-gear or interlocking of buffer-heads may occur.

Turntables. The utilisation of existing turntables, which were laid down when much less onerous conditions of traffic were contemplated, has very often to be taken into account. The diameter of the table should be known, also its surroundings relative to the overhanging parts of the engine and tender, such as the buffers, cowcatchers, etc.

Conditions Imposed by the Traffic Manager.

Loads and Speeds. The prescribed load to be hauled, the type and weight of the vehicles to be used, and the time to be taken between stations complete the necessary information on which may be based a calculation as to the necessary engine power, or on which may be based a criticism of an engine's performance.

Government Regulations are practically non-existent, as regards locomotives, in Great Britain. In such countries where they do exist and are enforced they are usually confined within the limits of the following list, *viz:*

Boiler Fittings such as Safety-Valves, Pressure-Gauges, Stop-Cocks on certain mountings, Water-level indicators and Speed indicators.

Spark-Arresters in the Smoke-box and at the Ash-pan dampers.

Wheel Tyre profiles.

Buffing and Draw-gear. Safety Chains.

Feed Pump.

Tank Water-Gauge.

Continuous Automatic-Brake Apparatus.

Example of Specification of General Conditions.

Climate, Water and Fuel ..English.

Water Stations ....50 Miles apart.

Coal „ ....100 „ „

Rail Gauge ....4 ft. 8½ in.

Loading Gauge ....English.

Inclines ....Maximum—1 in 100 for 5 miles, with easy approach.

Curves ....Minimum—1000 ft. radius on Main line and 600 ft at sidings.

Turntables................60 ft diameter.

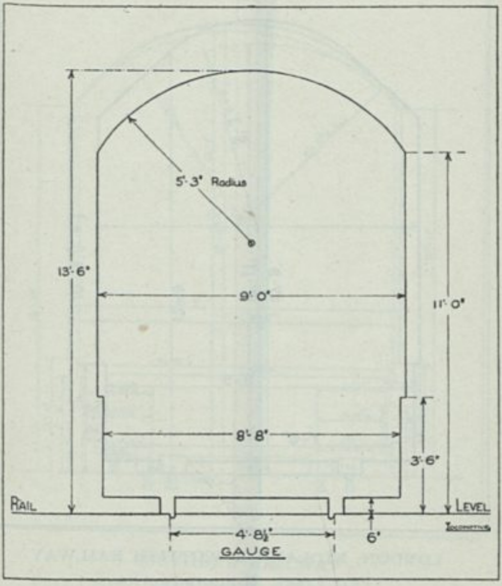
Load ....300 Ton gross weight of Express Passenger train of double bogie vehicles.

Speed ....60 Miles per hour on the level and an average of 30 miles per hour on the maximum grade.

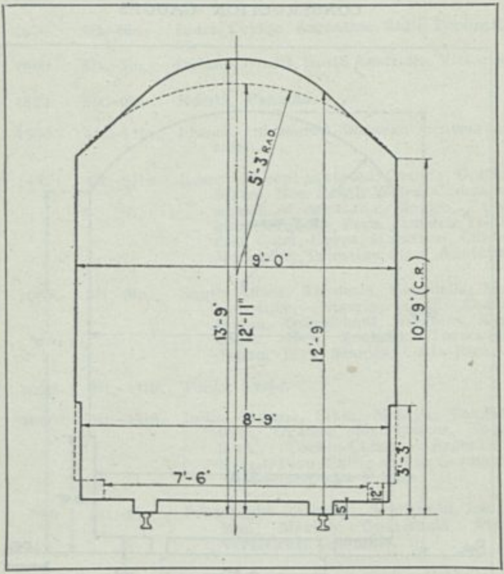
RAILWAY GAUGES

Metric	*British*	
1680	5ft.–6½in.	Spain.
1676	5ft.–6in.	India, Ceylon, Argentine, Chili, Portugal.
1600	5ft.–3in.	Ireland, Brazil, South Australia, Victoria.
1524	5ft.–0in.	Russia, Panama.
1500	4ft.–11in.	France (measured between centres of rails).
1435	4ft.–8½in.	Europe (except as stated) Canada, United States, New South Wales, Commonwealth of Australia, Mexico, Paraguay, Uruguay, Peru, Jamaica, Trinidad, Cuba, Egypt, Mauritius, China, Hongkong, Palestine, Siam, Anatolia
1067	3ft.–6in.	South Africa, Rhodesia, Benguella, Mozambique, Nigeria, Gold Coast, Sudan, Queensland, Western Australia, New Zealand, Tasmania, Japan, Java, Manila, Costa-Rica.
1050	3ft.–5⅜in.	Tunis, Syria.
1000	3ft.–3⅜in.	India, Burma, Siam, Malaya, Tanganyika, Uganda, Madagascar, Togoland, Cochin-China, Argentine, Brazil, Peru, Chili; and in Germany, Switzerland and France.
760	3ft.–0in.	Irish Light Railways, Southwold, Isle of Man, Mexico, Guatemala, Peru, Vera-Cruz, Colombia.
760	2ft.–6in.	India, Cyprus, Sierra Leone, Gold Coast. San Domingo.
686	2ft.–3in.	Scotland (Machrihanish).
610	2ft.–0in.	India (Darjeeling) South African Light Railways.
597	1ft.–11½in.	Great Britain (Festiniog, Welsh Highland and Lynton and Barnstaple)
381	1ft.–3in.	England (Ravenglass and Eskdale and Romney, Hythe and Dymchurch.)

CONSTRUCTION GAUGES



ENGLAND (AVERAGE)
GAUGE, 4 ft. 8½ in.

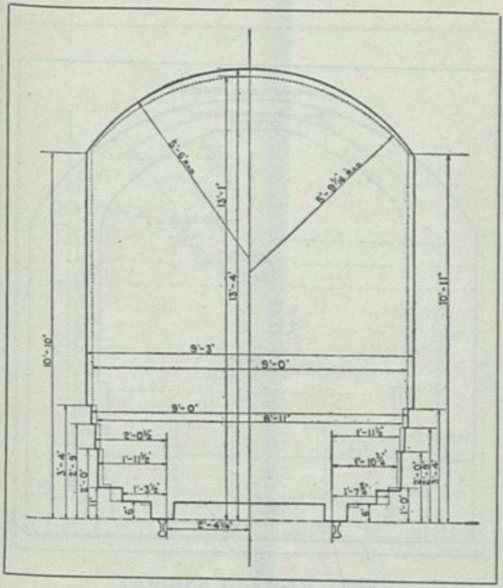


LONDON, MIDLAND & SCOTTISH RAILWAY

FULL LINES, MIDLAND SECTION

DOTTED ,, CALEDONIAN ,,

Gauge, 4 ft. 8½ in.

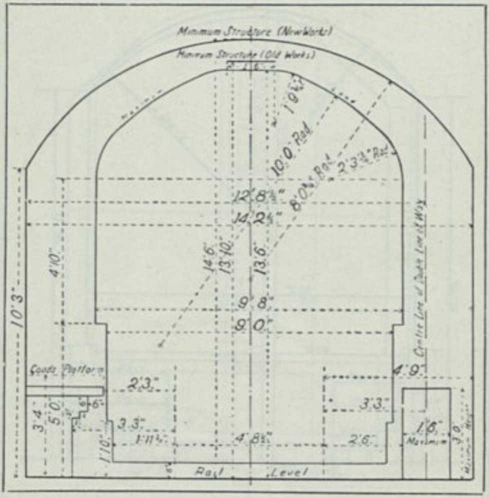


SOUTHERN RAILWAY

Full Lines, South Western Section

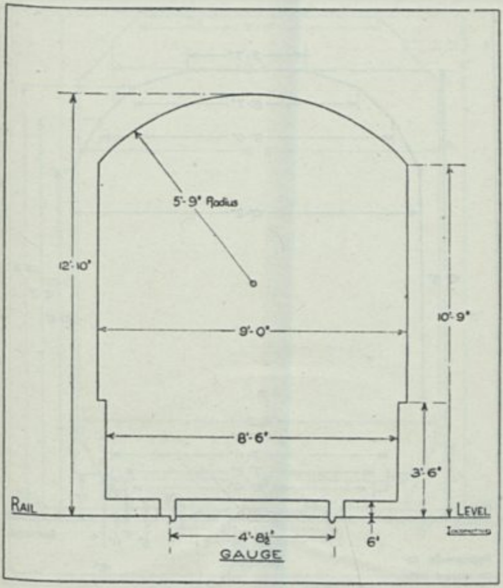
Dotted ,, South Eastern & Chatham Section

Gauge, 4 ft. 8½ in.

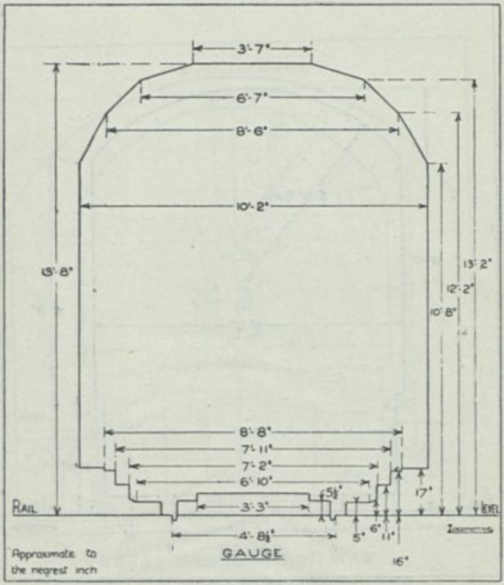


GREAT WESTERN RAILWAY

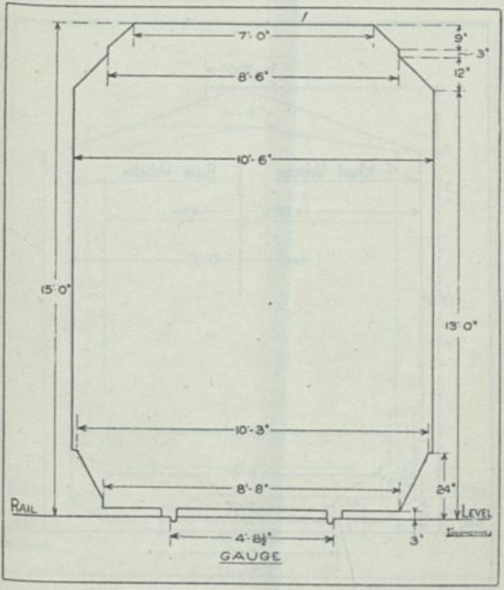
Gauge, 4 ft. 8½ in.



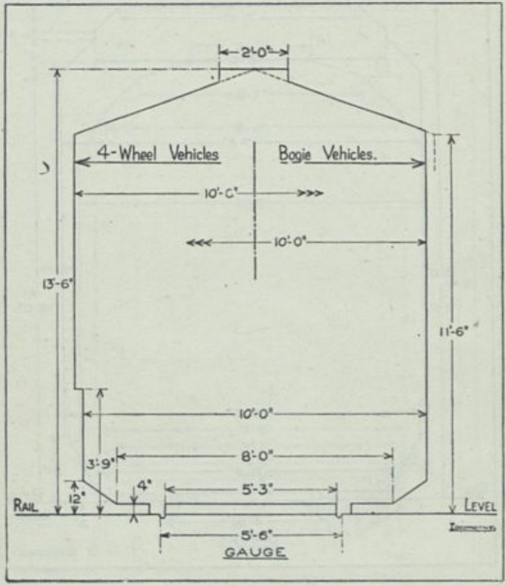
SCOTLAND (Average)
Gauge, 4 ft. 8½ in.



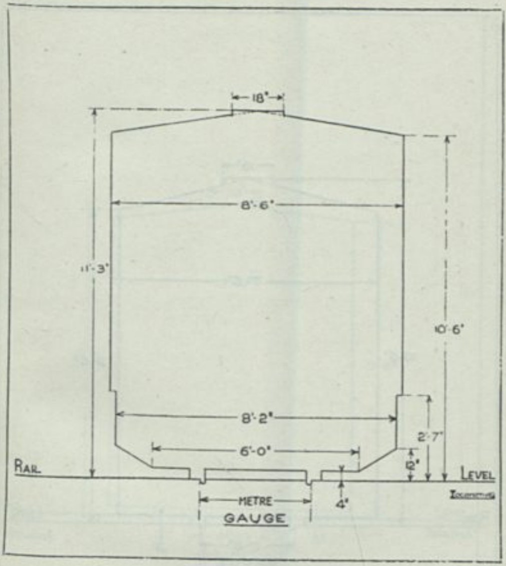
EUROPE (PASSE-PARTOUT)
Gauge, 4 ft. 8½ in.



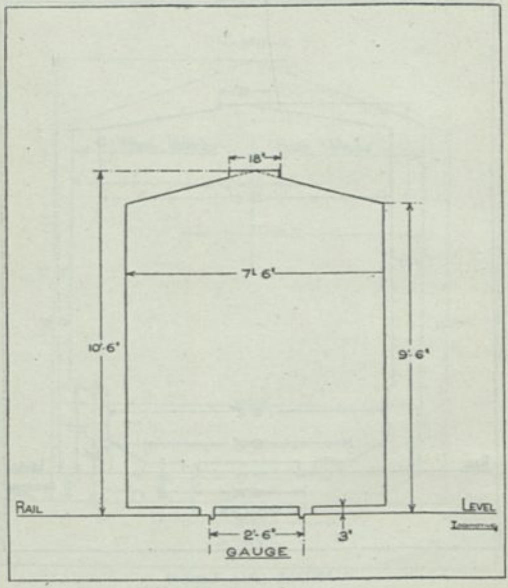
UNITED STATES (Eastern Roads)
Gauge, 4 ft. 8½ in.



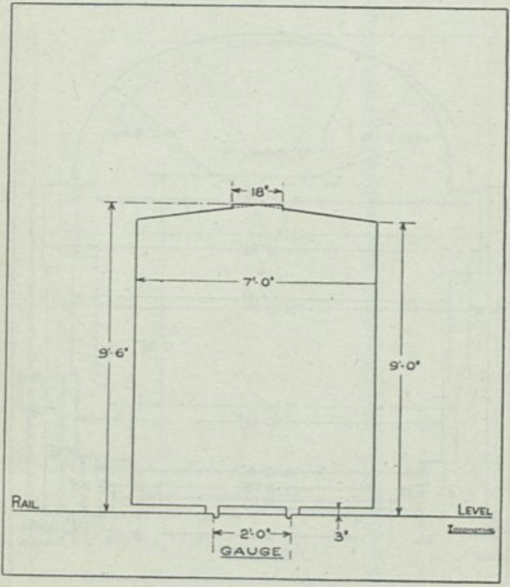
INDIA (Present Limitation)
Gauge, 5 ft. 6 in.



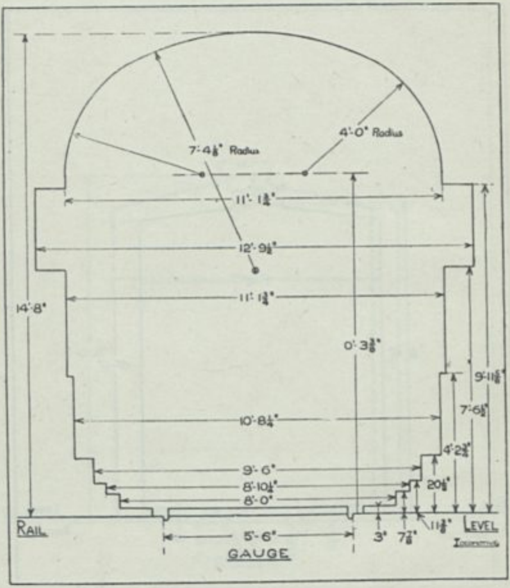
INDIA (ALL LINES)
Gauge, Metre.



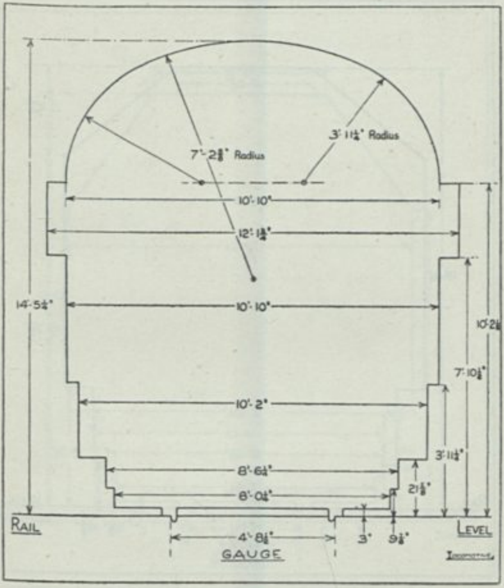
INDIA (ALL LINES)
Gauge, 2 ft. 6 in.



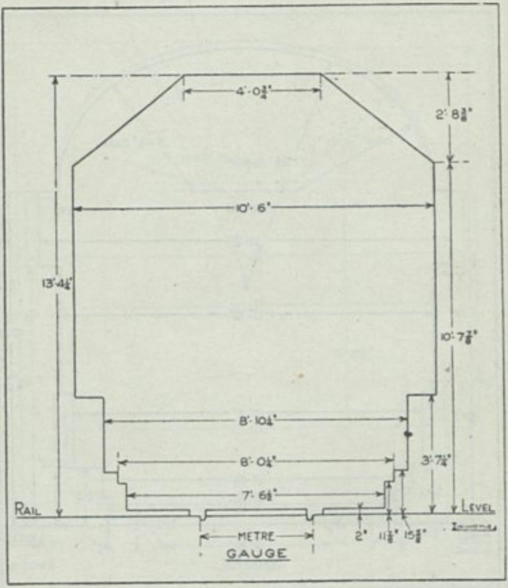
INDIA (ALL LINES)
Gauge, 2 ft. 0 in.



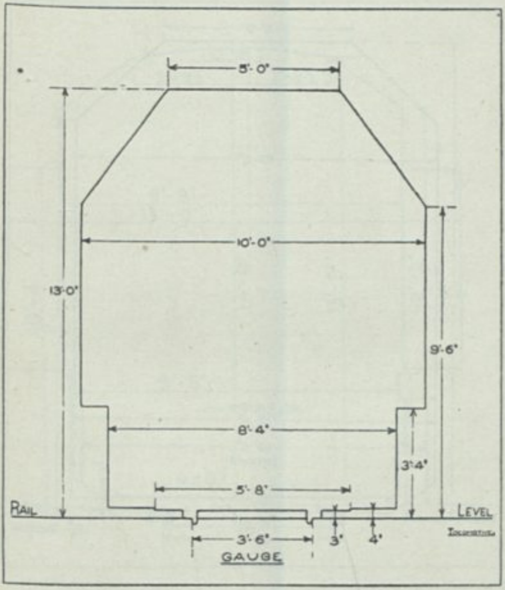
ARGENTINE (Government Requirements)
Gauge, 5 ft. 6 in.



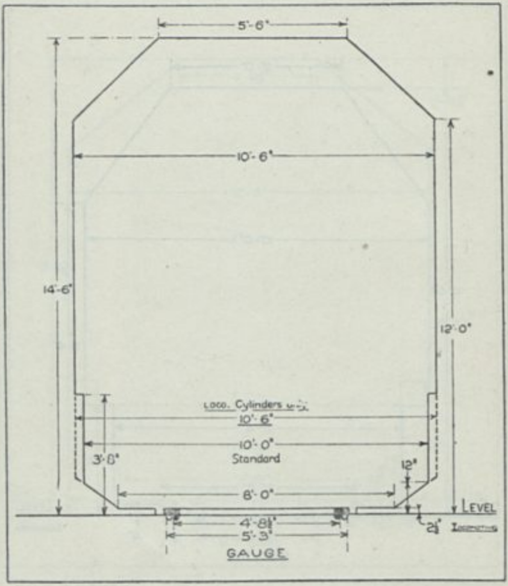
ARGENTINE (Government Requirements)
Gauge, 4 ft. 8½ in.



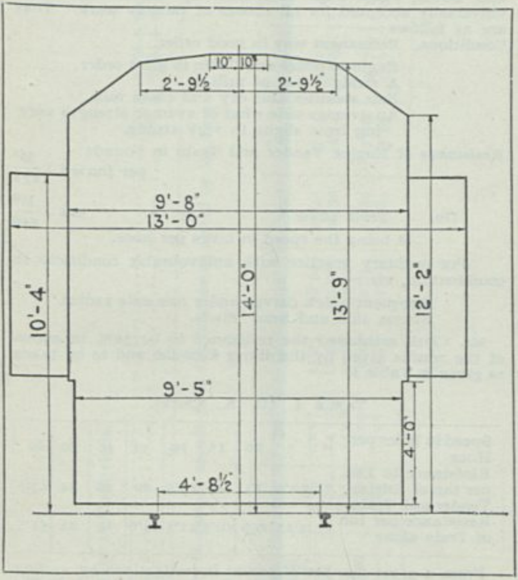
ARGENTINE (Government Requirements)
Gauge, Metre.



SOUTH AFRICA (GOVERNMENT LINES)
Gauge, 3 ft. 6 in.



AUSTRALIA (Commonwealth)
Gauges, 4 ft. 8½ in., 5 ft. 3 in.



NEW SOUTH WALES GOVERNMENT RYS.
Gauge, 4 ft. 8½ in.

II. RESISTANCE OF TRAINS.

(1) Resistance on the level.

D. K. Clark, in his work on "Railway Machinery," published in 1855, stated formulæ for the resistance of locomotives and trains, which until comparatively recent times were universally accepted for all classes of railway work. They are as follows :—

Conditions. Permanent way in good order.

Engine Tender and Train in good order.
A straight line of rails.
Fair weather and dry and clean rails.
An average side wind of average strength varying from slight to very strong.

Resistance of Engine Tender and Train in pounds per ton $=8+\frac{M^2}{171}$

Do. Train alone do. $=6+\frac{M^2}{240}$

M being the speed in miles per hour.

For ordinary practice with unfavourable conditions in combination, *viz.*:—

Frequent quick curves under one mile radius.
Strong side and head winds.

Mr. Clark estimated the resistance to be 50% in excess of the results given by the above formulæ and to be taken as given in Table I.

TABLE I. (D. K. Clark).

Speed in Miles per Hour	5	10	15	20	30	40	50	60
Resistance in Lbs. per ton of Engine, Tender and Train	12·2	13	14	15·5	20	26	34	43·5
Resistance per ton of Train alone	9·15	9·6	10·5	11·4	14·6	19	24	31·5

From a great number of recent investigations by various European experts, Mr. L. H. Fry has published ("The Engineer," Vol CVII), a series of mean formulæ of which the undernoted are approximate equivalents in terms of a unit of 1 ton (2240 lbs.), instead of a unit of 1,000 lbs.

Resistance in lbs. per ton of an **Engine with Tender.**

4 Wheels coupled	(79 in. Drivers) ..	$8·5 + ·0974M + ·004M^2$
6 „ „	(„) ..	$10·08 + ·126M + ·004M^2$
8 „ „	(56 in. Drivers) ..	$13·34 + ·48M + ·004M^2$

Resistance in lbs. per ton of **Train alone.**

4 Wheeled Wagons .... $3·6 + ·07M + ·0027M^2$
Bogie Coaches .... $3·6 + ·03M + ·0022M^2$

Table II. gives results at various speeds from the formulæ as stated by Mr. Fry.

TABLE II.

Speed in Miles per Hour ..	10	20	30	40	50	60	70	80
Resistance in lbs. per ton								
of 4 coup. Eng. with Tr.	9·88	12·07	15·05	18·86	23·45	28·85	35·05	42·06
6 ,, ,,	11·74	14·22	17·50	21·57	26·50	32·14	38·64	
8 ,, ,,	18·55	24·46	31·18	38·70				
of Four-wheeled Wagons	4·57	6·09	8·15	10·75	13·89	17·56	21·77	26·52
Bogie Coaches	4·09	5·06	6·47	8·33	10·64	13·39	16·77	20·24

Resistances on Rising Grades.

The Grade is a simple example of the "inclined plane." The proportion of the resistance to the weight is in ratio of the units of "rise" or "perpendicular" to units of length or "base"—the hypotenuse in this case is usually taken for simplicity, the difference being immaterial. Thus if the Grade be 1 ft. rise in 100 ft. and the Weight of the train be 1 ton or 2240 lbs. the resistance will be $\frac{2240}{100}$ or 22·4 lbs. In ordinary practice the Grade is variously stated as "rise in feet per mile" of length, length per unit rise, rise per cent. and rise per thousand. Thus a Grade of 1 in 100 may be described as a 1% (one per cent.) grade, as 10‰ (ten per thousand or per mille) grade or 10 m/m per metre, and as a 52·8 feet per mile grade.

TABLE III.

Gradient, 1 in.	20	25	30	35	40	45	50
Do. feet per mile	264	211·2	176	150·9	132	117·3	105·6
Do. per cent. (%)	5	4	3·3	2·8	2·5	2·2	2·
Do. Per mille. (‰) or m/m per M.	50	40	33·3	28·6	25	22·2	20
Resistance in Lbs. per ton. ..	112	89·6	74·7	64	56·	49·8	44·8

Gradient, 1 in.	55	60	70	80	100	120	150	200	300	400	500
Do. feet per mile	96·0	88·0	75·4	66·0	52·8	44·0	35·2	26.4	17·6	13·2	10·6
Do. per cent. (%)	1·8	1·6	1·4	1·2	1·0	·83	·66	·5	·33	·25	·2
Do. Per mille. (‰) or m/m per M.	18·2	16·6	14·3	12·5	10	8·33	6·66	5	3·33	2·5	2
Resistance in Lbs. per ton. ..	40·7	37·3	32·0	28·0	22·4	18·7	14·9	11·2	7·5	5·6	4·5

(3) Resistance on Curves.

It is not generally necessary to take this resistance into account as it is usually equated by a lowering of the speed, but in special circumstances or where curves are very greatly in evidence it may be most important that due allowance should be made for them. This resistance is caused by the additional friction developed by the slipping of the wheels due to the difference in the length of the inner and outer rails on the curve, and by the non-radial position of axles (due to their distance apart or "fixed wheel-base" in relation to the curve). Morison in the "Transactions of the Civil Civil Engineers," Vol. XXXI. formulated as under for these conditions, *viz.*:—

Resistance in Lbs. per Ton $= 2240 \frac{D+L}{2R} \times f$, where "D" = Rail Gauge, "L" = Rigid Wheel-base; "R" = Radius of Curve, all being in similar terms, and "f" a coefficient of friction varying from 0·1 to 0·27.

In American practice, the recommendation of the Master Mechanics' Association, presumably for U.S. conditions as to 4 ft. 8½ in. gauge and cars with short rigid wheel-base, is that 0·7 pound per ton, per degree of curvature be allowed for cars and 1·4 for locomotives. A 1° curve is approximately 5,730 feet; a 2° is 2,865 feet; a 5° is 1,146 feet, etc., and the American "ton" is 2,000 lbs. In this case the formula is:—

Resistance in lbs. per 2,000 lbs $= \frac{5730}{R} \times a$

Do per ton (2240 lbs).) $= \frac{573}{R} \times b$

Where R is the radius of the curve in feet, a is a constant having values of 0·7 for Cars and 1·4 for Locomotives, for the 2,000 lbs. Ton, and b is a constant having values proportionately of 0·78 and 1·56 for the 2,240 lbs. Ton.

Curves are usually specified in terms of their radius in chains, feet or metres or as in U.S. practice, referred to above, in degrees of curvature.

TABLE IV.

Car Resistance on Curves on the 4 ft. 8½ in. Gauge and 8 ft. Base.

f is taken at 0·27 for Morison's Formula.

b is taken at 0·78 for U.S. Formula.

Radius in Chains	6	10	15	30	87
Do. Feet	396	660	990	1980	5730
Do. Metres	120·6	201·1	301·6	603.4	1747
Degrees of Curvature	14·5	8·7	5·8	3	1
Resistance in lbs. per ton.					
Morison's formula	9·7	5·7	3·8	1·9	0·67
U.S. Do.	11·3	6·6	4·5	2·3	0·78

TABLE V.

Car Resistance on Curves. Various Gauges. 12 ft. Wheel-base. Morison's Formula. f=0·27.
Resistance is given in lbs. per ton for 15 Chain Curve.
For other curves the resistance is inversely proportional to the radius. Thus, for a 4 Chain Curve, multiply the figure given in the table by 15 and divide by 4.

Rail Gauge	2′ 0″	2′ 6″	3′ 0″	3′ 3½″	3′ 6″	4′ 8½″	5′ 3″	5′ 6″
Resistance in lbs. per ton.	4·3	4·4	4·6	4·67	4·7	5	5·26	5·4

Acceleration.

The Resistances exemplified in Tables I. and II. are for **uniform** velocity rates. There is a further resistance to be considered, *viz.*: that which the inertia of the train offers to a gradual increase in velocity. The force overcoming this resistance is called the accelerating force. The formulæ given below are modified from the usual text-book standard in respect that the resistance is given in pounds **per ton** and the velocities in **miles per hour.**

M=Higher velocity in **miles per hour** at close of selected period or space.
m=Lower velocity in **miles per hour** at beginning of selected period or space.
If the beginning is from zero then "m"=0 and M—m=M.
S =Space or distance in **Feet** over which the acceleration takes place.
t =Time or period in **Seconds** during which the acceleration takes place.

$$\text{Resistance in Lbs. per ton} = 74{\cdot}8\,\frac{(M^2-m^2)}{S} \text{ or } 101{\cdot}7\,\frac{M-m}{t}$$

Making an allowance for the **rotary** acceleration of the wheels and **axles** entails a further modification—giving finally :—

$$\text{Resistance in lbs. per ton} = 80\,\frac{(M^2-m^2)}{S} \text{ or } 108\,\frac{M-m}{t}$$

Example 1. "Time" Basis.

A train of 450 tons (Engine and Tender included) starts from a station, and in 1 minute is running at a velocity of 16 miles per hour, in 2 minutes from start at 25 m.p.h., in 4 minutes at 42 m.p.h., and in 6 minutes at 50 m.p.h. The **extra** resistances due to acceleration are as under, *viz.* :—

1st stage. From zero to 16 m.p.h. in 60 seconds.

$$\text{Resistance in lbs. per ton} = \frac{108\ M}{t} = \frac{108 \times 16}{60} = 28{\cdot}8$$

Do., total for 450 tons=450 × 28·8=12,960 lbs.

2nd stage. From 16 to 25 m.p.h. in 60 seconds.

Resistance in lbs. per ton $\frac{108\,(M-m)}{t}=\frac{108\times(25-16)}{60}=16\cdot$.

Do., total for 450 tons $=450\times16\cdot2=7290$ lbs.

3rd stage. From 25 to 42 m.p.h. in 120 seconds.

Resistance in lbs. per ton $\frac{108\,(M-m)}{t}=\frac{108\,(42-25)}{120}=15\cdot3$

Do., total for 450 tons $=450\times15\cdot3=6885$ lbs.

4th stage. From 42 to 50 m.p.h. in 120 seconds.

Resistance in lbs. per ton $\frac{108\,(M-m)}{t}=\frac{108\,(50-42)}{120}=7\cdot2$

Do., total for 450 tons $=450\times7\cdot2=3240$ lbs.

In the above examples the distances run in the various stages are :—

	Mean speed.		Time.		Distance.
1st stage	8 m.p.h.	......	1 min.	......	704 Feet.
2nd „	20½ „	......	1 „	....	1804 „
3rd „	33½ „	......	2 „	....	5896 „
4th „	46 „	......	2 „	....	8096 „
			Total distance		16,500 Feet

Example 2. "Distance" Basis.

A train of 450 tons (Engine and Tender included) starts from a station and at a distance of 704 feet is running at a velocity of 16 m.p.h.; 1804 feet further on at 25 m.p.h.: 5896 feet further on at 42 m.p.h.: and at 8096 feet, still further, at 50 m.p.h. The extra resistances due to acceleration are as under, *viz.* :—

1st stage. From zero to 16 m.p.h. in a distance of 704 feet

Resistance in lbs. per ton $=\frac{80\,(M^2)}{S}=\frac{80\times16^2}{704}=29$

Do. Total for 450 tons $=450\times29=13,050$ lbs.

2nd stage. From 16 to 25 m.p.h. in 1804 feet

Resistance in lbs. per ton $=\frac{80\,(M^2-m^2)}{S}=\frac{80\,(25^2-16^2)}{1804}=16\cdot3$

Do. Total for 450 tons $=450\times16\cdot3=7335$ lbs.

3rd stage. From 25 to 42 m.p.h. in 5896 feet.

Resistance in lbs. per ton $=\frac{80\,(M^2-m^2)}{S}=\frac{80\,(42^2-25^2)}{5896}=15\cdot4$

Do. Total for 450 tons $=450\times15\cdot4=6930$ lbs.

4th stage. From 42 to 50 m.p.h. in 8096 feet.

Resistance in lbs. per ton $=\frac{80\,(M^2-m^2)}{S}=\frac{80\,(50^2-42^2)}{8096}=7\cdot2$ lbs.

Do Total for 450 tons $=450\times7\cdot2\times3240$ lbs.

Note.—The slight difference in the results obtained from the two methods of working out the same problem is due to the fact that, in order to obtain simple constants, the percentage allowance, for **rotary acceleration** of the wheels and axles, is not the same in the two equations.

RESISTANCE OF TRAINS.

General Examples.

In the following examples, the case taken for illustration is that of a train of Bogie-coaches weighing 337 tons with a 6-coupled engine and tender weighing 113 tons.

Example I. On the level and straight road at 60 miles per hour.

		Cars.	E. & T.
Resistance in lbs. per ton at 60 m.p.h. (Table II.)		13·39	32·14
Do. Total for train	337 × 13·39 =		4512 lbs.
Do. Total for Engine and Tr.	113 × 32·14 =		3632 ,,
	Total		8144 ,,

Example II. On an incline of 1 in 100 at 30 m.p.h.

	Cars.	E. & T.
Resist. in lbs. per ton at 30 m.p.h. (Table II.)	6·47	17·50
Do. do. on 1/100 (,, III.)	22·4	22·4
Do do Total	28·87	39·9

Do. Total for train	337 × 28·87 =	9730 lbs.
Do. Total for E. and T.	113 × 39·9 =	4508 ,,
	Total	14,238 lbs.

Example III. On an incline of 1 in 100, with curves of 30 chains radius at 30 m.p.h.

	Cars.	E. & T.
Resist. in lbs. per ton as per Ex. II.	28·87	39·9
Do.do., for 30 chain curve (Table IV.)	1·9	3·8
Do. do. Total	30·77	43·7

Do. Total for train ..	337 × 30·77 =	10,369 lbs.
Do. Total for E. and T.	113 × 43·7 =	4,938 ,,
	Total	15,307 lbs.

Example IV. On an incline, 1 mile long, of 1/100, with curves of 30 chains radius, at an "approach" speed of 28 m.p.h. increasing to 32 m.p.h. at summit of grade.

		Cars.	E. & T.
Resist. in lbs. per ton as per Ex. III.		30·77	43·7
Do. do., due to acceleration	$\frac{80 \times (32^2 - 28^2)}{5280}$	3·63	3·63
Do. do.	Total	34·4	47·33

Do. Total for train	337 × 34·4 =	11592·8	lbs.
Do. Total for E. and T.	113 × 47·33 =	5348·2	„
	Total	16941	lbs.

Example V. As per Ex. IV, but with an "approach" speed of 32 m.p.h., decreasing to 28 m.p.h. at summit of grade.

Resist. in lbs. per ton as per Ex. III.			30·77	43·7
Do.	do.	"Negative" Accn.	3·63	3·63
Do.	do.	Total (being diff.)	27·14	40·07

Do. Total for train	337 × 27·14 =	9146·18	lbs.
Do. Total for E. and T.	113 × 40·07 =	4527·91	„
	Total	13674	lbs.

Example VI. As per Ex. IV., but with an "approach" speed of 40 m.p.h., decreasing to 20 m.p.h. at summit of grade, the average speed being thus 30 miles per hour as in the three previous examples.

Resist. in lbs. per ton as per Ex. III.			30·77	43·7
Do.	do.	"Negative" Accn.	18·1	18·1
Do.	do.	Total (being diff.)	12·67	25·6

Do. Total for train	337 × 12·67 =	4269·8	lbs.
Do. Total for E. and T.	113 × 25·6 =	2892·8	„
	Total	7162·6	lbs.

III. LOCOMOTIVE POWER.

The Maximum Power of any Locomotive is its Boiler Power, *i.e.*, its steam producing capacity. The Fuel (amount and quality) used in a stated time is the limitation of that power and over a given distance its commercial rating as to traffic working. In the latter case the rating is stated either as " Pounds of fuel per mile " or " Pound of fuel per ton-mile." For present purposes, a better defined rating relative to the work done and the speed at which it is done, has to be adopted and that rating is " Pounds of fuel per horse-power per hour."

Locomotive engineering practice differs from almost all other forms of Steam-engine practice in respect that it has no recognised standard of high economy for this rating and for the sufficient reason that comparisons of the results from locomotives working under various load, speed and weather conditions involve calculations of too complicated a nature, and that isolated experimental tests cannot be more than approximately true of average working conditions. From the results of the latter method, however, it may be taken that 3½ pounds of good English Coal per horse-power per hour represents economical working under saturated steam conditions, this quantity being reduced to 2·1 or 2·2 pounds in the case of a well-designed superheated engine.

Locomotive Power falls to be considered under its own three natural divisions, *viz.* :—Boiler-power, Engine-power and Adhesion.

BOILER POWER.

This is dependent on the amount and quality of the fuel and the efficiencies of the furnace, and of the heat absorbing surfaces. The amount of fuel that may be dealt with is rated in terms of " Pounds of fuel burned per square foot of Grate per hour," and this rate varies in ordinary working from 60 to 200. The latter rate, however, represents very uneconomical working. In designing, therefore, every effort should be made to ensure the engine meeting its peak steam demand at a very much lower rate of firing, say 130, than that indicated by the higher limit previously mentioned. The efficiency of the furnace falls as this rate rises, it varies with the volume of the fire-box and with such further special arrangements as may be made for facilitating complete combustion as for example a "Brick-arch" or in cases of "clinkering" coal a Rocking grate. The amount of heat dealt with is rated in terms of the evaporation secured, viz.: "Pounds of water" evaporated per square foot of total "Heating-surface per hour." This efficiency is limited only by the terms of the surface-exposure and the relative temperatures of the boiler-water, and that of the gas leaving the flues.

COMBUSTION AND EVAPORATION.

The quantity of heat required to raise one pound of water one degree Fahrenheit higher in temperature, is termed a " British Thermal Unit " (B.Th.U.).

The quantity of heat required to evaporate one pound of steam at 212° Fahr. from one pound of water at 32° Fahr. is 966 B.Th.U.

The quantities of heat required to evaporate one pound of steam at any given temperature in degrees Fahr.; or at the corresponding pressure in pounds per square inch, from water at 32° Fahr., are given in the "Table of the Properties of Steam."

For the complete combustion of one pound of good coal, as ascertained by a calorimeter test, 14,500 B.Th.U. is usually taken as a representative value. The best qualities, as may be seen from the tables given below, may develop over 15,000 B.Th.U., and poor qualities may not be value for 10,000 B.Th.U.

For the determination of the heat-value of fuel, two methods are in use, *viz.* :—The bomb-Calorimeter and analytical examination. The latter may be "ultimate," *i.e.*, a determinate of the elements, carbon, hydrogen, sulphur, etc., or "proximate," *i.e.*, a determinate, for commercial purposes, of the quantities of fixed carbon, volatile combustible matter, ash and moisture.

For a given sample of fuel, the calorific value can only be definitely ascertained by a bomb-calorimeter test. For elucidation and comparison analytical statements are valuable.

The heat value may also be approximately calculated from the ultimate analysis by the following formula (Dulong's as modified by Gray & Robertson).

C. H. O. and S. denote the respective percentages of Carbon, Hydrogen, Oxygen and Sulphur, as per analysis.

Quantity per lb. in B.Th.U.=

$$\frac{1}{100}\left\{1465C + 62100\left(H - \frac{O+N-1}{8}\right) + 4000S.\right\}$$

Table VI. exemplifies the results from this formula as applied to a few characteristic samples of Scotch coals (Gray and Robertson Journ. Soc. Chem. Indus. 1904) in which the Carbon varies from 62·55 to 85·7%. The "calculated" results show that variation from bomb tests is greatest in the large oxygen contents. The "proximate compositions" as calculated from the analysis by Messrs. Coste & Andrews are also given.

TABLE VI.

Carbon ..	62·55	65·5	69·50	73·77	77·00	85·7
Hydrogen ..	3·87	4·23	4·42	4·55	4·51	2·97
Sulphur ..	1·62	0·67	0·67	0·41	0·78	0·62
Water ..	8·63	7·92	9·28	7·99	2·31	3·15
Ash ..	11·78	10·15	5·97	1·76	7·17	3·59
Oxygen and Nitrogen ..	11·55	11·53	10·16	11·52	8·23	3·97
	100·00	100·00	100·00	100·00	100·00	100·00
Coke	61·74	61·06	59·12	56·93	74·61	92·03
Fixed Carbon	49·96	50·92	53·15	55·17	67·44	88·44

PROXIMATE COMPOSITIONS.

Moisture ..	8·63	7·92	9·28	7·99	2·31	3·15
Volatile matter	29·63	31·01	31·60	35·08	23·08	4·82
Fixed Carbon	49·96	50·92	53·15	55·17	67·44	88·44
Ash	11·78	10·15	5·97	1·76	7·17	3·59
	100·00	100·00	100·00	100·00	100·00	100·00
Bomb test, B.Th.U. ..	10940	11590	12404	13086	13516	14232
Calculation B.Th.U. ..	10813	11437	12247	12838	13554	14097

For some other fuels in general use Tables VII. and VIII. give representative values.

TABLE VII.

FUELS—Average Thermal Values per pound (Lewes).

	Cals.	B.Th.U.		Cals.	B.Th.U.
Coal—			Wood—		
Newcastle	8446	15203	Elm	4728	8570
Welsh	8402	15123	Ash	4711	8480
Lancs.	8113	14602	Oak	4620	8316
Derbys.	8120	14616	Petroleum		
Anthracite	8677	15619	Fuel —		
Coke—			American	10904	19627
Oven	8020	14436	Russian	10800	19440
Peat—			Texas	10700	19242
30% wat.	3000	5400	Caucasus	10340	18611
10% wat.	5000	9000	Borneo	10461	18831
Wood—			Burma	10480	18864
Pine	5085	9153	Petroleum		
Fir	5035	9063	(·684)	11624	20923
Beech	4774	8591	Shale Oil	10120	18217
Birch	4771	8586			

TABLE VIII.

LIQUID FUELS ("Holden"), Instn. C.E. 1910-11.

	Spec. Grav.	Flash pt.	Water evap. f. & a 212°		B.Th.U. *
			G.E.R. prac.	Theoretical.	
			lbs.	lbs.	
Creosote	1·075	180° F.	12·5	17·4	16810
Coal-gas Tar	1·220	150° F.	11·6	15·6	15070
Russian Astaki	0·900	200° F.	14·0	21·0	20290
Texas Oil	0·935	150° F.	13·5	20·3	19610
Borneo Oil	0·960	170° F.	13·5	20·3	19610
Green Oil	1·115	220° F.	12·7	17·3	16710
Oil Gas Tar	1·070	120° F.	12·8	17·8	17200

* The B.Th.U. is calculated as = Evaporation (Theoretical) × 966.

The calorimeter test gives the "**Higher Calorific Value,**" and represents the total heat produced by combustion until the products are cooled to a temperature of 64° Fahr.

The "**Lower Calorific Value**" represents the heat produced until the products are cooled to a temperature of 212° Fahr.

In the combustion of fuel in a boiler furnace it is not possible to lower the temperature of the furnace gases below that of the water in the boiler. The net Heat Value in such case is termed the "**Available Calorific Value.**"

Further, in the Calorimeter test the combustion agent is pure oxygen, and in the boiler furnace Air, a mixture of Oxygen and Nitrogen, is used. The nitrogen takes no part in the combustion; it passes through the furnace and carries away a considerable amount of heat.

The following example of these values for Nixon's Navigation Coal is derived from Prof. Dalby's "Steam Power" and for the "Available Calorific Value" the temperature of the water in the boiler is taken at 356° Fahr.

Higher Calorific Value	..	15,300 B.Th.U.
Lower " "	..	14,940 "
Available " "	..	14,020 "

For an assumption of 14,500 B.Th.U., it will thus be evident that an approximate value of only 13,300 B.Th.U., can be taken as the "Available Calorific Value under ordinary boiler conditions."

Under ordinary boiler conditions the " Available Calorific Value " is, however, not usually realised. The formation of " Black Smoke " and " Carbon Monoxide " lowers the efficiency. Under the extraordinary conditions of Locomotive running, the demand on the boiler is a continuously varying quantity, ranging between zero and utmost capacity. Professor Nicholson (Trans.: Engineers and Shipbuilders, Scotland, Vol. LIV.) from investigations of the Louisiana and other tests, estimated that the loss due to unburned or partly burned fuel being drawn through the flues varied with the rate of firing, thus :—

If F=The rate of firing in pounds per square foot of grate per hour.
and H=Heat capacity of one pound of fuel in B.Th.U.
then 50F=Loss in B.Th.U. per pound of fuel. and F × (H—50F)=Total heat produced per square foot of grate per hour.

TABLE IX.

(Available Heat Value of one lb. Fuel, 13,300 B.Th.U.)

F	30	60	90	120	150
H—50F	11800	10300	8800	7300	5800
$\frac{H-50F}{966}$	12·2	10·6	9·1	7·6	6

The Heat developed in the Furnace is communicated to the heating surfaces of the boiler. In the Firebox the **Radiant heat** from the incandescent fuel acts on the walls of the firebox, *i.e.*, the " Firebox heating surface." In the firebox, heat is also **conducted** through the walls, but the amount is negligibly small, and probably also through the flame particles of carbon. **Convected heat** from the hot gases acts on the walls of the flues.

Evaporation from Firebox Surfaces. For the estimation of **Radiant heat,** Stefan & Boltzman's formula is generally accepted, but for its use the temperature of the furnace must be known.

The temperature of the furnace may be estimated from an analysis of the products of combustion or from an analysis of the fuel. The former is the more reliable method, if the whole of the constituents of the products are known. In the other method the quantity of air used with the fuel has usually to be assumed, and this is capable of variation between very wide limits. From the heat capacity of the fuel and of the products of combustion (weights and mean specific heat of the constituents of the products), the **Temperature of the furnace** can be ascertained. The method is similar to that employed below, in which, however, the "products" are estimated from the fuel constituents, only :—

Let C, H, S and O indicate respectively the proportions of Carbon, Hydrogen, Sulphur and Oxygen in one pound of the fuel, then the **weight of air** (A), theoretically, necessary for its complete combustion will be :—

$$A = \frac{2\tfrac{2}{3} C + 8 H + S}{0{\cdot}231}$$

and the minimum weight of the products of combustion (P) will be

$$P = A + O + C + H + S$$

If, for example, the respective weights of the elements in one pound of fuel are ·86 lb. C ; ·04 lb. H ; ·01 lb. S and ·02 lb. O, then Weight of air required

$$A = \frac{(2^2/3 \times {\cdot}86) + (8 \times {\cdot}04) + {\cdot}01}{0{\cdot}231} = 11{\cdot}25.$$

and the weight of the products of combustion (P) will be :—

$$P = 11{\cdot}25 + {\cdot}02 + {\cdot}86 + {\cdot}04 + {\cdot}01 = 12{\cdot}18.$$

An excess of air is usually admitted to the furnace, and may amount to double the amount theoretically required. In the Louisiana tests the products weighed from 20 lbs. with a rate of firing of 30 lbs. per sq. ft. of grate per hour, to 15 lbs. with a rate of 140.

To ascertain the temperature in degrees Fahr., of the furnace

let H = Total heat value of one pound of the fuel,
P = Weight of products of combustion per lb. of fuel.
S = Mean specific heat of the products (this may be taken at 0·24).

then T = H and PS.

Thus for a fuel value of 14,500 lbs., and a weight of products of 12·18, the theoretical temperature would be :—

$$T = \frac{14500}{12{\cdot}18 \times 0{\cdot}24} = 5000^{\circ} \text{ Fahr.}$$

If double the quantity of air be admitted to the furnace the weight of the products would be 12·18 + 11·25 = 23·43

$$\text{then } T = \frac{14500}{23{\cdot}43 \times 0{\cdot}24} = 2600^{\circ} \text{ Fahr.}$$

In the Louisiana tests a maximum temperature (Eng. 3000) of the furnace, as ascertained by a pyrometer, was 2339° Fahr., with a rate of firing of 134·15 lbs. per sq. ft. per hour and a maximum of 1856° Fahr. with a rate of firing of 25·79 lbs. per sq. ft. per hour, and (engine 585) a maximum temperature of 1739° with a rate of firing of 49·44 lbs. and a minimum of 1059° with 35·81.

RADIANT HEAT (Stefan & Boltzman).

Let T=Absolute Temperature in degrees Fahr. of the furnace.
T—461=Temperature of the firebox.
R=Radiant heat in B.Th.U. per sq. ft. per hour,

then $R=1600 \left(\frac{T}{1000}\right)^4$ B.Th.U.

(For examples see Table X.)

Professor Nicholson (Transactions Eng. & Ship, Scotland, Vol. L.I.V.), assumes that the Radiant heat acts only from the area of the Fire surface. If the Firebox Heating surface is assumed to be five times the area of the fire surface, then the rate of action per square foot on this heating surface will be 1/5th of the rate given off by the Fire surface. Prof. Dalby holds that as "the firebox is filled with flame, and the surface of the flame is composed of a continuous surface of incandescent carbon," the volume of the firebox is filled with the radiating body, and the whole firebox surface should therefore be taken. For the heat values given in table, the equivalent evaporations f and a 212°F are :—

TABLE X.

Firebox Temp.	2000°	2205°	2610°	2665°	2600°
Absolute Temp.	2461°	2666°	3071°	3126°	3061°
Radiation B.Th.U.	58690	81000	142500	152800	12000
Evap. A	12	21	36	39	31
Evap. B	60	84	146	158	124

The theoretical evaporations A and B are f and a 212°F. A is calculated on Prof. Nicholson's assumption, and for a ratio of firebox heating surface/Grate=5/1. B is calculated on Prof. Dalby's assumption of entire surface action.

In the "Coatisville boiler test," quoted by the American Locomotive Company in their Bulletin No. 2017, the evaporation from a Firebox surface of 246·2 sq. ft., was found to be 13,500 lbs. or 54·8 lbs. per sq. ft., and the Company has consequently adopted 55 lbs. as the value for estimate purposes. This corresponds with a temperature of about 1980°F (as deduced from the above formula), and "entire surface action," so that Prof. Dalby's contention may be considered as proven by experimental work.

Evaporation from Tube Surface. According to M. L. Ser, the distinguished French physicist, the transfer of heat through the boiler-tube surfaces could be estimated as follows, viz. :—Assuming a firebox temperature of about 2000° Fahr. and a desirable smokebox temperature of 500°, a heat transmission from the tubes of 4,500 B.Th U. per pound of fuel (equivalent to a theoretical evaporation of 4·7 lbs. f and a, 212°), would be attained with a rate of firing of 40 lb. per sq. ft. of grate, and a ratio of heating surface grate of 60/1, or with a rate of 80 lb. and a ratio of 85/1.

The Pennsylvania Railroad Co. (U.S.A.) have, from an extensive series of observations, made a valuable contribution to the subject by preparing a " Temperature Chart," based on these observations. Some particulars are given in the diagram herewith. In extent it shows for a 25 ft. tube surrounded (as in boiler conditions), by water at a temperature of 380° Fahr., the rate of fall of temperature in a gas which enters at a temperature of 1800° Fahr. and which is supplied at a rate corresponding to the combustion of 100 to 115 lbs. per square foot of grate. This temperature line is marked A. A corresponding line marked B is here added, showing from the same base the loss of temperature due to the heat transferred to the boiler water. Thus for the temperature at 18 ft. of 600°, the loss is (1800—600) 1200°.

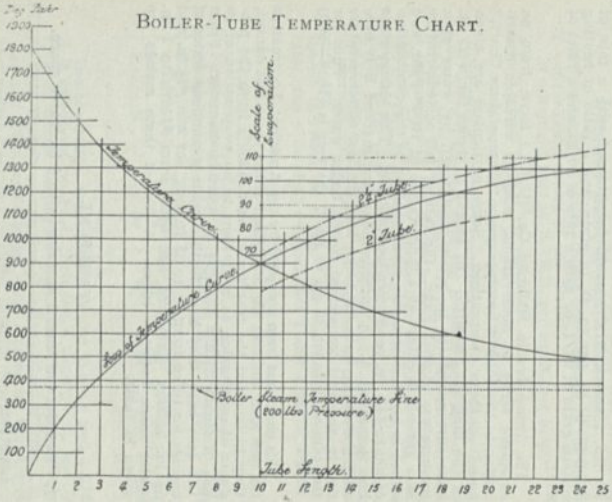
This chart has been accepted by the American Locomotive Co. (see their Bulletin No. 2017) and at the point just named, they have rated the transfer of heat (1200°) from the products of combustion as equivalent to an evaporation of 10 lbs. of steam with a tube 2¼ in. outside diameter. From this as a base, they have further made a complete series of ratings for tubes from 10 to 25 ft. long, for 2 in., 2¼ in. and 5½ in. outside diameters, and with from 9/16th to 1 in. water space between tubes. A few of these ratings are given in table.

TABLE XI.

I. Evaporation from 2 in. tubes with ¾ in. water space.

Length of tube. ft.	10	12	14	16	18	20
Evap. per sq. ft. lbs.	12·08	11·18	10·36	9·6	8·95	8·32
Eva. per tube. lbs.	63·25	70·24	75·94	80·43	84·35	87·03

Boiler-Tube Temperature Chart.



II. Evaporation from 2 in. tubes with 1 in. water space.

Length of tube. ft.	10	12	14	16	18	20
Evap. per sq. ft. lbs.	13·12	12·13	11·24	10·44	9·72	9·05
Eva. per tube	68·69	76·21	82·38	87·46	91·61	94·77

III. Evaporation from 2¼ in. tubes with ¾ in. water space.

Length of tube ft.	10	12	14	16	18	20	25
Evap. per sq. ft. lbs.	12·62	11·7	10·88	10·15	9·46	8·83	7·55
Evap. per tube	74·33	82·7	89·72	95·66	100·27	104·03	111·18

IV. Evaporation for 2¼ in. tubes with 1 in. water space.

Length of tube	10	12	14	16	18	20	25
Evap. per sq. ft. lbs.	13·55	12·57	11·69	10·9	10·18	9·51	7·98
Evap. per tube	79·81	88·85	96·4	102·73	107·91	112·04	117·51

V. Evaporation for 5½ in. tubes with 1 in. water space.

Length of tube ft.	10	12	14	16	18	20	25
Evap. per sq. ft. lbs.	14·08	13·15	12·3	11·52	10·82	10·22	8·9
Evap. per tube	202·73	227·21	247·95	265·4	280·43	294·31	320·38

The ratings for 2 in., 2¼ in. and 5½ in. tubes, as expressed in evaporation per tube, have been plotted alongside the B. curve in the chart, and it will be noted that they follow, approximately, to that line, *i.e.* the heat transmitted is proportional to the loss of temperature.

Boiler Efficiency. Professor Dalby ("Steam Power") in an analysis of the performance of Locomotive No. 2512 in the Louisiana Exhibition, has drawn up the following "balance sheet." The coal burned per square foot of grate per hour was 91 lbs. The grate area was 33·39 sq. ft. The firebox heating surface 177 sq. ft. The tube heating surface was 1469 sq. ft., and was composed of 139 "Serve" tubes, 176 inches long and 2¼ in. outside diameter. Total coal fired 9116 lbs.; cinders in smokebox 2135 lbs.; sparks from chimney 345 lbs. Temperature in smokebox 590° Fahr. Evaporation from and at 212° Fahr. 7·9 lbs.

Heat Developed.		B.Th.U.
Calorific value per lb. of dry coal		14868
Heat unproduced because of imperfect combustion	478·8	
Heat unproduced in cinders	2952·	
Heat unproduced in sparks thrown from the chimney	435·6	3866·4
		11001·6

Heat Transmitted.

Heat transferred to motive power circuit	7677	B.Th.U.	= 51·7%
Heat carried away by chimney gases	1446·6	„	= 9·7%
Heat absorbed in heating, evaporating and superheating water in furnace gas	649·6	„	= 4·3%
Heat lost in radiation, ashes, etc. ..	1238·4	„	= 8·3%
	11001·6	„	=74·0%

The heat transferred to the water in the boiler is 51·7% of the total heat in the coal, and this is the **efficiency** of the boiler as a whole. The heat actually produced in the furnace is 74% of the total heat in the coal, reckoned in terms of the gross calorific value.

Grate Area.

The rate of heat transmission or evaporative power is stated above in respect of (1) the firebox surface, in terms of "per square foot of firebox heating surface" (55 lbs.), and of (2) the tube surfaces in terms of "per square foot of tube heating surface" (as per Table XI.) for a rate of firing of 100 lbs. per square foot grate area.

Reckoning on an efficiency of evaporation of 8 lbs. water per pound of fuel, the evaporation would be 8 × 100 = 800 lbs. per hour per square foot of grate.

If the maximum demand for steam by the engine, in pounds, has been estimated, then the required grate-area can be determined. Thus, for a demand for 20,000 lbs. of steam the grate area would be 20,000/800 = 25 sq. ft.

Average conditions of running would lower the demand from the engine and thus permit a more economic rate of firing.

Example.

Estimated Evaporative powers of similar boilers fitted respectively for saturated steam and superheated steam production.

1 **Saturated Steam.** Working pressure 180 lbs. per sq. in. Tubes 2 in. dia., 15·6 long. Grate area 24·5 sq. ft.

Tube surface	1721 sq. ft.	at 9·75 lbs.	=	16780
Firebox „	130 „	55·0 „	=	7150
	1851 „	Total	=	23930

Evap. per sq. ft. of Total surface	= 12·9
Fuel per sq. ft. of Grate area	= 100
Total Fuel 100 × 24·5	= 2450
Evap. per lb. fuel $\frac{23930}{2450}$	= 9

2 **Superheated Steam.** Working pressure 160 lbs. per sq. in. Grate Area 24·5 sq. ft.

Ordinary tubes, surface	980 at 9·75 lbs.	= 9551		
Large Tubes, „	450 at 11·9 lbs.	= 5355	14906	
Firebox Surface	130 at 55 lbs.	=	7150	
	1560		22056	

Evap. per sq. ft. of total surface	= 13·3 lbs.
Fuel per sq. ft. of grate area	= 100
Total fuel 100 × 24·5	= 2450
Evap. per lb. fuel $\frac{21056}{2450}$	= 8·6

Consumption of Steam.

The consumption of steam in the engine is governed by the number of cylinders, the volume of each cylinder, the amount of clearance space between the piston at the end of its stroke and the valve face, the ratio of " cut off " to the stroke, the amount of steam in the clearance space at compression and by the condensation of steam in the cylinder.

Let V = the volume of the cylinder in cubic feet (exclusive of clearance space).
c = the volume of the clearance space expressed as a decimal fraction of V.
r' = the " cut off " as a decimal fraction of the stroke.
r'' = the beginning of compression fraction of the stroke.
S' = the specific volume of the steam per lb. corresponding to the " cut off " pressure per sq. in.
S'' = the specific volume at " compression," or beginning of compression.
N = Number of piston strokes per revolution.
R = Revolutions per min. or $60\,R$ = Revs. per hour.

If the pressure of the steam in the clearance space at " compression " is the same as at the point of Cut off, then

$$\frac{V \times r'}{S} \times N = \text{Lbs. steam per revolution.}$$

$$\frac{V \times r'}{S'} \times N \times 60R = \text{Lbs. steam per hour.}$$

If the pressure of the steam in the clearance space when fully compressed is known, then,

$$\left\{\frac{V(r'+c)}{S'} - \frac{Vc}{S''}\right\} \times N = \text{Lbs. steam per rev.}$$

$$\left\{\frac{V(r'+c)}{S'} - \frac{Vc}{S''}\right\} \times N \times 60R = \text{lbs. per steam per hour.}$$

If the pressure of the steam at the beginning of compression, and the fraction of the stroke at which it occurs, is known, then.

$$\left\{\frac{V(r'+c)}{S'} - \frac{V(r''+c)}{S''}\right\} \times N = \text{Lbs. steam per rev.}$$

$$\left\{\frac{V(r'+c)}{S'} - \frac{V(r''+c)}{S''}\right\} \times N \times 60R = \text{Lbs. steam per hour.}$$

Examples.

Evaporation and Consumption of Steam.

I. **Saturated Steam.**

Heating Surface—Tubes 1721
Heating Surface—F'box 130 1851 sq. ft.

Grate Area .... 24·5
Boiler pressure lbs. per sq. in. .. 180
Total evap. per hour (as per previous example) 23930 lbs.
Cylinders 20 in. × 26 in. Volume 4·72.
" Cut off " at ·5 and at a pressure of 90 lbs. per sq. in. Spec. Vol. 4·23.
Compression pressure equal to " cut off " pressure.
Revs. per min. 160.

Steam per rev. $\frac{V \times r'}{S'} \times N.$

" " $\frac{4{\cdot}92 \times {\cdot}5}{4{\cdot}23} \times 4 = 2{\cdot}23$

per hour $2{\cdot}23 \times 160 \times 60 = 21208$ lbs.

II. **Superheated Steam.**

Heating surface, ordinary tubes 980
Large tubes 450
Firebox 130 1560 sq. ft.

Grate 24·5 "
Boiler pressure lbs, per sq. in. 160
Total evap. per hour (as per previous example) 21056 lbs.
Cylinders 21 in. × 26 in.. Volume 5·21.
" Cut off " at ·5 and at a pressure of 80 lbs. per sq. in., Spec. Vol. 6·09.
Compression pressure equal to " cut off " pressure.
Revs. per min. 160.

Steam per rev. $\frac{V \times r'}{S'} \times N.$

" " $\frac{5{\cdot}21 \times {\cdot}5}{6{\cdot}09} \times 4 = 1{\cdot}768.$

Steam per hour $1{\cdot}768 \times 16060 = 16873$ lbs.

III. The particulars are taken from the Purdue University, U.S.A. tests of a locomotive.

Cylinders 17 in. × 24 in.; Cylinder Volume (less piston rod). 3·1318 cub. ft., Cylinder clearance space 0·1 of cylinder volume.

Strokes per revolution, 4. Revs. per min. 189·55.

"Cut off" at ·3188. "Cut off" pressure 89·98 lbs. per sq. in. Spec. vol. 4·23.

"Compression" at ·2869. "Compression" pressure from 11·78 lbs. per sq. in. Spec. Vol. 15·72.

$$\text{The steam per rev.} = \left\{ \frac{V(r'+c)}{S'} - \frac{V(r''+c)}{S''} \right\} \times N =$$

$$\left\{ \frac{3{\cdot}1318\,({\cdot}3188 + {\cdot}1)}{4{\cdot}23} - \frac{3{\cdot}1318\,(28{\cdot}69 + {\cdot}1)}{15{\cdot}72} \right\} \times 4 =$$

$$({\cdot}3100 - {\cdot}07708)4 = {\cdot}9568 \text{ lb.}$$

The Steam per hour $= {\cdot}9568 \times 60\,R = {\cdot}9568 \times 189{\cdot}55 \times 60 =$ 10780 lbs.

Actual Steam consumed per hour (on a two-hour test) 12981

IV. The particulars are taken from the tests of the 2-8-0 type locomotive for the Pennsylvania Rly. at the Louisiana Exhibition.

Cylinders 22in. × 28 in., Cylinder Volume (less piston rod) = 6 cub. ft.

Cylinders clearance space 0·11 of cylindêr volume.

Strokes per revolution 4. Revs. per minute 160·9.

"Cut off" at ·33. "Cut off" pressure 99 lbs. per sq. in. Spec. Vol. 3·912.

"Compression" ·34. "Compression" 11 lbs. per sq. in. Spec. Vol. 15·72.

$$\text{Total steam per rev.} = \left\{ \frac{V(r'+c)}{S'} - \frac{V(r''+c)}{S''} \right\} \times N$$

$$\text{Total steam per rev.} = \left\{ \frac{6({\cdot}33 + {\cdot}11)}{3{\cdot}912} - \frac{6({\cdot}34 + {\cdot}11)}{15{\cdot}72} \right\} \times 4$$

$$\text{Total steam per rev.} = ({\cdot}675 - {\cdot}171)\ \ 4 = 2{\cdot}016 \text{ lbs.}$$

Total steam per hour $= 2{\cdot}016 \times 60\,R = 2{\cdot}016 \times 160{\cdot}9 \times 60 =$ 19462 lbs.

Actual water consumpt. per hour (as delivered to Injector) = 26007 lbs.

TABLE XII.
VOLUME IN CUBIC FT. OF ONE CYLINDER AS SWEPT BY THE PISTON.

Stroke / Dia.	20	22	24	26	28	30
14	1·78	1·96	2·13	2·31	2·49	2·6[illegible]
15	2·04	2·24	2·45	2·65	2·86	3·06
16	2·32	2·55	2·78	3·02	3·25	3·48
16½	2·47	2·72	2·97	3·22	3·46	3·71
17	2·64	2·90	3·17	3·43	3·70	3·96
17½	2·78	3·06	3·34	3·62	3·90	4·17
18	2·94	3·23	3·53	3·82	4·12	4·41
18¼	3·03	3·34	3·64	3·94	4·25	4·55
18½	3·11	3·42	3·73	4·04	4·35	4·66
18¾	3·20	3·52	3·84	4·16	4·48	4·8
19	3·28	3·61	3·94	4·26	4·59	4·92
19½	3·45	3·80	4·14	4·48	4·83	5·17
20	3·64	4·00	4·37	4·73	5·10	5·46
21	4·00	4·40	4·80	5·20	5·60	6·00
22	4·40	4·84	5·28	5·72	6·16	6·60
23	4·80	5·28	5·76	6·24	6·64	7·20
24	5·22	5·74	6·26	6·79	7·31	7·83
25	5·68	6·25	6·82	7·38	7·95	8·52
26	6·14	6·75	7·37	7·98	8·60	9·21
27	6·62	7·28	7·94	8·61	9·27	9·93
28	7·12	7·83	8·54	9·26	9·97	10·68
29	7·64	8·40	9·16	9·92	10·69	11·45
30	8·18	9·00	9·81	10·63	11·44	12·26

HEATING SURFACE AND GRATE AREA.

To ensure that the calculations for the " Heating Surfaces " and " Grate Areas " are made on the same bases for all boilers, the method stated below, in conformity with that adopted by the " Locomotive Railway Engineers Association " should be observed as Standard Practice.

1 **Firebox.** The area of the **outside,** *i.e.*, the " Water contact," surface of the inner firebox plates is to be taken. This excludes the surfaces covered by the Foundation Ring and the Firehole Ring and the area of the tube holes. If the firehole is of the flanged plate type, the area within the junction of the plates is to be excluded. No deductions are to be made for side, roof or tubeplate stays.

If water tubes are fitted in the Firebox, the inside, *i.e.*, the " Water contact," surface of the tube is to be taken and the area of the tube holes (for these tubes) Firebox plates is to be deducted.

2 **Tubes.** The area of the **outside,** *i.e.*, " Water contact " surface of the Tubes is to be taken, and is to be calculated on uniform diameters for both ordinary and large flue-tubes. The length of the tubes between the tube-plates is to be taken.

3 **Elements.** The Area of the **inside,** *i.e.*, the " Steam contact " surface of the tubes is to be taken ; **the effective length of the element being from and to the smokebox-end of the large flue-tube.**

4 **Smokebox Tube Plate.** The area of this plate is not to be included.

5 **Grate Area.** The Area of the Grate as measured between the firebox sides at the level of the top face of the firebars, is to be taken. No deduction is to be made for the round corners or plate-flange at the foundation-ring.

The following figures derived from the data of carefully conducted tests are of considerable importance, etc.

Purdue University Experimental Boiler. (W. F. M. Goss.)
Coal in pounds consumed per square foot of Grate per hour relative to Water evaporated per pound of Coal.

Dimensions of Boiler. Grate area 17·25 sq. ft. Heating surface in Fire-box 132·1; in Tubes (internal) 1071·8; in Front-head 10·5; Total 1214·4 sq. ft., 200 Tubes 11 ft. 5 in. long and 1·78 inside diameter.

Ratio of Heating-surface to Grate area = 70·4.

The mean values of 35 tests are represented by the formula

$$\text{Evaporation per pound of coal} = \frac{10{\cdot}08}{1 + {\cdot}00421G}$$

where "G" is pounds of coal per sq. ft. of grate. The table gives a few of these values. The coal used was "Indiana Brazil Block," having a thermal value of about 13000 B.T.U. per pound of dry coal. The evaporations given are the "Equivalent evaporations from and at 212° Fahr."

TABLE XIII.

Water evap. in lbs. per lb. coal	5	6	7	8	9
Coal in lbs. burned per sq. ft. grate	240	160	100	60	30

These values may be increased by the use of a better coal by about 15 per cent.

St. Louis Exhibition Locomotive Tests.

From the report on these tests Mr. L. H. Fry has, relative to the boilers, deduced some important figures ("Combustion and Heat absorption in Locomotive Boilers," Engineering Vol. LXXXVII.), a few of which are given in Tables.

1. As to the amount of **Heat-absorbing surface** that should be allowed **per square foot of Grate-area,** *i.e.*: Ratio of Heating-surface to Grate-area the figures are:—

TABLE XIV.

Ratio of Heating-surface to Grate	50	60	70	Infinite
Percentage of Heat taken out of Gas	70·4	73·9	75·0	82·6

2. As to the **efficiencies of the Heating-surfaces** in each of four boilers, the particulars of which are given, the rate of firing being 90 pounds per square foot of Grate. In the first two examples given the fire-box is fitted with a brick arch; in the other two it is not so fitted.

TABLE XV.

Grate	Heat Sur.	Ratio HS/G	Tubes Length	Tubes Dia.	Per Cent. Efficiencies. Heat Production.	Per Cent. Efficiencies. Heat Absorption.
33·76	2541	75·27	14′ 10⅞″	2″	68·2	78·8
49·9	3000	60·1	15′ 11¼″	2″	72·5	79·4
49·21	2482	50·44	13′ 8½″	2″	63·5	76·7
48·36	2902	60·1	18′ 8″	2¼″	66·1	79·7

3. As to the percentage of the total heat absorbed which is **taken up by the firebox.** The figures given are for four types of boilers and for different rates of firing.

TABLE XVI.

Rate of firing Lbs. Coal per sq. ft. of grate.	Ratio of Firebox Sur- to grate.	Evaporation per sq. ft. of total H.S.	Percentage Heat absorbed by Firebox.
90	2·33	12·3	43
140	5·46	12·1	30
120	3·99	13·8	39
130	2·3	15·9	34

Northern Railway of France, Boiler Test. (MM. Petiet and Havrez, 1874). To determine the evaporative value of **different portions of the heating surface** of a locomotive boiler.

The experiment was carried out on a boiler having 792·43 sq. ft. of heating surface, of which 60·28 was firebox surface. The tubes were 12 ft. 3 in. long, and for the purposes of the test were compartmented in five divisions of 3·02 ft. of 179 sq. ft. each. The 3 in. next the firebox was included in the firebox surface. Fuel used: Briquettes.

TABLE XVII.

Surface.	Fire-box.	1st section.	2nd.	3rd.	4th.	Total.
Water evap. in lbs. per sq. ft. per hour	36·9	11·44	5·72	3·52	2·31	8·9
„ section do.	2820	2047	1024	630	414	6935
Per cent. of total evap. per section	40	30	15	9	6	100

Furness Railway. W. F. Pettigrew (Iron and Steel Institute, Sept., 1903). Tests as to the comparative value **of certain British fuels.**

Boiler used :—Grate 20·5 sq. ft. ; Heating-surface Tubes 1029 ; Firebox 105 ; Total 1134 sq. ft. Tubes, 1¾ in. diameter and 10 ft. 9¾ in. long. Boiler Pressure 150 lbs.

Ordinary working conditions of 6 wheels coupled Goods Locomotive.

TABLE XVIII.

Coal, class	Yorks.	Welsh	Lancas.	Cumber.	Scotch.
Do. samples ..	5	1	2	2	5
Do. thermal value (mean) B.T.U.	13660	14206	12919	13102	12563
Mean rate of firing–Coal in lbs. per sq. ft. of grate	52·2	50·1	52	52·5	57·2
Evaporation in pounds per sq. ft. of heating surface (from and at 212°)	9·04	9·23	8·22	8·68	8·34
Do. per pound of coal	10·92	11·6	10·25	10·4	9·76

North-Eastern Railway. W. M. Smith (Proceedings M.I. Mech. E., 1898). Tests as to the average evaporative values from five types of boilers under similar conditions of Engine service.

TABLE XIX.

	A	B	C	D	E
Grate area.. sq. ft.	15·0	20·7	20·7	19·6	17·0
Heating surface, Tubes ,,	999·7	1016·0	1089·0	1220·0	1026·2
Do. Firebox ,,	104·0	123·0	127·0	121·0	110·0
Do. Total ,,	1013·7	1139·0	1216·0	1341·0	1136·2
Tubes, number of ..	206	203	201	225	205
Do. diam. outs ..	1¾	1¾	1¾	1¾	1¾
Boiler barrel, length	10′ 3″	10′ 7″	11′ 6″	11′ 6″	10′ 7″
Boiler pressure	140	175	175	175	160
Calorific value of fuel in lbs. water evap., f & a 212° ..	15·32	15·02	14·85	15·04	15·11
Mean rate of firing Coal in lbs. per sq. ft. of grate	136·4	109·6	90·79	99·96	110·95
Water used per pound of coal f & a 212°	7·91	9·73	10·28	9·42	9·71

BOILER POWER-RATING.

The power of a boiler is its steam producing capacity or " Water evaporated in pounds per hour," a capacity which varies with the quality of the fuel, the rate of firing and the efficiency of the heat absorbing surfaces. The measurement of this power, however, is most conveniently stated in the same terms as that of the engine, *viz.*: " Horse Power."

Accepting for average working conditions of a " simple " engine, a consumption of 28 lbs. steam per horse-power per hour, and for the boiler an evaporation of 12 lbs. per square foot of heating-surface per hour, as good representative values, and as proposed by Prof. Goss from the data of the Purdue University tests, we have :—

Evaporation per sq. ft. of heating-surface, per hour = 12 lbs.
Consumpt. per Indicated horse-power, per hour .. = 28 ,,

1 H.P. per sq. ft. heating-surface $= \frac{12}{28} = \cdot 43$

Heating-surface, per 1 H.P. .... $= \frac{28}{12} = 2\frac{1}{3}$

Assuming a **ratio** of Heating-surface to grate of 60 to 1 then:
Evap. per sq.ft of Grate per hour $= 12 \times 60 = 720$ lbs.

1 H.P. Do. do .... $= \frac{60}{2\frac{1}{3}} = 25\cdot 7$

Assuming a **Rate of Firing,** say 90 lbs. per sq. ft. grate per hour then :—

Evaporation per lb. coal.......... $\frac{720}{90} = 8$ lbs.

Lbs. coal per I.H.P............... $\frac{90}{25\cdot 7} = 3\cdot 5$ lbs.

In German practice (Von Borries " Eisenbahn Technik der Gegenwart " 1903) the following values have been given for I.H.P. per sq. ft. Heating-surface, *viz.* :—

TABLE XX.

	Revolutions of Driving Axle per minute.						
	60	90	120	150	180	210	240
Passr. & Express Engine Simple		·39	·42	·45	·47	·49	·50
Do. Do. 2 Cylr. Compound		·42	·48	·53	·57	·61	·64
Do. do. 4 do. do.		·56	·60	·64	·67	·69	·70
Goods & Tank engines Simple	·33	·36	·38	·40	·42		
Do. do. 2 Cylr. Compound	·35	·39	·42	·45	·47		

Note.—These values are given relative to, in the case of Passenger and Express Engines, a ratio of grate to heating-surfaces of 1/50 to 1/60; and boiler pressure of 176 lbs. for Simple and 2-Cylr. Compound and 206 for 4-Cylr. Compound; and in the case of the Goods and Tank Engines a ratio of grate to heating-surface of 1/55 to 1/65, and boiler pressure of 147 for Simple and 176 for Compound. Further the values also represent average coal and can be taken 10% higher for best coal.

Tables XXI. and XXVI. give calculated results by L. H. Fry ("Engineering" Vol. XCV, 1913) from the data of Prof. Gross extensive experiments as stated in his "High steam pressures in Locomotive service" and "Superheated steam in Locomotive service." The plant employed was a locomotive with 16 in. × 24 in. cylinders (clearance space 7·6%).

TABLE XXI.

Steam per Horse-Power Hour.

Boiler Press-ure.	Rev. per Min.	Cut-Off 20%			Cut-Off 40%			Cut-Off 60%		
		Sat.	Sup.	Supt. as % of Sat.	Sat.	Sup.	Supt. as % of Sat.	Sat.	Sup.	Supt. as % of Sat.
lb.per sq.in.	R	lb.	lb.	%	lb.	lb.	%	lb.	lb.	%
120	60	32·5	29·7	88·5	30·6	24·6	80·5	37·8	26·2	69·2
	180	28·4	25·1	88·5	27·9	22·5	80·5	35·6	24·6	69·2
	300	32·6	28·9	88·5	28·5	22·9	80·5	35·7	24·7	69·2
180	60	29·3	25·0	85·5	28·8	22·8	79·4	36·3	25·3	69·6
	180	25·6	21·9	85·5	26·5	21·0	79·4	34·4	24·0	69·6
	300	28·4	24·2	85·5	27·3	21·6	79·4	34·5	24·1	69·6
240	60	26·9	22·4	83·4	27·0	21·4	78·6	34·4	24·6	71·5
	180	23·7	19·8	83·4	25·0	19·6	78·6	32·5	23·2	71·5
	300	26·0	21·7	83·4	25·7	20·2	78·6	33·1	23·6	71·5

In the North-Eastern Railway Tests, referred to on a previous page, on 5 Express Engines over a distance of 65 miles at an average speed of about 50 miles per hour, the value of the mean rate of Horse-power per sq. ft. Heating-surface is as under, *viz.* :—

TABLE XXII

	A	B	C	D	E
Heating-surface square feet	1103·7	1139	1216	1341	1136·2
Average horse power, I. H.P.	560·35	729·2	643·3	645·9	606·5
I.H.P. per sq. ft. Heating-surface	·50	·64	·53	·47	·53

In the Furness Railway Fuel Tests, Table XVIII, the engine used had a heating-surface of 1134 sq. ft.; the mean I.H.P. developed in the cases of the Lancashire and Scotch coals was 461, giving a rate per sq. ft. Heating-surface of ·406; for the Cumberland coal, 475, giving ·42; for the Yorkshire, 467 giving ·41; and for the Welsh 497, giving ·438. The maximum Indicated Horse-powers were 50% in excess of the means stated.

ENGINE POWER.

The power of an engine is its ability to perform a given amount of **Work** in a given **Time.** "Horse-power" is a standard measure of power, *viz.* :—33,000 foot-pounds of work per minute.

With special reference to the Locomotive, the term "Horse-power" has three applications, *viz.* :—

Indicated Horse-power. I.H.P. As in ordinary Steam-engine practice—the power developed by the steam in the cylinders.

Rail Horse-power. R.H.P. The power developed at the rail, *i.e.*, the I.H.P. minus the power absorbed by the friction of the engine mechanism.

Draw-Bar Horse-power. D.H.P. The power transmitted between the engine (or if a tender engine, the engine with tender), and the train, *i.e.*, the I.H.P. minus the power absorbed by the friction of the engine mechanism and by the haulage resistances of the engine itself (or in tender engines of the engine and tender).

Indicated Horse-power of the Locomotive is thus defined as **the work done by the steam in the cylinders at a rate of 33,000 foot pounds per minute,** and may be calculated by the use of the well-known formula $= \frac{PLAN}{33000} =$ I.H.P. per Cylinder.

In Locomotive practice it is more convenient to calculate the I.H.P. on the basis of the "Tractive Force" formula.

Tractive Force. Applying the principle of "Work" to the Locomotive engine :—The work done by the Steam on the Pistons must (friction neglected) be equal to the work done on the Rail by frictional contact with the wheel. Expressing this equation in general terms :—

Let D = Diameter of Cylinder in inches.

p = Mean Steam pressure per square inch of Piston.

$D^2 \times .7854 \times p$ = Total Pressure on Piston in pounds.

S = Stroke of Piston in inches.

4 = Number of strokes (2 cylr. engine) per revolution of axle.

$(D^2 \times 7854 \times p) \times 4\ S$ = Work done on Pistons in one revolution in inch-pounds.

W = Diameter of Driving Wheel in inches.

$W \times 3{\cdot}1416$ = Circumference of do.

F = Frictional resistance in pounds at circum. of wheel.

$W \times 3{\cdot}1416 \times F$ = Work done in one revolution at circum. of wheel in inch-pounds.

$(D^2 \times 7854 \times p) \times 4\ S = W \times 3{,}1416 \times F.$

or $D^2\ p\ S \ = \ W\ F.$

The Tractive Force (friction neglected) being equal to the resistance:—

$$\text{Tractive Force in pounds} = T = \frac{D^2\ S\ p}{W}$$

Let v = Velocity of Train in Feet per Minute.

M = Do. in Miles per Hour.

$$\text{Then Indicated Horse-power} = \frac{T \times v}{33000} \text{ or } = \frac{D^2 \times S \times p}{W \times 33000} \times v$$

Or for a Speed expressed in Miles per hour the equivalent formula is:—

$$\text{Indicated Horse-power} = \frac{T \times M}{375} \text{ or } \frac{D^2 \times S \times p}{W \times 375} \times M$$

Examples showing application of above formulæ.

To find the **Tractive Force** of a Locomotive having cylinders 18 in. diameter and 30 in. stroke, Driving Wheels 6 ft. 8½ in. diameter, and a Boiler Pressure of 225 pounds per square inch, the Mean Pressure on the Piston being 60% of the Boiler Pressure.

$$\text{Tractive Force} = \frac{D2 \times S \times p}{W} = \frac{18 \times 18 \times 30 \times 225 \times {\cdot}6}{80{\cdot}5} =$$

16300 Pounds.

To find the Indicated Horse-power of above Locomotive at a speed of 30 Miles per hour.

$$\text{Indicated Horse-power} = \frac{T \times M}{375} = \frac{16300 \times 30}{375} = 1304$$

Mean Pressure. In the use of the Tractive Force formula, the Mean Pressure "p" is usually taken at:—For "Starting" purposes, 75% of the Boiler Pressure, and for "Working at **maximum power**" 60 to 65%. American practice is to take 85% for "Starting."

The Mean Pressure varies with the boiler pressure, the Steam-chest Pressure, the rate of "Cut-off" and with the speed of the engine.

The following tables fully illustrate these variations.

TABLE XXIII.

Mean Pressure, approx. (D. K. Clark's "Railway Machinery.")

p=Mean Pressure in % of maximum pressure of admission.
a=Period of Admission in % of length of Stroke.
$p = 13.5 \sqrt{a} - 28.$

a	17·5	20	25	30	35	40	45	50	55	60	65	70	75
p	28	32	40	46	52	57	62	67	72	77	81	85	89

TABLE XXIV.

Relation of Initial Pressure to Boiler Pressure (Henderson) Full Throttle opening.

Revols. per minute	Starting	50	100	150	200	250	300
Initial Pressure %	98	95	92	90	88	87	86

TABLE XXV.

Mean pressure, in per centage of Boiler Pressure, as affected by the Speed. Deduced from results of Purdue University Tests. Prof. Goss' "Locomotive Performance."

Revols. per minute	81	135	188	242	296
Piston Speed (mean) feet per minute	324	540	752	968	1184
"Cut-off" per cent 25 ..	34·5	25·6	22·4	17·4	14·1
do. do. 35 ..	48·5	40·4	31·3	25·8	21·3
do. do. 45 ..		50·7	38·6		

Available Mean Pressure.—Only within the range of the boiler capacity can the mean pressure values, as determined by the foregoing methods, possibly be **available** in the cylinders. The boiler capacity (steam supply) has been defined (page 70) in terms of equivalent power units, or "horse power." Taking 0·43 and 25·27 respectively as constants for the square foot values of the heating surface and grate area, for average conditions :—

Let HS=Heating surface in square feet.

G=Grate area in square feet.

Then HP=0·43 HS, or 25·7 G (the lower value of the two, as applicable to a particular boiler, to be taken), and this, consequently, will be, for that rating, the maximum power that can be developed in the cylinders. Therefore

$$0{\cdot}43\text{HS, or } 25{\cdot}7\ \text{G}=\text{IHP}=\frac{D^2S}{375W}\times pM$$

For any given cylinder and wheel dimensions D, S and W

$$\text{let } C=\frac{D^2S}{375W}$$

$$\text{Then IHP}=C\times pM,$$

and it is evident that the horse-power of the engine is in direct proportion to the product pM (mean pressure and speed).

TABLE XXVI.

Mean Effective Pressure (see note at Table XXI).

Boiler Pressure.	Revs. per Min.	Cut-Off 20 %		Cut-Off 40 %		Cut-Off 60 %	
		Saturated.	Superheated	Saturated.	Superheated	Saturated	Superheated
lb. per sq. in.							
120	60	36·4	33·2	68·6	68·9	87·0	101·0
	180	24·4	22·2	50·0	50·2	66·7	77·6
	300	12·4	11·3	31·2	31·4	46·5	54·2
180	60	61·8	57·9	108·0	109·0	130·0	149·0
	180	42·2	39·5	78·0	79·0	96·8	111·0
	300	22·6	21·2	47·5	48·1	64·3	73·9
240	60	90·6	86·0	154·0	155·0	179·0	199·0
	180	62·3	59·2	110·0	111·0	132·0	147·0
	300	34·2	32·4	66·4	66·7	79·6	88·4

Diagram on page 75 may, incidentally, be taken to illustrate these points. If the ordinates of the curve F represent the *mean pressures* at the given speeds, then the ordinates of the curve B as representing the *Horse Powers* will be proportional to the product, mean pressure × speed. Thus at 180 revolutions per minute the mean pressure is ·42 and 180 × ·42 =75·6. At 240 it is ·32 and 240×·32 is 76·8. The Horse powers at these speeds will be, relatively, proportional as 75·6 : 76·8.

The "Characteristic" diagram on the following page, to which reference has just been made, shows, from two authorities on U.S. practice, the available mean pressure realized in U.S. engines at various revs. per minute of the driving axle. The **full line** F shows the pressures as given in Table XXVII., and the **dotted line** G, those arrived at by Mr. G. R. Henderson. The IHP curves B and C are plotted from these pressures and speeds.

Two specific examples of the readings of these curves are :—

Express Loco.: 19" × 26" cylrs.; 91½" drivers; 175 lbs. working pressure.

Mineral Loco.: 19¾" × 26" cylrs.; 56" drivers; 175 lbs. working pressure.

The scale on the L.H. side of the diagram gives the mean pressure values measured on curve F or G for 175 lbs. boiler pressure, for both engines. "Miles per hour" scales, for each engine, are given below revs. per min. Scale Et shows for the Express the tractive force at the relative mean pressures also measured on curve F or G, and as may be calculated from $\frac{D^2S}{W} \times p = \frac{19^2 \times 26}{91\frac{1}{2}} \times p = 102{\cdot}58 \times p.$

Scale Eh shows, for the Express engine, the IHP values measured on curve B or C at the relative tractive forces and speeds as may be calculated from

$$\frac{DS^2}{375W} \times Mp = \frac{19^2 \times 26}{375 \times 91\frac{1}{2}} \times Mp = {\cdot}273\ Mp.$$

Similarly for the Mineral are the scales Mt and Mh based on :—

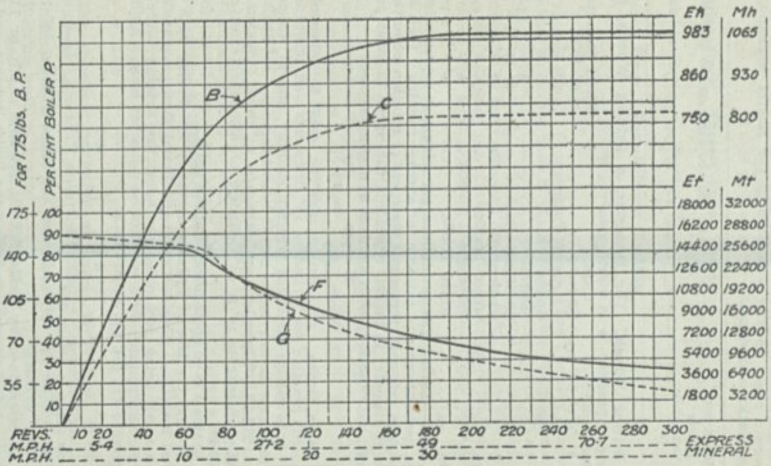
$$\text{Tractive force} = \frac{D^2S}{W} \times p = \frac{(19\frac{3}{4})^2 \times 26}{56} \times p = 181{\cdot}1 \times p.$$

$$\text{Horse-power} = \frac{D^2S}{375W} \times Mp = \frac{(19\frac{3}{4})^2 \times 26}{375 \times 56} \times Mp = {\cdot}483\ Mp.$$

The Boiler Capacity must be equal to the maximum IHP. The latter occurs at 180 revs., corresponding in the Express to 49 m.p.h. and in the Mineral to 30 m.p.h. The mean pressure value, taking the full line (or Table XXVII.), is $175 \times {\cdot}42 = 73{\cdot}5$ lbs.

Express Horse-power Max.: $\cdot273\ Mp = {\cdot}273 \times 49 \times 73{\cdot}5 = 983$

Mineral do. do. $\cdot483\ Mp = {\cdot}483 \times 30 \times 73{\cdot}5 = 106$



FOR 175 lbs. B.P.
PERCENT BOILER P.
175
140
105
70
35
100
90
80
70
60
50
40
30
20
10
B
C
F
G
Eh
Mh
983
1065
860
930
750
800
Et
Mt
18000
32000
16200
28800
14400
25600
12600
22400
10800
19200
9000
16000
7200
12800
5400
9600
3600
6400
1800
3200
REVS. 10 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
M.P.H. 5·4 27·2 49 70·7 EXPRESS
M.P.H. 10 20 30 MINERAL

TABLE XXVII.

Mean **Available** Pressures, in per centage of Boiler **Pressure**. From a chart in the possession of the Master Mechanics' Association (America).

Revs.per minute	60	80	100	120	140	160	180	200	220	240	260	280	300
Available M.P	86	76	[illegible]	58	51	46	42	39	34	32	30	29	28

Driving Wheels. The Diameter of Driving Wheels, in general practice, is as under, *viz.*:—

Rail Gauge.	Class.	Wheel diameter
5′ 6″ to 4′ 8½″ ..	Express	6′ 6″ to 7′ 0″
do. ..	"Heavy" Passenger	6′ 0″
do.	Goods	5′ 0″
do.	Mineral	4′ 6″
do.	Shunting	3′ 6″ to 4′ 6″
3′ 6″	Passenger	5′ 2″
do.	Mixed Traffic	4′ 0″
3′ 3⅜″	Passenger	4′ 9″
do.	Mixed Traffic	4′ 0″

Note.—Taking **224 revolutions per minute** as representing the desirable rate of rotation for average running; then as 336 revs. per min. represents the speed of rotation when the wheel diameter **in inches** represents the speed in **miles per hour,** the equation, using symbols as above, becomes :—

$$W = \frac{M \times 336}{224} = 1\tfrac{1}{2}\ M$$

Piston Stroke. 26″ Stroke may be said to represent general practice for Cylinders 18″ Diameter and upwards. 30″ is in use on the Great Western Railway, and 28″ to 32″ is in use on the heaviest of recent freight engines. 24″ Stroke for 16″ and 17″ Cylinders; 20″ Stroke for 13″ to 15″ Cylinders; and 18″ Stroke for 10″ to 12″ Cylinders, are also representative figures.

Example as to application of above notes.

To find the **Size of Cylinder** necessary for dealing with a total Resistance (Engine Tender and Train) of 16,300 pounds, the speed being 26·6 miles per hour, the Driving Wheels being also suitable for a speed of 60 miles per hour. Boiler Pressure 225 lbs. per square inch.

$$T = \frac{D^2\ S\ p}{W} \text{ or } D^2 = \frac{WT}{S\ p}$$

T as given is 16,300 lbs.

W as suitable for 60 m.p.h. may be taken at from 78″ to 84″ say 80½″

p as determined by Table XXVII for 26·8 m.p.h. or 112 r.p.m. of an 80½″ wheel is 60% of the Boiler Pressure, and is thus $225 \times \cdot 60 = 135$ lbs.

S may be taken at 26″.

Substituting these values :—

$$D^2 = \frac{80\cdot5 \times 16300}{26 \times 135} = 373\cdot8$$

$$D = \overline{73\cdot8} = 19\cdot3''$$

Tractive Force. Three-Cylinder Engines.

$$T = \frac{3\ D^2\ S\ p}{2\ W}$$

Tractive Force. Four-Cylinder Engines.

$$T = \frac{2\ D^2\ S\ p}{W}$$

Tractive Force. Compound Engines. The Tractive Force **is calculated on the basis of the Mean Pressure being referred** to the diameter of the Low-Pressure cylinder. For "Cut-offs" of 30 to 40% in the Simple engine, the corresponding "Cut-offs" in the Compound are 50 to 60%. Von Borries gives the following per centages of Boiler Pressure that may be taken for Mean Pressure for Ratios of Piston area of from 2 to 2·9.

	Simple.	Compound. Ratio of Piston Area			
		2	2·25	2·5	2·9
Passenger and Express Locomotives	50	44	42	42	38
Goods and other Locomotives	60	50	48	45	40

ADHESION AND NUMBER OF COUPLED AXLES.

The coefficient of friction of the wheel load with the rail, as determined by the results of Capt. Douglas Galton's Brake experiments, in 1878 is :—

At the point of coming to rest, the coef. is			0·242
At 6·8 miles per hour	....	do.	0·088
At 34·1 do.	....	do.	0·065
At 54·5 do.	....	do.	0·038

The American investigator A. M. Wellington, in his "Railway Location," gives the following determinations :—

Ultimate coef.	with loads over 10,000 lbs. per wheel	0·35
Working coef.	with sand	0·33
do.	in summer Max. limit with loads under 10,000 lbs. per wheel	0·25
do.	in winter (damp or frosty rail)....	0·20

These determinations confirm the figures in general use in British practice, *viz.* :—

Adhesion per Ton of Load on Driving Wheels (Molesworth).

When the rails are very dry	600 lbs.	....	coef.	0·268
do. very wet	550 ,,	....	do.	0·245
In ordinary English weather	450 ,,	....	do.	0·2
In misty weather, if the rails are greasy	300 ,,	....	do.	0·13
In frosty or snowy weather ..	200 ,,	....	do.	0·09

The Adhesion or Adhesive Force must be somewhat in excess of the maximum Tractive Force. The latter is usually taken as that with a mean steam pressure of 75% of the Boiler Pressure. In American practice, it is that with a mean pressure of 85% and with the tyres half-worn.

The number of Coupled Axles is determined by the Maximum Load that may be carried on any one axle, the Maximum Load being itself determined by the strength of the permanent way, bridges, etc.

Let R = Weight of Rails in pounds per yard
L = Maximum Load in tons per Axle.

Then $L = \frac{R}{5}$

Let N = Number of Coupled Axles.

Then L × N = Maximum Load on Coupled Axles, in tons

and $\frac{L \times N}{5} =$ Do. Adhesive Force (for coef. of 0·2) in tons.

T = Tractive Force in pounds.

$\frac{T}{2240} =$ Do. tons.

The Adhesive Force must be equal (at least) to the Tractive Force

$$\frac{L \times N}{5} = \frac{T}{2240}$$

$N = \frac{5T}{2240L} =$ Number of Coupled Axles. (The fractional part of the product, if any, must be reckoned as unity).

Example. For an Engine with a Tractive Force of 20,160 pounds and suitable for a road laid with rails weighing 90 pounds per yard. To determine the Maximum Load per Axle and the Number of Coupled Axles.

Maximum Load per Axle for 90 lb. Rail—

$$L = \frac{R}{5} = \frac{90}{5} = 18 \text{ Tons.}$$

Number of Coupled Axles for Tractive Force of 20,160 lbs. and Maximum Axle Load of 18 Tons.

$N = \frac{5T}{2240L} = \frac{5 \times 20160}{2240 \times 18} = 2\frac{1}{2}$ To be taken as 3 axles

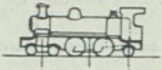
It will be noted in this example that the tractive force is 20,160 pounds, or 9 tons, and that the adhesive weight required is therefore $9 \times 5 = 45$ tons. With two axles, this would give $\frac{45}{2} = 22\frac{1}{2}$ tons per axle, which is in excess of the "maximum load." With three axles, it gives $\frac{45}{3} = 15$ tons, per axle, which is well under the "maximum."

TANK ENGINE ADHESION. In the case of tank engines in which the weight, or part of the weight, of water and coal is carried on the coupled wheels it may be necessary that the *nett adhesive weight* should be taken as that available for the most exacting condition of service, *i.e.*, on the one hand the weight on the coupled wheels being that obtaining when the tank and bunker are practically empty ("practically" in this connection being when only sufficient provision remains for the requirements until the next "supply station" is reached), and on the other hand, "starting" a train of maximum load on an up grade.

WHEEL ARRANGEMENTS.

Consideration, with respect to the wheels, has heretofore only been concerned with the number and diameter of the coupled wheels. Carrying or "trailing" wheels, also, are required where the total weight of the engine is in excess of the sum of the maximum weights per coupled axle and, in many cases, where flexibility has to be given to the wheel base. Before dealing with the various arrangements, reference must first be made to the systems of notation used for describing the relative position of the wheels.

WHEEL ARRANGEMENT—NOTATION. In British and American practice and as adopted in the previous pages of this book, the system of *wheel* arrangement is denoted by the use of the "Whyte" system of a group of three figures. The central figure of the group denotes the number of wheels coupled and the first and third denote respectively the number of front and hind carrying wheels. In France the system is similar, but the notation is for *axles*. In Germany the old system was a fractional figure denoting the proportion of coupled *axles* to the total number of axles; the new system is similar to the French, but the number of coupled *axles* is denoted by a letter—the letters A, B, C, D, E, F, etc., denoting the numbers 1, 2, 3, 4, 5, 6, etc. respectively. Names are also adopted, for several types, in U.S. practice. Example:—"Atlantic type."



British & American	4	4	2	thus 4-4-2.
French	2	2	1	,, 2-2-1.
German (New)	2	B	1	,, 2-B1.
,, (Old)	2/5 Coupled			,, 2/5 Coupled

Whytes.	U.S. Name.	French.	German. New.	Old.
0-4-0	4 Wheel Switcher	0-2-0	B	2/2 Coupled.
0-6-0	6 ,, ,,	0-3-0	C	3/3 ,,
0-8-0	8 ,, ,,	0-4-0	D	4/4 ,,
0-10-0	10 ,, ,,	0-5-0	E	5/5 ,,
0-12-0	12 ,, ,,	0-6-0	F	6/6 ,,
0-4-2		0-2-1	B1	2/3 ,,
0-6-2		0-3-1	C1	3/4 ,,
0-8-2		0-4-1	D1	4/5 ,,
2-4-0		1-2-0	1B	2/3 ,,
2-6-0	Mogul	1-3-0	1C	3/4 ,,
2-8-0	Consolidation	1-4-0	1D	4/5 ,,
2-10-0	Decapod	1-5-0	1E	5/6 ,,
2-12-0	Centipede	1-6-0	1F	6/7 ,,
0-4-4	" Forney " 4 Coupled	0-2-2	B2	2/4 ,,
0-6-4	,, 6 ,,	0-3-2	C2	3/5 ,,
0-8-4		0-4-2	D2	4/6 ,,
2-4-2	Columbia	1-2-1	1B1	2/4 Coupled.
2-6-2	Prairie	1-3-1	1C1	3/5 ,,
2-8-2	Mikado	1-4-1	1D1	4/6 ,,
2-10-2	Santa Fé	1-5-1	1E1	5/7 ,,
2-4-4		1-2-2	1B2	2/5 ,,
2-6-4		1-3-2	1C2	3/6 ,,
2-8-4		1-4-2	1D2	4/7 ,,
4-2-2	Bicycle	2-1-1	2A1	1/4 ,,

Whytes.	U.S. Name.	French.	German. New.	German. Old.
4-4-0	American	2-2-0	2B	2/4 Coupled.
4-6-0	10 Wheel	2-3-0	2C	3/5 ,,
4-8-0	12 Wheel	2-4-0	2D	4/6 ,,
4-10-0	Mastodon	2-5-0	2E	5/7 ,,
4-4-2	Atlantic	2-2-1	2B1	2/5 ,,
4-6-2	Pacific	2-3-1	2C1	3/6 ,,
4-8-2	Mountain	2-4-1	2D1	4/7 ,,
4-4-4		2-2-2	2B2	2/6 ,,
4-6-4		2-3-2	2C2	3/7 ,,
0-4-4-0	Mallet	0-2-2-0	BB	2·2/2 Coupled.
0-6-6-0	,,	0-3-3-0	CC	2·3/3 ,,
0-8-8-0	,,	0-4-4-0	DD	2·4/4 ,,
2-4-4-0	,,	1-2-2-0	1BB	
2-6-6-0	,,	1-3-3-0	1CC	
2-8-8-0	,,	1-4-4-0	1DD	
2-4-4-2	,,	1-2-2-1	1BB1	
2-6-6-2	,,	1-3-3-1	1CC1	
2-8-8-2	,,	1-4-4-1	1DD1	
2-10-10-2	,,	1-5-5-1	1EE1	
4-4-6-2	,,	2-2-3-1	2BC1	

WHEEL ARRANGEMENT TYPES. These are comprised under four main divisions, *viz.* :—

I. All wheels coupled.

II. Carrying wheels in *front* of the coupled wheels.

III. do. *behind* the coupled wheels.

IV. do. both in *front* of and *behind* the coupled wheels. Carrying wheels under the above divisions may be in single pairs or in groups.

Articulated engines of the Fairlie, Meyer, Mallet, etc., systems usually employ two sets, as under divisions I., II. and III.

I. ALL WHEELS COUPLED. In the types under this division, the total weight of the engine is utilized for adhesion. Representative engines are the 0-4-0 and 0-6-0 tank "shunting" or contractors' engines, and the 0-6-0 and 0-8-0 goods and mineral engines of British main line practice. In recent Continental practice, the 0-10-0 has been built in considerable numbers, the very long wheelbase having the requisite amount of flexibility given to it by side play allowances on the axle-boxes of the first, third and fifth axles.

II. Carrying Wheels in front of the Coupled Wheels. Engines of this type, 2-4-0, with one pair of carrying wheels on the main frame, were at one time most popular for passenger service, but, for high speeds, their long rigid base is unsuitable. The 4-4-0 type with the front carrying wheels on a bogie frame, now generally used, gives the necessary flexibility, with a guiding action, and provides for the additional weight of a larger boiler. The 4-6-0, with its greater adhesion, is the natural development of the 4-4-0, in response to the demand for greater haulage power. The 4-6-0, which has been built in rapidly increasing numbers in Great Britain during the last twenty years has, together with the 4-8-0, been a long accepted type on railways abroad where axle load restrictions are far more severe than in this country. The 2-6-0 and 2-8-0 types represent the standard freight engines of American practice. Their rigid wheelbase is shorter than in the corresponding engines of the "all coupled" types. The boiler is larger as compared with the latter types and smaller as compared with the 4-6-0 and 4-8-0 types, comparisons in all cases being made with engines of similar maximum weights.

III. Carrying Wheels behind the Coupled Wheels. Engines of this type, 0-4-2 with one pair of carrying wheels on the main frame, have been used for express passenger traffic. The type, however, much better suits the requirements of tank engines, providing as it does carrying wheels for the varying weight (or greater part thereof) of water and coal in such a way as to entail the minimum diminution of the weight on the coupled axles. The 0-6-2 and 0-6-4 are representative types.

IV. Carrying Wheels both in front of and behind the Coupled Wheels. Most important among engines of this type are the 4-4-2, 4-6-2 and 4-8-2, representing the further development of the 4-4-0, the 4-6-0 and the 4-8-0 types, respectively, in the provision of greater boiler capacity.

In tank engines belonging to this division the "Double-ender" or 2-4-2, 2-6-2, 4-4-2, 4-6-2, 4-4-4 and 4-6-4 types have the characteristic of the third division, with the further one of either a more flexible wheelbase, or greater boiler and tank capacities.

Weight of Locomotives. An estimate of the weight of a locomotive is usually based on the known weight of a similar engine, additions or deductions from the latter being made in accordance with the known differences in the details.

In many cases, however, there has to be adopted the laborious method, *viz.*, the making of a schedule of the estimated weights of all constituent parts.

Under either method, a comprehensive list of the " total " and " empty " weights of engines of various *types* and in various *sizes* and *gauges* is a most valuable asset, and part of such a list, representing the 4 ft. 8½ in. gauge, forms one of the useful features of this " Pocket Book." This feature is further extended below, by an example of a schedule of the *detail* weights of an engine.

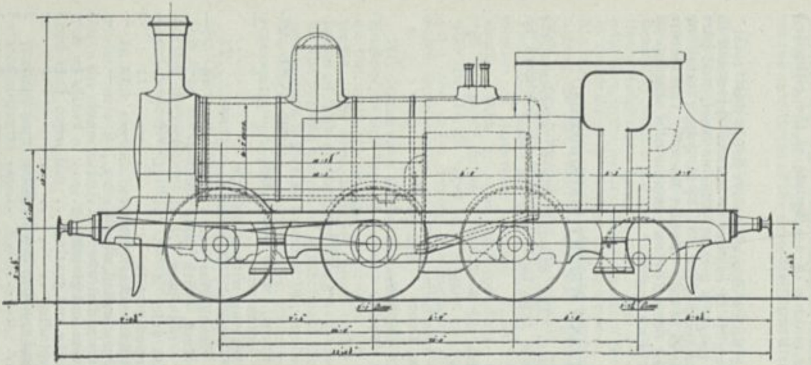
WEIGHT AND WEIGHT DISTRIBUTION.

DETAIL WEIGHTS. The example given represents the weights of an 0-6-2 type tank locomotive, as shown on illustration (page 84).

Cylinders (inside), 17½ × 26.
Coupled wheels, 5 ft. 1 in.
Radial Wheels, 3 ft. 8 in.

Heating Surface, Tubes		935 sq. ft.
Do.	Firebox,	85 do.
	Total,	1020 do.
Grate area ..	.. ..	19·7 do.
Tank capacity	.. ..	1200 gals.

	Tons.	Cwt.	Qr.
Coupled Wheels, Front, with axle and crank-pins	2	6	—
Do. Driving, with crank-axle, eccentric sheaves and crank-pins	2	19	—
Do. Hind, with axle and crank-pins	2	6	—
Wheels, radial with axle	1	10	—
Axleboxes for coupled wheels	—	12	2
Radial axlebox with side-check gear.. ..	—	12	—
Springs and gear for coupled wheels ..	1	—	—
Do. for radial wheels	—	4	3
Cylinders with covers and glands	1	12	—
Do. water cocks and gearing	—	1	3
Slide valves and spindles	—	2	—
Piston with rods and crossheads with slides	—	5	3
Slide-bars	—	5	2
Connecting rods	—	7	1
Coupling rods (side rods)	—		3



PARTICULARS AFFECTING "DETAIL WEIGHTS."

THICKNESS OF PLATES.

Boiler Barrel	$\frac{1}{2}$ in.
Firebox Copper Tube plate	1 & $\frac{5}{8}$ in.
" " Back plate	$\frac{5}{8}$ in.
" " Covering	$\frac{1}{2}$ in.
Ash Pan	$\frac{1}{4}$ & $\frac{3}{8}$ in.
Clothing	14 W.G.
Boiler Tubes (Iron) ..	13 "

Frame ..	1 in.
Buffer Beams	$1\frac{1}{4}$ in.
Cab	$\frac{3}{16}$ in.
Coal Bunker	$\frac{1}{4}$ in.
Tank ..	$\frac{1}{4}$ in.
bottom	$\frac{3}{8}$ in.

GENERAL.

Bearings (Coupled) ..	$7\frac{1}{2}$ in. dia. × 7 in. long.
" Radial ..	6 in. " × 8 in. "
Tyres	$5\frac{1}{2}$ in. × 3 in.
Coupling Pins, Driving	4 in. dia. × $4\frac{3}{8}$ in. long
" Front & Hind	$3\frac{1}{2}$ in. " × $4\frac{3}{8}$ in. "

Stephenson Link Motion.

Vacuum Brake.

	Tons.	Cwt.	Qr.
Link motion including eccentric straps ..	—	10	—
Do. Reversing gear including reversing shaft and balance-weight and auxiliary steam cylinder	—	10	—
Framing, including footplates and buffer beams..	8	17	—
Buffers and draw-gear and screw-couplings	—	12	—
Front splashers, sand-boxes and sanding gear	—	16	—
Cab and coal bunker	1	4	—
Tanks	2	18	—
Boiler with tubes and copper box	8	—	—
Do. Mountings, including steam valves, injectors, feed pipes and check valves	—	6	—
Do. Regulator and gear with main and branch steam pipes	—	5	—
Do. Fire door, ash-pan and gear.. ..	—	10	2
Do. Safety valve	—	1	—
Do. Grate with supports	—	12	—
Boiler Clothing, including wood lagging..	—	14	—
Do. Smokebox, including chimney ..	—	17	2
Do. Blast-pipe	—	1	3
Brake gear	1	1	—
Brake, vacuum brake fittings and pipes, etc	—	8	—
Firing irons, tools, screw-jack..	—	5	—
"Empty" weight Total..	43	—	—
Water in boiler	3	—	—
Water in tanks..	5	7	—
Fuel in bunker	2	10	—
Sand in boxes	—	3	—
"Full" working order weight. Total	54	—	—

DISTRIBUTION OF THE WEIGHT ON THE AXLES.

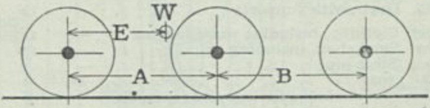
1. CENTRE OF GRAVITY.

In order to determine the amount of weight which will rest on each axle, it is necessary that the longitudinal position of the "centre of gravity" (C G) of the total weight resting on the springs should first be ascertained. The "dead" weights, *i.e.*, the weights which do not rest on the springs, such as the wheels, axles, axleboxes, side-rods, etc., do not form part of the weight, the distribution of which can be adjusted.

When the weights and positions of all parts are known, it is a simple, though tedious, process to determine the position of their common centre of gravity.

In the more usual case where an engine, the total and distributed weights of which are known, is taken as a *base* for a calculation to determine the weight, and the position of the C G of another engine, the method is as follows, *viz.*: 1. From the known distributed weights, *i.e.*, the weights on each axle, are deducted the "dead" weights, and the C G of the remaining weights (the weights on the springs) is then ascertained. Thus in Fig. 1 the letters P Q R denote the weights on the axles (at the rail) and W the total weight of the engine; p q r the respective dead weights at these axles and w the total dead weights; A and B the distance apart of the axle centres, and E the distance of the CG from the axis round which the moments are taken. (It will be understood that the units represented by these symbols must be in similar terms of weight or distance.)

Fig. 1.



Weights			
On Rail	P	Q	R = W
Dead	p	q	r = w
On Springs	P-p	Q-q	R-r = W-w

Taking the moments of the weights on the springs round the axis of axle P the equation for equilibrium is:—

$$A(Q-q)+(A+B)\ (R-r)=E\ (W-w)$$

Distance of C.G. from $P=E=\dfrac{A(Q-q)+(A+B)\ (R-r)}{W-w}$

The moments may, of course, be taken round any other convenient axis, say, as at axle Q, E, in that case, will be the distance of the CG from Q and will be situate on that side of the axis on which is the weight having the greater moment. Assuming that A(P-p) is the greater, then :—

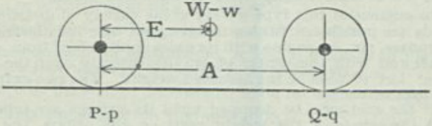
$$A(P-p)-B(R-r)=E(W-w) \quad \text{and}$$

Distance of C.G. from $Q=E=\dfrac{A(P-p)-B(R-r)}{W-w}$

Having ascertained for the base engine the total weight resting on the springs and the position of its centre of gravity, the modifications determined upon for the other engine must then be taken into account and, thereby, the modified weight and the position of its centre of gravity ascertained. Modifications on the dead weights must be ascertained separately and for each axle.

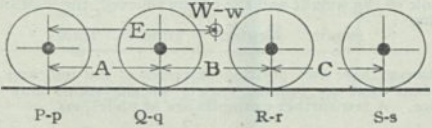
In the example given on page 86 of the method of finding the centre of gravity of the weight on the springs, the *three-axle* engine is taken as the example. For the *two* and *four-axle* engines, the formulæ are, for convenience, here also stated.

Fig. 2.



$$A(Q\text{-}q) = E(W\text{-}w) \text{ or } E = \frac{A(Q\text{-}q)}{W\text{-}w}$$

Fig. 3.



$$A(Q\text{-}q) + (A+B)(R\text{-}r) + (A+B+C)(S\text{-}s) = E(W\text{-}w)$$

$$E = \frac{A(Q\text{-}q) + (A+B)(R\text{-}r) + (A+B+C)(S\text{-}s)}{W\text{-}w}$$

2. DISTRIBUTION.

Given that the total weights and the position of the centre of gravity of the weight on the springs has been ascertained for the new engine, the method of allocating the load to each axle may now be stated for various systems of axle and spring arrangements.

The conditions relative to the distribution of the weight over two points are sufficiently simple to obviate their discussion here. This group includes the two-axle engine, the three-axle engine with compensated springs, and the four-axle engine, two axles of which are combined in a bogie and the others have compensated springs.

NOTE.—Relative to the use of compensating beams between the bearing springs it may be important here to note that the purpose for which a "compensating" or "balance" beam is fitted is entirely connected with the *running* of the engine. In effect it gives greater elasticity to the springs and thus lessens the shocks due to inequalities of the road, etc. It has, incidentally, the effect of limiting the, otherwise, possible range of adjustments of the *static* weights. The beam is never fitted to *make possible* an equal distribution of the static loads on those axles, between the springs of which it is placed.

1. Three-Axle Engine with independent springs.

In engines of this type a very great variety of distributed loads are possible. Taking the simplest case for illustrative purposes, *viz.*, an engine with its axles equi-distant from each other and with the centre of gravity directly over the mid axle. Let 36 tons be the assumed weight. The two extreme variations are:—

If the mid axle be dropped until its springs are relieved and the whole of the weight rests on the others the distribution being

Front.	Mid.	Hind.	Total.
18	0	18	36

If the mid axle be raised until its springs are loaded with the whole of the weight and the others relieved, the distribution being—

Front.	Centre.	Hind.	Total.
0	36	0	36

Between these two position extremes of the mid axle it is evident that an infinite variety of gradations may take place. A few further examples are as under, *viz.*:—

Front.	Mid.	Hind.	Total.
18	0	18	36
17	2	17	36
16	4	16	36
14	8	14	36
12	12	12	36
10	16	10	36
7	22	7	36
3	30	3	36
0	36	0	36

The main point to be here noted is that, within the limits of equilibrium, an adjustment can be obtained to suit the arbitrary selection of the weight which may be considered desirable for any one axle. Putting aside the ideal conditions of the above illustration and taking the case of an actual engine for which the distributed weights are:—

Front.	Centre.	Hind.	Total.
14	13	10	37

It will be evident that it is within the *limit of equilibrium* that the load on the mid wheel could be increased to 14, 15 or 16 tons or decreased to 10, 9 or 8 tons, as might be arbitrarily selected. The effect on the other weights would be governed by the positions of the three axles relative to that of the central gravity.

A similar arbitrary selection of weight for either the front or the hind axle is, of course, possible, but only one of the three weights may be so selected.

For general application, the formulæ are as under, *viz.*

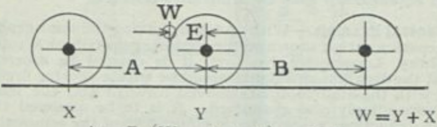
Let W = The total weight to be distributed on three axles.
,, y = The weight determined upon for one axle.
,, x = The weight on a second axle.

Then W-(x+y) = The weight on a third axle.

The equation for equilibrium, A and B being as in Fig. 4, the distance apart af the axles is as under, *viz.* :—

With y as the weight determined upon for the *mid* axle, and x as the weight on the *front* axle.

Fig 4.



$$Ax - B\,(W - (y+x)) = EW$$

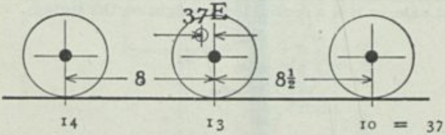
or with y as the weight determined upon for the *hind* axle and x as above

$$Ax - By = WE$$

NOTE.—Ax in these equations is assumed to be the greater moment.

Taking for an example the actual distribution quoted above and assuming the positions of the axles as A = 8 and B = 8½

Fig. 5.



the position of the "centre of gravity" will b

$$(14 \times 8) - (10 \times 8\tfrac{1}{2}) = 37E$$
$$E = 0{\cdot}73$$

Readjusting the distribution to suit an arbitrary selection of 16 for the weight on the mid axle,

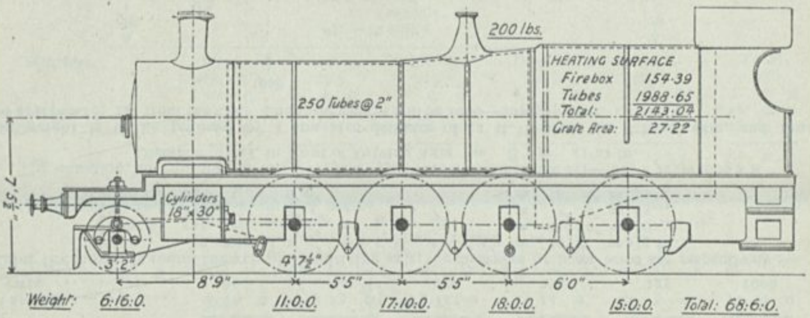
$$x = \text{Load on Front axle.}$$
$$y = 16$$
$$37 - (x + 16) = \text{Load on Hind axle.}$$
$$8x - 8\tfrac{1}{2}\,(37 - (x \times 16) \quad = 37 \times 0{\cdot}73$$
$$x = 12{\cdot}45$$
$$y = 16$$
$$37 - (x \times y) = \ 8{\cdot}55$$

II. For engines with more than three points of support, *i.e.*, with four or more axles fitted with independent springs, or five or more axles with compensated springs, etc., it will be sufficient now to state generally that, in the calculation for distribution, where W represents the total weight on the springs and **x** represents one of the distribution weights, a second distributed weight will be W—(**x** + the remaining weights), and that these remaining weights may (consistent with equilibrium) each be arbitrarily selected.

General Example.—With an engine having the same general dimensions of that shown on the opposite page (Great Western Railway Locomotive No. 97), it is desired to ascertain what the distributed weights would be with a shorter firebox and with the hind footplate moved forward and the frame correspondingly also shortened. It is to be assumed that these deductions amount to an equivalent of the removal of a weight of one ton, at a distance of 12 feet behind the driving axle.

The position of the C.G. for the weight on the springs, of the base engine, is first to be ascertained. For this purpose the dead weights —the weights respectively for each axle, of the wheels and axles with crank-pins and eccentric side rods, part of connecting rod, axleboxes, bearing springs and such parts of the valve gear as are hung directly on the axle connections—must first be computed. For the purpose of this example, let them be taken as stated herewith under the distributed weights. The weight of the pony truck is, it may be noted, assumed to be part of the dead weight for that axle, as it is a central loose weight on the springs.

2-8-0 Type.



MINERAL LOCOMOTIVE No. 97, G.W.R.

DISTRIBUTION OF WEIGHTS.

	Pony.	COUPLED AXLES. Front C.	Int. C.	Driving	Hind C.	Total.
	t c q	t c q	t c q	t c q	t c q	t c q
Weight on Rail	6 16 0	11 0 0	17 10 0	18 0 0	15 0 0	68 6 0
Dead	2 6 0	3 15 0	3 18 0	4 6 0	3, 15 0	18 0 0
On spring	4 10 0	7 5 0	13 12 0	13 14 0	11 5 0	50 6 0
In cwts.	90	145	272	274	225	1006

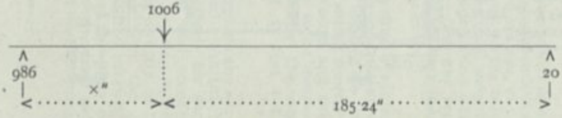
Taking the moments round the axis of the driving axle; the distances or lever arms are respectively :—

Pony	90 cwts. at	8′ 9″ + 5′ 5″ + 5′ 5″	= 19′ 7″	= 235 in.
Front C.	145 ,,	5′ 5″ + 5′ 5″	= 10′ 10″	= 130 ,,
Int. C.	272 ,,	5′ 5″	= 5′ 5″	= 65 ,,
Hind C.	225 ,,	6′ 0″	= 6′ 0″	= 72 ,,

The equation for equilibrium is — $(90 \times 235) + (145 \times 130) + (272 \times 65) - (225 \times 72) = 1006 \times E$

Distance of CG. in front of Driving Axle = E = 41·24 in.

The weight is to be reduced by 1 ton at a distance of 12 ft. behind the driving axle, and thus 144″ + 41·24″ = 185·24″ from the CG. The total weight will be 1006—20 = 986 cwts.



Movement of CG. $= x = \dfrac{20 \times 185{\cdot}24}{986} = 3{\cdot}77$ in.

The distance of the CG. in *front of the driving axle*, for the modified weight, will therefore be 41·24″ + 3·77″ = 45·01″

Distribution of the modified weight. Four examples.

1. With equal weights on the springs of the coupled axles.

Let x=weight on each coupled axle. Then 968—4x=weight on pony axle

With the distances as above, for position of axles, the equation is—

$$(986-4x)\,235 + 130x + 65x - 72x = 968 \times 45$$

$$x = 229{\cdot}3$$

$$986 - 4x = 68{\cdot}8$$

Weights.	Pony. Cwts. 68·8	Front C. 229·3	Int. C. 229·3	Driving. 229·3	Hind C. 229·3	Total. 986
	t c q	t c q	t c q	t c q	t c q	t c q
On Springs	3 9 0	11 9 0	11 9 1	11 9 1	11 9 1	49 6 0
Dead	2 6 0	3 15 0	3 18 0	4 6 0	3 15 0	18 0 0
On Rail	5 15 0	15 1 1	15 7 1	15 15 1	15 4 1	67 6 0

2. Retaining weight on Pony as on base engine.

Weight on Pony = 90.

" on Front, Int. C, and Driving = x.

" on Hind = 986 — (3x + 90).

Equation, $$(90 \times 235) + 130x + 65x - 225\,(986 - (3x + 90)) = 986 \times 45$$

$$x = 213{\cdot}4$$

$$986 - (3x + 90) = 255{\cdot}8$$

	Pony. Cwts. 90	Front C. 213·4	Int. C. 213·4	Driving. 213·4	Hind C. 255·8	Total. 986
	t c q	t c q	t c q	t c q	t c q	t c q
On springs	4 10 0	10 13 2	10 13 2	10 13 2	12 15 2	49 6 0
Dead	2 6 0	3 15 0	3 18 0	4 6 0	3 15 0	18 0 0
On Rail	6 16 0	14 8 2	14 11 2	14 19 2	16 0 2	67 6 0

3. With 225 cwt. as the selected weight for the Hind Coupled, 90 cwt. for the Pony, and with the weights on the Int. Coupled and Driving equalized.

On Pony = 90.
On Int. C. and Driving = x.
On Hind C = 225.
On Front C. = 986 — (2x + 90 + 225) or 671-2x.

Equation. $(235 \times 90) + 130\ (671 - 2x) + 65x - 72x) = 986 \times 45$

$x = 245{\cdot}2$

$671 - 2x = 180{\cdot}6$

	Pony.	Front C.	Int. C.	Driving.	Hind C.	Total.
Cwts.	90	180·6	245·2	245·2	225	986
	t c q	t c q	t c q	t c q	t c q	t c q
On springs	4 10 0	9 0 2	12 5 1	12 5 1	11 5 0	49 6
Dead	2 6 0	3 15 0	3 18 0	4 6 0	3 15 0	18 0 0
On Rail	6 16 0	12 15 2	16 3 1	16 11 1	15 0 0	67 6 0

4. In this, the final example, the selected weights, *viz.*, those for the front C., Int. C. and Driving, are identical with the corresponding weights of the base engine.

Weight on Pony = x.
" Front C. = 145.
" Int. C. = 272.
" Driving = 274.
" Hind C. = 986 — (x + 145 + 272 + 274) or 295 — x

Equation. $235x + (130 \times 135) + (272 \times 65) - 72\ (295 - x) = 986 \times 45$

$x = 94{\cdot}4$

$295 - x = 200{\cdot}6$

	Pony.	Front C.	Int. C.	Driving.	Hind C.	Total.
Cwts.	94·4	145	272	274	200·6	986
	t c q	t c q	t c q	t c q	t c q	t c q
On springs	4 14 2	7 5 0	13 12 0	13 14 0	10 0 2	49 6 0
Dead	2 6 0	3 15 0	3 18 0	4 6 0	3 15 0	18 0 0
On Rail	7 0 2	11 0 0	17 10 0	18 0 0	13 15 2	67 6 0

Of the four alternative solutions given above, No. 1 has the effect of placing on the Pony Truck what would probably be too little weight, for *guiding* purposes, relative to the total weight of the engine, and that given by No. 2 places too much on the Hind Coupled. Of Nos. 3 and 4 that effected in No. 3 seems the better.

Compensating Beams.—After the distribution has been finally decided upon, arrangements as regards "compensating beams" may be considered. In practice on our home railways "*simplicity of parts*" has been such a governing principle, that to avoid complication in the case of the spring gear it is characteristic that each of the springs is independently connected to the main frame of the engine, whereas, in Colonial and foreign practice, the use of the compensating beam to give inter-communication between the springs is equally characteristic. The fundamental differences of chaired and spiked permanent way and relative standards of maintenance achieved, largely decide the question of whether compensating gear shall be fitted or omitted.

The "Two Groups" system of compensated springs is to be generally recommended. In the 0.6.0. type engine this means that the springs of one axle are independent and that those of the others are compensated. In the 4.4.0 type, that the bogie forms one group and the springs of the coupled axles are compensated. In the 2.6.0. type that the springs of the pony and Leading Coupled are compensated in one group and that those of the Driving and Hind Coupled are also compensated, etc.

In the engine, the distribution of which has been discussed above, the best arrangement would probably be to couple the springs of the Pony and Front Coupled, and of the Int. Coupled, Driving and Hind Coupled.

For such an arrangement, with the distribution as given in No. 1, the beams between these springs of Int. Coupled and Driving would have equal arms, as the loads on the spring are identical. For the distribution given in No. 4 the arms of the beams between Int. C. and Driving would be equal, but for those between Driving and Hind Coupled the arms would be as 274 to 200—the shorter arm being connected to the heavier weight. The beam, between the Pony and Front Coupled springs, as usually arranged, connects the *centre pivot* of the Pony with a transverse beam between the front *ends* of the Front Coupled springs, and is to be proportioned therefore in ratio of the weight on the Pony pivot to one-half of the weight on the front axle springs, *i.e.*, in No. 1 as 68·8 ; 114·6 and in No. 4 as 94·4 : 72·2.

VARIATION OF DISTRIBUTED WEIGHTS IN TANK LOCOMOTIVES.

Consideration has been given above to a method by which the distributed weights for "**Full Working order**" conditions may be calculated. In Tank Engines, it is further desirable, in many cases, to ascertain what changes will be made on that distribution consequent on a partial or total emptying of the tanks and bunker. Such a case, for instance, is that in which, on account of the tanks (water and fuel) being situated over a hind carrying axle, there is a danger of the weight on the wheels being reduced beyond a safe running limit.

The method here described and exemplified has reference to engines in which the spring-carried weight rests on three or more points. The simpler case of the two-axle engine or of that in which the weight is carried on two points only, it is unnecessary to discuss.

The three conditions on which the method is based are:—

I.—The centre of gravity (C.G.) of the engine with tanks and bunker empty, is known, *i.e.*, the C.G. in "full working order," and the movement from it due to the position and weight of the water and fuel. The distributed weights in "Empty" condition will be in equilibrium on this (Empty) C.G.

II.—The sum of the differences between the full and empty weights is known. It is equal to the weight of the water and fuel.

III.—The amount of deflection per unit load on the bearing springs is known. From the vertical movement of the engine, as measured at its spring-supported points, the change on the load of these springs can therefore be deduced.

In Fig. 1, let P.Q.R.S. denote the distributed weights and W the total weight in full working order; let p.q.r.s. denote the differences on these weights and w the sum of these differences for the "tanks and bunker empty" condition; let A.B.C.D.E. denote the distances as shown, G being the position of the C.G. "Empty." Let "d" denote

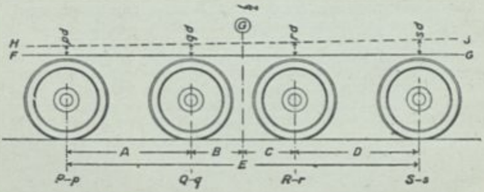


Fig. 1.

the deflection per unit of load for all the bearing springs and let the dotted line H.J. relative to the level line F.G. show the vertical movement of the engine due to relief of the springs.

I. $(P-p)\ (A+B)+(Q-q)\ B=(R-r)\ C+(S-s)\ (C+D).$

II. $p+q+r+s=w.$

III. $rd=(sd-pd)\ \frac{A+B+}{E}\ +pd.$

IV. $qd=(sd-pd)\frac{A}{E}+pd.$

These equations apply to a movement in which all the springs are relieved. It often happens, however, that on one or more sets of springs, the movement is reversed. The numerical example given below illustrates such a case.

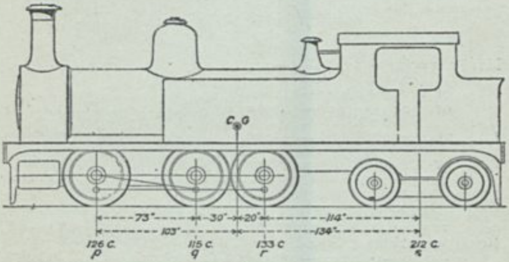


Fig. 2.

In Fig. 2 is illustrated a 0-6-4 type Tank Engine. The weights in cwts. on the springs, in full working order, are given. The C.G. is that with the "tanks and bunker" empty. The positions of the axles, etc., are given in inches.

It is to be assumed that, from the position of the tanks, the greater part of the weight will come off the hind coupled and bogie wheels, and that there will be an increase of weight on the front coupled wheels. Fig. 3 illustrates the assumed directions of the movement.

Let, as before, p.q.r.s. and w denote the variations in weight in cwts. The deflection of the springs of the coupled wheels is 11/64-in. per ton, and of the bogie 12/64-in. per ton. For purposes of the following calculation the comparative values $d=11$ and $e=12$ are sufficient.

$(126+p)\ 103+(115-q)\ 30=(133-r)\ 20+(212-s)\ 134$
or $103p-30q+20r+134s=14{,}640$ ....(1)

II. $+p-q-r-s=-122$ ....(2)

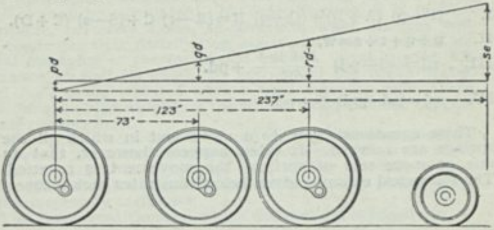


Fig. 3.

III. $11r=(12s+11p)\ \frac{123}{237}-11p.$

or $1254p+2607r-1476s=0$
or $24p+\ 50r-\ 283s=0$ ....(3)

IV. $11q=(12s+11d\frac{73}{237}-11p.$

or $1804p+2607q-876s=0$
$34{\cdot}6p+50q-16{\cdot}8s=0$ ....(4)

From equations (1) and (2).
$73p+50r+164s=18300$ ....(5)
$123p-50q+114s=12200$ ....(6)

From equations (3) and (5).
$-49p-192{\cdot}3s=-18300$ ....(7)

From equations (4) and (6).
$157{\cdot}6p+97{\cdot}2s=12200$ ....(8)

From equations (7) and (8).
$522s=46720$
$s=90$

By substitution $p=22$, $q=15{\cdot}6$ and $r=38{\cdot}4$.

For these values and the given deflections Fig. 3 shows in vertical scale, the movement in "full size" and in horizontal scale the relative positions of the axles.

The weights on the springs in cwts. in full working order are :—

Front C.	Driv.	Hind C.	Bogie.	Total.
126	115	123	212	586
The differences as calculated above are :—				
+22	—15·6	—38·4	—90	122
The weights on the springs in "Tanks and Bunker Empty" condition are therefore :—				
148	99·4	94·6	122	464

It may be of interest to state that the weights in "full working order" represent the weights of an engine, as actually built, and that the "differences" between these and the "Tanks and Bunker Empty" weighing were:—

+16 —10·25 —34 —93·5 121·75

As the engine was weighed first in full working order, the friction of the movement pivots, etc., partly accounts for the differences between the calculated and actual differences.

STABILITY ON CURVES.

Let W=Weight of Locomotive in pounds.

V=Velocity in feet per second.

R=Radius of Curve in feet.

C=Centrifugal force in pounds.

Then $C=\frac{WV^2}{32\cdot 2 \times R}$

Or, as may be more readily applicable—

Let M=Velocity in miles per hour.

Then $C=\frac{WM^2}{15R}$

Let A=Vertical distance in inches of the "centre of gravity" of the engine, from the top of the outer rail.

Then $CA=\frac{WM^2A}{15R}$ = The moment, of the centrifugal force tending to overturn the engine.

Let B=The horizontal distance, in inches, from the "centre of gravity" of the engine to the centre of the outer rail

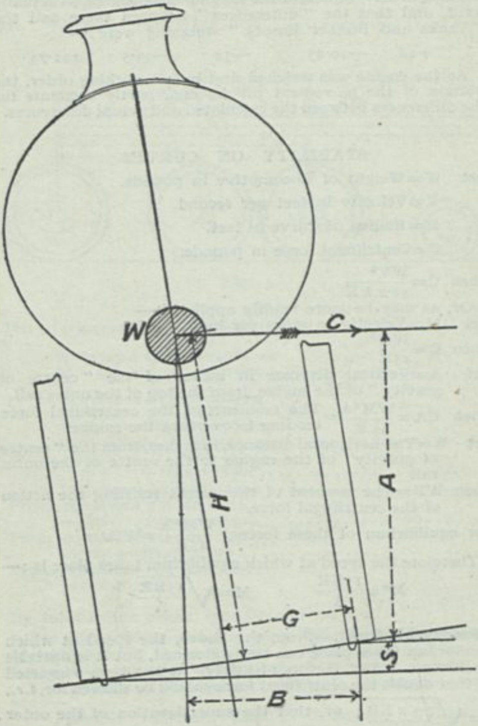
Then WB=The moment of the weight resisting the action of the centrifugal force.

For equilibrium of these forces, $\frac{WM^2A}{15R}=WB$.

Therefore the speed at which equilibrium takes place is:—

$$M^2=\frac{15BR}{A} \qquad M=\sqrt{\frac{15BR}{A}}$$

Permissible Speed.—From the above, the speed at which equilibrium takes place can be determined, but it is **unstable** equilibrium. As "factors of safety" it has been suggested (1) that **double** the centrifugal force should be allowed for, *i.e.*, $M=\sqrt{\frac{7\cdot 5 \times BR}{A}}$; or, that the superelevation of the outer rail should **not** be taken into account, *i.e.* $=\sqrt{\frac{15\,GR}{H}}$ where "G" is equal to one half of the distance between the centres of the rails and "H," the height of the "centry of gravity" of the engine from the level of both rails.



S = Superelevation in Inches.

$A = H - \frac{S}{2}$

$B = G + \frac{HS}{2G}$

Example.*

Gauge, 4 ft. 8½ in. C.G. of engine, 60 in. above rails. Curve, 12 chain radius (792 ft.), with 1½ in. superelevation, merging into 8 chain (528 ft.) with 3½ in. sup. :—

Thus G=29½ in. H=60 in. And by calculation for 1½ in. sup., A=59·43 in., and B=30·64 in.; while for 3½ in. sup., A=58·25 in. and B=33·06 in. (see diagram).

(1) On the 792 ft. curve.

With superelevation.

$$M=\sqrt{\frac{15BR}{A}}=\sqrt{\frac{15\times30\cdot64\times792}{59\cdot43}}=\sqrt{6125}=78 \text{ m.p.h.}$$

Sup. not taken.

$$M=\sqrt{\frac{15GR}{H}}=\sqrt{\frac{15\times29\cdot5\times792}{60}}=\sqrt{5841}=76 \text{ m.p.h.}$$

With double "C."

$$M=\sqrt{\frac{7\cdot5BR}{A}}=\sqrt{\frac{7\cdot5\times30\cdot64\times792}{59\cdot43}}=\sqrt{3062}=55 \text{ m.p.h.}$$

(2) On the 528 ft. curve.

With superelevation.

$$M=\sqrt{\frac{15BR}{A}}=\sqrt{\frac{15\times33\cdot06\times528}{58\cdot25}}=\sqrt{4487}=67 \text{ m.p.h.}$$

Sup. not taken.

$$M=\sqrt{\frac{15GR}{H}}=\sqrt{\frac{15\times29\cdot5\times528}{60}}=\sqrt{3884}=62 \text{ m.p.h.}$$

With double "C."

$$M=\sqrt{\frac{7\cdot5BR}{A}}=\sqrt{\frac{7\cdot5\times33\cdot06\times528}{58\cdot25}}=\sqrt{2243}=47 \text{ m.p.h.}$$

* In the case ("The Engineer," CII., page 355) from which the particulars for this example are taken, the permissible speed was 30 m.p.h., and derailment was supposed to have occurred at a speed of about 70 m.p.h.

WHEEL-BASE IN RELATION TO CURVES.

Determination as to the suitability of any wheel-base for traversing a curve of a given radius is dependent, in the first instance, on the following considerations, *viz.* :—

1. The clearance between the tyre-flange and the shoulder of the rail. A normal example of this, with flanges and rails of full contour, *i.e.*, not worn, is shown in Fig. 1. The movement for which allowance is made, *i.e.*, "clearance," is indicated by the dotted line and amounts to $\frac{3}{16}$ inch. The total clearance for the two tyres on an axle is thus ⅜ inch. In Fig. 2 is further illustrated an example of the thin flange frequently adopted for

intermediate wheels, such as the driving wheels of an 0-6-0 type engine, and this, as shown, allows for $\frac{3}{8}$ inch clearance, or for the two tyres $\frac{3}{4}$ inch total clearance.

2. The clearance between the axleboxes and their guides and the end clearance between axlebox bearings and axle journals: Usually these clearances are only the normal fitting allowances. Between the axlebox and guides (inclusive of those for the coupled wheels) there are many cases where additional side-play or clearance is given.
3. Allowance for lateral movement at bogie pivots or centre slides.
4. "Widening of the Gauge" at curves: On British railways it is not usual to widen the gauge at curves. ("Spreading" of the gauge, due to the thrust of vehicles against the outer rail, proceeds only until a "regulation" maximum is reached, and the gauge is then re-adjusted to normal.) On the Continent of Europe "Widening" seems generally adopted, but a very great disparity exists in the practice of the various administrations as to its amount. A few examples from important railways are given in the table herewith, from which it will be seen that as much as 30 millimetres (say $1\frac{3}{16}$ inches) for a 300 metre (say 1,000 feet) radius of curve, is allowed. The dimensions given in the table are metrical.

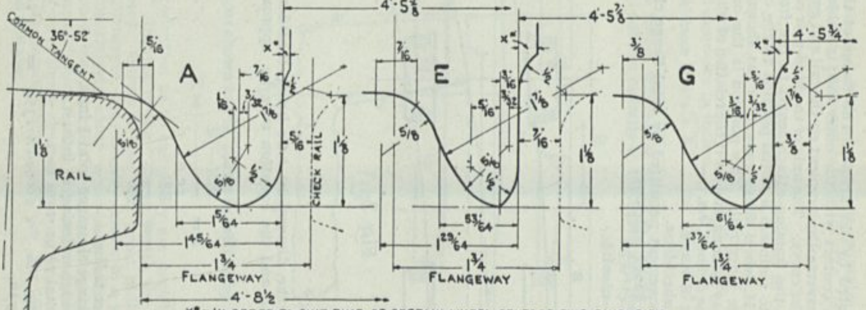
GAUGE WIDENING.

Railway.	Radius of Curve in Metres (widening in mm.).						
	100	200	300	400	600	800	1000
Austria A.S.R.	—	—	30	24	12	12	12
,, H.S.R.	—	—	—	20	10	10	10
Swiss Federal Rys..	20	20	20	20	10	10	0
Saxon State Rys. ..	—	25	25	20	7	0	0
Prussian State Rys	30	24	18	15	9	3	0
Wurtemburg State Rys.	15	15	15	12	9	6	0
Dutch Railway Co.	15	15	15	11	8	6	5
Belgian State Rys...	10	10	10	10	0	0	0
France P.L.M.	10	10	10	10	0	0	0
Danish State Rys...	17	17	17	9	0	0	0

The determination, it will be understood, is to be made chiefly with the object of ensuring a minimum rolling resistance in the passage of curves and, consequently, a minimum "wear and tear" of wheel flanges and rail heads, as caused by the side pressures due to guiding action. Fig. 3 shows, for a two-axled vehicle on a curved road, the position of the tyre flanges in relation to the rails, the running direction

B.E.S.A. STANDARD TYRE CONTOURS (REPORT No. 276-1927)

FOR BRITISH RAILWAYS 4'-8½" GAUGE.



X* – IN ORDER TO SUIT RIMS OF CERTAIN WHEEL CENTRES THIS DIMENSION MAY BE VARIED AS DESIRED UP TO A MAXIMUM OF 3/16 INCH.

A	LEADING & TRAILING WHEELS FOR BOGIES, PONY TRUCKS ETC.
A OR G	COUPLED WHEELS WHEN LED BY BOGIES ETC.
A OR G	TRAILING COUPLED WHEELS WHEN FOLLOWED BY BOGIES ETC.
G OR E	COUPLED WHEELS OTHER THAN LEADING & TRAILING IN COUPLED WHEEL GROUPS OF 6, 8, OR 10 COUPLED.

being as indicated by the arrow. The flange of the L.H. front wheel, in contact with the outer rail, is subject to a continuous transverse displacement on the rail and guides the vehicle round the curve. The axle of the hind pair of wheels is parallel (by the framing attachments) to the front axle and will tend to maintain a radial position to the curve so long as the R.H. wheel flange runs clear (as shown in the diagram) of the inner rail. This position is the one most conducive to easy running, and for it the relation of wheel-base to curve may be defined, *viz.* :—

Let R = Radius of curve.
B = Rigid wheel-base.
C = Side movement permitted by total flange clearance and gauge widening.

Then $R^2 - (R - c)^2 = B^2$

$2Rc - c^2 = B^2$

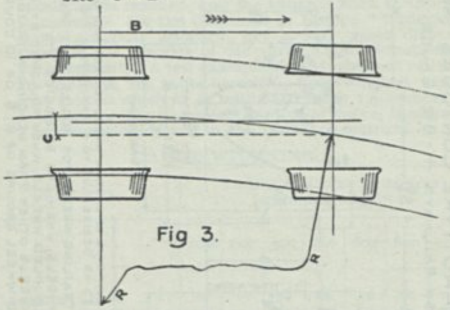


Fig 3.

Relative to the dimensions here being considered c^2 is negligibly small and the equation may be approximately stated as

$$B = \sqrt{2Rc}$$

$$R = \frac{B^2}{2c}$$

$$c = \frac{B^2}{2R}$$

Example :—
Curve—600 feet radius.
Clearances—Flange clearance total ⅜ inch.
,, Gauge widening 1¼ inch.
,, Total 1⅝ or ·1354 foot.

$B = \sqrt{2Rc} = \sqrt{2 \times 600 \times \cdot 1354} = \sqrt{162 \cdot 48}$
$= 12$ ft. 9 in.

The following table gives a few examples of this rule as given in the recommendations of the German Railway Union :—

Rigid Wheel-base in Relation to Curves.				
Radius in feet	1600	1600	650	650
Total clearance in inches ..	$\frac{3}{8}$	1	$1\frac{3}{16}$	$1\frac{3}{4}$
Wheel-base $B = \sqrt{2\ Rc}$ ..	10′ $4\frac{1}{2}$″	16′ 5″	11′ 0″	14′ 0″

For a longer wheel-base or for a sharper curve the hind axle will not run radially to the curve and the radial position

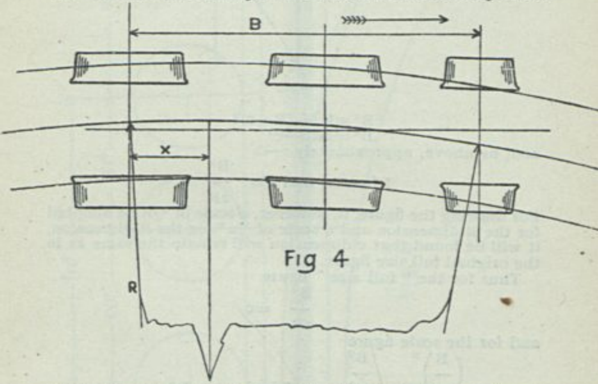


Fig 4

will fall, as shown in Fig. 4, and be defined by the equation :—

$$X = \frac{B^2 - Rc}{2B}$$

Determination as to suitability are usually made from a "scale" drawing of the "Curve," with the "Wheel-base" superposed. Curves of the very great radii here involved are not, however, conveniently drawn to a scale which, for the comparatively short wheel-base, allows of an exact definition of the clearances of the wheel flanges with the rail. Roy's method obviates this difficulty and allows within the range of an ordinary sheet of drawing paper and a moderate length of trammel compasses, for the clearances being shown in full size.

ROY'S METHOD.

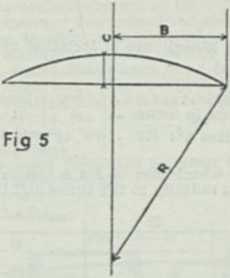


Fig 5

$$B^2 = R^2 - (R - c)^2$$
$$B^2 = 2Rc - c^2$$

and, as above, approximately :—

$$B^2 = 2Rc \text{ and } c = \frac{B^2}{2R}$$

For drawing the figure, if, however, a scale of $^1/n$ be adopted for the B dimension and a scale of $^1/n^2$ for the R dimension, it will be found that c dimension will remain the same as in the original full size figure.

Thus for the " full size " figure

$$\frac{B^2}{2R} = c$$

and for the scale figure

$$\frac{\left(\frac{B}{n}\right)^2}{\frac{2R}{n^2}} = \frac{\frac{B^2}{n^2}}{\frac{2R}{n^2}} = \frac{B^2\, n^2}{2R\, n^2} = \frac{B^2}{2R} = c$$

It is to be specially noted that the use of this equation is confined to cases where R is *very great* relative to c.

Fig. 6 shows the application of this method to the drawing of the curve in relation to the wheel-base of a 2-6-0 type engine. The curves a, a^1 represent the inside edges of the outer and inner rails respectively. The line f represents the touch or contact line of the wheel flanges with the rail, the left-hand side of the line representing the touch line of the left-hand wheels and the right-hand side of the line representing similarly the R.H touch line of the R.H. wheels. Again

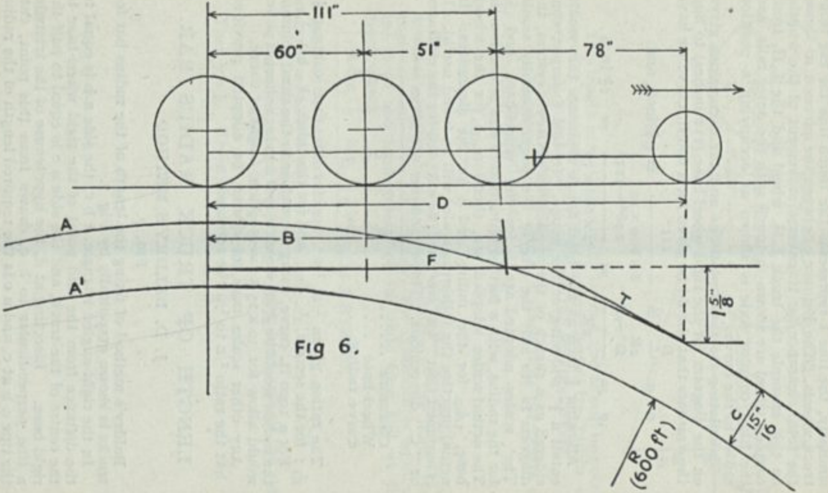


Fig 6.

similarly, the line t represents the touch line for the front truck wheels. The distance c between the curves a, a^1 shows the total clearance for transverse movement of the wheels. In this example the truck L.H. wheel and the L.H. front coupled wheel are shown in touch with the outer rails, and the hind coupled axle is shown as occupying a position radial to the curve.

Calculating for those positions and the dimensions given on the diagram for the rigid wheel-base (111 inches) to find the *clearance* that should be given for a 600 ft. curve we have

$$c = \frac{B^2}{2R} = \frac{111^2}{2 \times 600 \times 12} = \tfrac{7}{8} \text{ inch, and}$$

$$e = \frac{D^2 - B^2}{2R} = \frac{198^2 - 111^2}{2 \times 600 \times 12} = 1\tfrac{7}{8} \text{ inch}$$

Allowing ⅜ inch as the total flange clearance this would entail a ½" widening of the gauge. In this example, considered as a sketch of the application of Roy's system, the diagram is (to suit the size of the page) absurdly small. The scales adopted are $\frac{1}{80}$ for the wheel-base and $\frac{1}{400}$ for the radius, with a further reduction of size to one-fourth. The actual scales adopted are, therefore, $\frac{1}{80}$ for the wheel-base, $\frac{1}{1600}$ for the radius and ¼ for the clearances. In actual practice the following scales will be found useful. It is assumed that "*half size*" will be adopted for the clearance or "C" dimensions. Three examples are given :—

Clearance	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Wheel-base	$\frac{1}{16}$	$\frac{1}{20}$	$\frac{1}{25}$
Curve radius ..	$\frac{1}{128}$	$\frac{1}{200}$	$\frac{1}{312 \cdot 5}$

The ratios given $^1/n$, $^1/n^2$, are for the first column $\frac{1}{8}$, $\frac{1}{64}$; for the second, $\frac{1}{10}$, $\frac{1}{100}$; and for the third, $\frac{1}{12 \cdot 5}$ to $\frac{1}{156 \cdot 25}$.

For a 1000 ft. curve, using the values in the third column, the radius would be $\frac{1000}{312 \cdot 5} = 3 \cdot 2$ ft., and a 30 inch sheet of paper would allow for $30 \times 25 \times 2 = 1500$ ins. *length* of curve.

Any other scales may, of course, be adopted provided hat the ratio $^1/n$ to $^1/n^2$ be retained.

LENGTH OF TRUCK RADIUS BAR.

J. D. BALDRY'S METHOD.

FIG. 7.

Baldry's method of fixing the length of the radius bar for trucks is shown graphically by Fig. 7.

In the right-angled triangle, a b c, the side a b is equal to the distance from the mid point of the rigid wheel-base to the centre of the truck, and the side a c is equal to half the rigid base. Bisecting at d, the hypotenuse of the triangle, a line perpendicular to b c, drawn from this point, cuts the line a b at e, and a e is the required length of the radius bar.

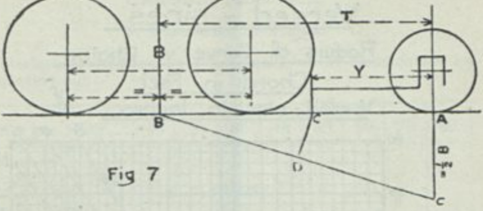


Fig 7

This length is mathematically correct and as will be noted from the construction is quite independent of the radius of curve. It may be calculated from the equation where,

y=The required length (ac).
T=Distance (ab) of centre of truck from the centre of the rigid base.
F=Half of the rigid base (ac).

by $y = \frac{1}{2}\left(T - \frac{F^2}{T}\right)$

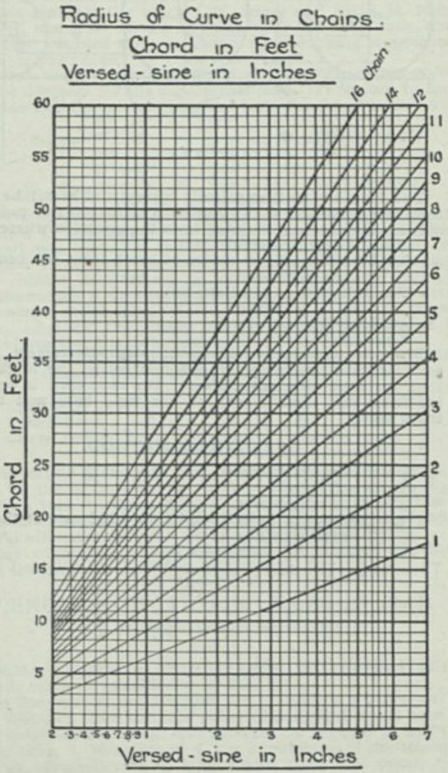
The rule, however, is only mathematically correct for an assumed position of the wheels relative to the track, *viz.*, that on each side respectively, the clearance is equal at the front and hind wheels of the rigid base and at the truck wheel.

G. LOTTER'S METHOD.

Let y=the required length.
B=Rigid base.
D=Total wheel-base.
x=Distance of radial point from hind axle of the rigid base as in Fig. 4.

Then $y = \frac{1}{2}\left\{(D - \mathbf{x}) - \frac{(B - \mathbf{x}.)^2}{D - \mathbf{x}}\right\}$

Versed - sines



GERMAN PRACTICE.

1. Resistance of Trains.

I. Resistance per ton of Train inclusive of Locomotive on the level road.

Miles per Hour ..	10	20	30	40	50	60	70	80
Shunting Engine	9.7	11						
Secondary Rlys. (Clark) ..	6.2	7.5	10.3					
Main Lines (Erfurt) ..			9.5	12	15.5	19.5		
Do. (Von Borries)			7	8	10	12	15	18.5
Do. (Barbier) ..			6½	8	10.2	13	16.5	20.5

II. Resistances per ton of Train.

For contractors' shunting locomotives the resistance on the level road may be taken at 18 lbs. for the locomotive and 9 to 12 lbs. for the wagons.

Resistance of Locomotive and Tender on the level road. The resistances for the carrying wheels or bogies of the locomotive and of the tender wheels are taken at 5,6 lbs. per ton, and the resistances for the coupled wheels are taken at the rates given herewith.

Resistance in lbs. per ton of load on Coupled Axles.

No. of Cylinders.	No. of Coupled Axles				
	2	3	4	5	6
2	12·78	16·33	18·8	20·24	22·4
4	13·45	16·8	19·28	21·27	22·7

ATMOSPHERIC RESISTANCE, ETC.

In lbs. per sq. ft. of Frontage at Speed in Miles per Hour.

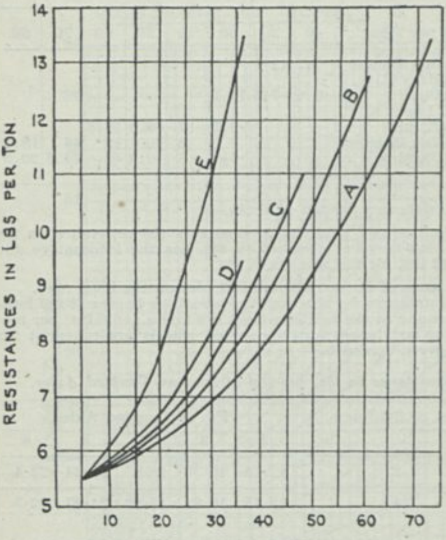
$$R = \cdot 12 \left\{ \frac{1\cdot 6\ M + 12}{10} \right\}^2$$

when R = Resistance in lbs. per sq. ft.
= Miles per hour.

M.p.h.	10	20	30	40	50	60	70
Lbs. per sq. ft.	.94	2.32	4.32	6.93	10.15	14.0	18.5

RUNNING RESISTANCES (STRAHL)

TRAIN WITHOUT LOCOMOTIVE.



MILES PER HOUR

A	FOR	CORRIDOR AND HEAVY GOODS TRAINS
B	"	PASSENGER TRAINS.
C	"	FAST GOODS TRAINS.
D	"	ORDINARY GOODS TRAINS
E	"	TRAINS OF EMPTY 2 AXLE WAGONS

GERMAN STATE REGULATIONS.

Maximum rate of Revolutions per Minute of Driving Wheels.

I. Locomotives with two outside cylinders or three cylinder (two outside and one inside) locomotives.

(*a*) One axle must be behind or below the firebox.

	Leading Bogie.	Leading carrying axle or bissel.	Without Leading Axle.
4 or 6 coupled	320	280	260
8 ,,	260	260	200
10 ,,	230	230	200
(*b*) With overhung Firebox.			
4 or 6 coupled	240	240	220
8 or 10 ,,	—	—	180

II. Locomotives with inside cylinders or four cylinders (two inside and two outside) with cranks at 180°

(*a*) With or without trailing axle, trailing bogie or trailing Bissel truck.

4 or 6 coupled	360	310	280
8 or 10 ,,	280	280	250

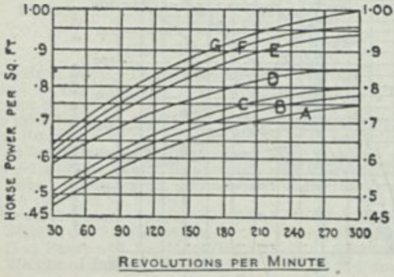
(*b*) with overhung firebox, same as above, for outside cylinder.

III. Articulated Locomotives.
With or without overhung firebox, and any position of cylinders. 200 r.p.m.

SUPERHEATER LOCOMOTIVES

HORSE POWER PER SQ. FT. OF HEATING SURFACE

WITH COAL OF 14500 B.T.h.u.



A.	Single Expansion – Boiler Pressure		180 Lbs
B.	Do.	Do.	190 –
C.	Do.	Do.	200 –
D.	3 Cyl.s Single Expansion	Do.	– –
E.	4 – Compound	Do.	– –
F.	4 – Do.	Do	220 –
G.	4 – Do.	Do	235 –

Heating Surface does not include Superheater

Ratio $\frac{\text{Internal H.S}}{\text{Superheater Surface}} = 2{\cdot}5 \text{ to } 3.$

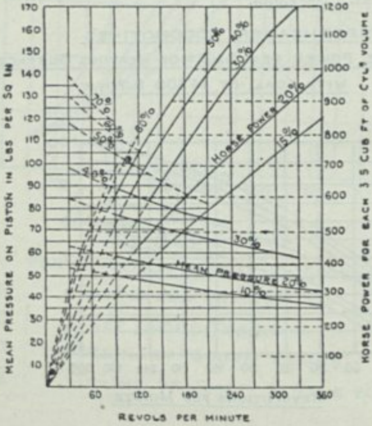
Ratio $\frac{\text{Heating Surface}}{\text{Grate Area}}$ = 50 to 55 per Express Passenger and 55 to 70 per Goods Locomotives

Locomotive with Superheater

Mean Pressure on Piston & Horse Power (Brückmann)

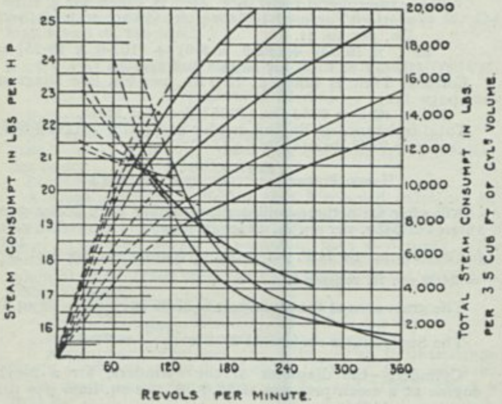
Mean pressures are plotted for 170 lbs per sq in boiler pressure
Horse power is plotted for 2 cylinders of 3.5 cub ft volume each,
e.g. about 17½" diam × 26 stroke.

Example Mean Pressure at 50% cut off and 180 revs = 87 lbs per sq in
Horse Power at 50% cut off and 180 revs = 950



Locomotive with Superheater.

Steam Consumption in lbs. per 1 h.p. hour and total consumption per 3.5 cub. ft. of cylr. vol. plotted for 170 lbs. per sq. in. boiler pressure. The total consumption is plotted for 2 cylrs. of 3.5 cub. ft. capacity each *e.g.*, 17½″ × 26″



BASIS CALCULATION FOR AN EXPRESS LOCOMOTIVE.

(Superheated Steam).

Required Duty—To take a Corridor Train of 541 tons (550 tonnes) on the level at a speed of 68·35 miles per hour (110 Km. per hour).

To take the same train up 1 in 100 at 28 miles per hour.

The limiting load per axle is 17·7 tons (18 tonnes).

A rough estimate indicates that three coupled axles are required and the available adhesion will thus be 17·7 × 3= 53·1 tons. Allowing for a four-wheel bogie the total weight may be taken at 76.7 tons.

The weight of the tender may be allowed for at 59 tons.

Weight on Coupled Axles	53·1 tons
Do., Bogie and Tender Axles.. ..	82·6 tons
Weight of Engine and Tender ..	135·7 tons

For a speed of 68·35 m.p.h. the dia. of the driving wheels may be taken at 78·75 in. (2000 m/m) giving the revs. per minute at 300.

The piston stroke may be taken at 25⅝ in. (650 m/m).

Resistances on the level at 68·35 m.p.h. :—

Engine (coupled axles only) is taken at 16·33 lbs. per ton (see Table above).

The engine bogie and tender are taken at 5·6 lbs. per ton.

The atmospheric resistance, etc., is taken for a cross-sectional area of 107·6 sq. ft. (10 sq. m.) at 18·25 lbs. per sq. ft.

53·1 × 16·33) + (82·6 × 5·6) + (107·6 × 18·25) = 3293 lbs. total for engine and tender.

Corridor Train is taken at 12·3 lbs. per ton (see Diagram on page 112).

541 × 12·3 = 6654 lbs. (3025 kilos.) for Train.

Total resistance of Engine, tender and train = 3293 + 6654 = 9947 lbs. (4510 Kg.)

$$\text{Horse Power, } \frac{9947 \times 68\cdot35}{375} = 1813$$

Allowing for a three-cylinder locomotive with boiler pressure of 200 lbs. per sq. in. diagram page 114 curve D ; gives for 300 r.p.m. ·84 H.P. per sq. ft. Heating surface and $\frac{1813}{\cdot84}$ = 2160 sq. ft. required.

The grate area at the average rate of 55 is $\frac{2160}{55}$ = 39 sq. ft.

The Superheater surface at 2.75 is $\frac{2160}{2\cdot75}$ = 78·5

Cylinders—the diameter of the cylinders, for a 2-cylr. engine at a mean pressure of 52.6 lbs. per sq. inch (see diagram page 114) is

$$D = \sqrt{\frac{9947 \times 68\cdot35}{25\cdot62 \times 52\cdot6}} = 24 \text{ in.}$$

For a three-cylinder engine the diameter is

$$D = \sqrt{\frac{24^2}{1\cdot5}} = 19\tfrac{5}{8} \text{ in.}$$

Resistances on 1/100 at 28 m.p.h.

Engine, coupled axles only, is taken at 16·33 per ton.
Engine bogie and tender are taken at 5·6 lbs. per ton.
The atmospheric resistance, etc., is taken at 4 lbs. per sq. ft.

The grade resistance is $\frac{2240}{100}$ = 22·4 lbs. per ton.

(53·1 × 16·33) + (82 × 5·6) + (107·6 × 4) + (135·1 × 22·4) = 4745 lbs.

The Train resistance is 6·73 lbs. per ton.

(541 × 6·73) × (541 × 22·4) = 15759 lbs.

Total resistance of engine tender and train 4745 + 15759 = 20504 lbs.

Horse Power $\frac{20504 \times 28}{375} = 1530.$

At the lower speed 28 m.p.h. or 120 revs. per min. the H.P. per sq. ft. of heating surface is ·74 and $\frac{1530}{\cdot 74} = 2070$ sq. ft. which approximates to the value ascertained above for the high speed on the level.

BASIS CALCULATION FOR A GOODS LOCOMOTIVE.

(Superheated Steam).

Required duty—

1180·7 tons at 28 m.p.h. on the level (45 Km. per hour).

1180·7 „ „ 15·53 „ on a long grade of 1/100 (25 Km. per hour).

Limiting load per axle 15·75 tons (16 tonnes).

A rough estimate indicates that 5 coupled axles are required, and the available adhesive weight will thus be 15·75 × 5 = 78·75 tons. A front carrying axle is provided for at 11·8 tons. The total weight of engine is thus 90·5 tons. The tender is allowed for at 49 tons. The coupled wheels are taken at 55 in. (1400 m/m) and the piston stroke at 25·6 in. (650 m/m).

Resistances on the level at 28 m.p.h. :—

Engine, coupled axles only, 20·24 lbs. per ton.

Engine carrying axle and tender 5·6 per ton.

Atmospheric resistance, etc., 4 lbs. per sq. ft. of frontage.

(78·75 × 20·24) + (60·8 × 5·6) + (107·6 × 4) = 2378 lbs.

The train resistance is taken at 6·7 and 1180·7 × 6·7 = 7920 lbs.

Total resistance of engine tender and train 2378 + 7920 = 10298.

Horse Power $\frac{10298 \times 28}{375} = 769$

At 28 m.p.h. the revs. per min. of a 53-in. wheel are 168 and the H.P. per sq. ft. of heating surface (diagram page 113) is 0·73.

For 769 H.P. the required surface is therefore $\frac{769}{\cdot 73} = 1050$

Resistances on 1/100 at 15·53 m.p.h.

Engine, coupled axles only, is taken at 20·24 lbs. per ton.

The engine carrying axle and tender taken at 5·6 lbs. per ton.

The atmospheric resistance is taken at 1·7 lbs. per sq. ft.

The grade resistance $\frac{2240}{100}$ is taken at 22·4 lbs. per ton.

(78·75 × 20·24) + (60·8 × 5·6) + (107·6 × 1·7) + (139·55 × 22·4) = 5243

Train resistance is taken at 5·8
(1180·7 × 5·8) + (1180·7 × 22·4) = 33400.
Total resistance of engine tender and train.
5243 + 33400 = 38643.

$$\text{Horse Power } \frac{38643 \times 15\cdot53}{375} = 1600$$

Cylinder diameter. On the grade of 1/100 the mean pressure is taken at 60% of the boiler pressure, *i.e.*, 200 × ·6 = 120

$$D = \sqrt{\frac{38643 \times 53}{120 \times 25\cdot6}} = 26\cdot3 \text{ in.}$$

$$\text{For 3-cylinders } \sqrt{\frac{26\cdot3}{1\cdot5}} = 21\tfrac{1}{2} \text{ in.}$$

At a boiler pressure of 200 lbs. and a speed of 15·53 m.p.h. *i.e.*, 96 res. per min. the H.P. per sq. ft.(Table 113) is 0·7, and $\frac{1600}{\cdot07}$ = 2285 sq. ft. of heating surface and the superheater surface is $\frac{2285}{2\cdot75}$ = 832.

The heating surface is thus determined by the duty on the gradient.

LOCOMOTIVES SPECIALLY DESIGNED FOR SERVICE ON HEAVY GRADES OR MOUNTAIN RAILWAYS.

The engines, with which this article deals, are those which have been specially constructed for work on grades having a greater inclination than 1 in 45.

Perhaps the earliest case in point, on record is that of the "Semmering" Railway in the Styrian Alps, with a mountain section of 26 miles, with an average rise of 1 in 47 and a maximum grade of 1 in 40, and for working the traffic of which the locomotive builders of the period were invited to put forward engines for competitive tests. This contest took place in 1851, and its importance in locomotive history is second only to that of the "Rainhill" trials of 1829. Reference here must be limited to one interesting fact, *viz.*, that in this contest there were exemplified two systems of special design, still in use, the "Engerth" and the "Seraing." The latter, in a considerably modified form, has for its modern representative the well-known "Fairlie" engine.

The following are the principal systems now in use :—

MEYER SYSTEM.

In the 1862 Exhibition (London), Meyer, of Vienna, first showed his designs for articulated locomotives of great power. Engines of this type were built at Fives Lille in 1868, by M. M. Cail in 1870, at Chemnitz in 1892. The boiler was of the ordinary "locomotive type," and the wheels were arranged in groups in independent bogies. In the two-bogie type, the front bogie was "free," carrying its load on a centre pivot, and the hind bogie carried its load on side bearings of a hemi-spherical shape. The "Kitson-Meyer" and the "Du Bosquet-Meyer" are modern examples of this system. It combines the ordinary boiler with two free bogies, each of which has two cylinders arranged at the inner ends of their frames, *i.e.*, at the centre of the engine. The Meyer engine has been built both as a "Simple" and as a "Compound." In the original Meyer engines the tanks were carried on the bogies and the connection between the bogies was made by a draw-bar and buffers. In later engines the "Fairlie" cradle frame (carrying the boiler and tanks) was adopted. In the De Bosquet-Meyer, tanks were carried on one of the bogies.

A few examples are herewith given, *viz.* :—

"KITSON-MEYER" ARTICULATED TANK LOCOMOTIVES.

The loads (in 2240 lbs. per ton) are exclusive of engine **and at a speed of 10 m.p.h.**

Gauge.		Type.	Cylinders.	Coup. Wheels.	Heating Surface.		Tanks.		Weight tons.	Load on 1 on 50
					Evap	Super.	Water gals.	Coal. tons.		
ft.	in.		ins.	ins.						
4	8½	0-6-6-0	13 × 22	42	1458	—	2500	4	80·75	367
3	0	0-6-6-0	14 × 18	34¾	870	171	1750	2½	64·2	386
3	3⅜	2-6-6-4	14 × 18	34¾	1291	—	3000	5	79·15	414
2	6	2-6-6-4	14 × 18	37½	1156	—	3750	4½	85·	386
2	6	2-6-6-2	14 × 18	37½	1792	—	3100	4	89·55	389
3	6	2-6-6-2	16 × 20	39	1748	352	3000	4	92·4	483
5	6	2-8-8-0	14¾ × 24	48	1901	—	2300	2½	101	449

FAIRLIE SYSTEM.

As already noted the main features of the Fairlie are to be found in the "Seraing" of 1851. It had the double boiler (fire-box at centre with barrels running fore and aft), and the two free bogies, each with its two cylinders arranged at the **outer** ends of its frame. The Fairlie system came into use in 1865, and has had a very considerable adoption on various gauges of railway, and for both light and heavy engines. The modern representative differs from the "Seraing" in the efficient manner in which the flexibility of the steam and exhaust connections to the cylinders is attained, and in the mechanical arrangements by which the various actions of the bogies are controlled. In one of the early applications of the Fairlie System, it is noteworthy that an ordinary type boiler was used, and that only one of the bogies was fitted with engines. In some recent applications, two ordinary boilers have been fitted instead of the double type.

"MODIFIED FAIRLIE" SYSTEM, 1923.

The "Modified Fairlie," as its name implies, retains the characteristic features of the "Fairlie," *viz.*, (1) the cradle frame carries the boiler and connects the two bogies; (2) the bogie pivots are approximately at the centre of the bogie; (3) the tanks are carried on the cradle frame. (4) Under all conditions as to the amount of water and fuel in the tanks the weight on the axles is proportionately distributed. In its modified form, the cradle frame is extended, the tanks and fuel bunker are placed fore and aft of the boiler and the wheel base has been increased, thus allowing for the boiler being much larger in diameter and with a larger grate area and making it entirely accessible. Special attention has been given to an arrangement for control of the bogies to avoid unnecessary wear of tyre flanges on the curves. The engine is reported to be working successfully on the South African Railways, taking 300 ft. reverse curves with ease and running through curves at 30 m.p.h. without oscillation.

MALLET SYSTEM.

This system, like its predecessors—the Meyer and the Fairlie—employs two groups of wheels. The rear set are arranged in the main framing, which carries the boiler, and the front set in a bogie framing, which is hinged or pivoted to the main frame. The engines are "compound," two H.P. cylinders, situated on the main frame, actuating the rear set of wheels, and two L.P. cylinders, situated on the bogie frames, actuating the front set. The articulated steam pipes, forming in this system the receiver between the H.P. and L.P. cylinders, are under L.P. steam pressure only. Mons. A. Mallet first published his scheme in 1877, his French patent was taken out in 1884, and his first engine was built in 1887. In 1900 there were about 400 engines in service on the European continent, and to-day considerably more than 2,000 engines have been constructed, amongst the latter being the heaviest and most powerful engines in the world.

GARRATT SYSTEM.

Of recent introduction, this system is similar to the Meyer in respect of the boiler, and to the Fairlie in respect of the position of the cylinders. It differs from the latter in that the tanks are arranged on the bogies, and in the placing of the bogies much further apart. It gives greater freedom for the application on simple lines of boilers of large diameter with wide and deep fireboxes. It has generally been constructed with four H.P. cylinders and has been reported to have given very satisfactory results at high speeds. The articulation is simple and there is no control gear. The boiler in its cradle-frame is suspended between the two bogies on seatings similar to that of an ordinary wagon bogie, except that the pivots are near the inner ends of the bogies. On the South African Railways, locomotives on this system and of the undernoted dimensions are at work and are reported to have taken the loads (exclusive of the weight of the engine) herewith stated.

Gauge. ft. in.	Curve. ft.	Grade.	Type.	Cylinder. ins.	Coup. Wheels in s.	Heating Surface. Sq. ft.	Weight. tons.	Load. tons.
2 0	150	1 in 33	2-6-6-2	10½ × 16	30	980	44·75	150
3 6	300	1 in 30	2-6-6-2	18 × 26	48	2554	133·75	400
3 6	726	1 in 100	2-6-6-2	18 × 26	48	2554	133·75	1800

The 300-ft. curve is not compensated for curvature.
The load is given in tons of 2,000 lbs.

FELL SYSTEM.

By this system there is required on the railway a third rail, a double-headed rail laid with its bearing faces in a vertical position and placed centrally between the ordinary rails. The engine has the usual set of adhesion wheels, supplemented by a set of horizontal wheels, which are loaded by compressed springs and bear on both faces of the central rail. Two sets of engines are fitted, one (outside cylinders) for ordinary adhesion, and the other (inside cylinders) for the spring-loaded horizontal wheels, and these engines are arranged for independent or simultaneous working.

HAGANS SYSTEM.

Haswell's "Steyerdorf," in the London Exhibition of 1862, may be said to be the precursor of this system. In it the boiler rested on two bogies coupled together by a pivot bolt. Two cylinders, located on the front bogie, served for the driving power direct to the front group of wheels, and, through a Pius Fink radial parallel motion, to the hind group also. In the Hagans system, the frame carrying the front group of wheels is rigid with the boiler, and the hind group is in a truck frame. Two cylinders, as in the "Steyerdorf," supply the power. They are located on the rigid frame, with direct drive to the front group of wheels, and, through a compound lever (situate at the articulation of the framing), to the group on the bogie frame. The boiler is of the ordinary type.

SHAY-GEARED SYSTEM.

In this system two or three groups of wheels are employed. On the main frame are carried the boiler and a set of vertical engines, usually three-cylinder. The engines drive a longitudinal shaft, with flexible coupling at each frame articulation. The shaft carries bevel pinions gearing into the face of each of the wheels. The engines are situate alongside the boiler, the latter being placed "off centre" of the engine sufficiently to balance the engine, or in some cases to suit the "loading gauge."

RACK RAILWAYS.

On these railways the old system of the earliest days of the locomotive is revived. The object is the same, *viz.*, increase of tractive power with minimum deadweight of engine. In modern applications the rack is placed centrally between the ordinary rails. There are several types in use, chiefly the "Riggenbach" or ladder type and the "Abt" or tooth rack. Two or three rack bars, as may be necessary, are used in the Abt system, and the method of laying these, one in advance of the other, differentiates the position of the teeth and ensures smooth working.

ABT COMBINED RACK AND ADHESION ENGINE.

Various types of this engine are in successful service. It has two sets of engines. The inside cylinders supply the power for working the rack pinions, and the outside cylinders act in the usual manner on the coupled wheels. Both sets can be worked simultaneously on sections requiring maximum tractive power, and the adhesion engine only can be used on the easier grades.

PURE RACK ENGINE.

This simpler type, dependent on rack working only, is used where the ruling grade is practically continuous for the entire length of the railway.

EXAMPLES OF HEAVY GRADE WORKING.

I.—ADHESION ENGINES. ORDINARY TYPE.

	Gauge.	Curves. Ft. Rad.	Grade.	E Type.	Coup. Wheels.	Cylinders.	H. S. Sq. Ft.	E Weight. Tons.	T Weight. Tons.	Load (Ex. E & T) Tons.
	ft. in.				ft. in.	in. in. in.				
New South Wales Govt. Rys. ..	4 8½	—	1 in 40	4-6-0	5 0	(2) 20 × 26	1922	56·75	31·75	275
Austrian State Rys.	4 8½	600	1 in 40	2-10-0	4 9	(4) $14\frac{9}{16}$ & 24¾ × 28⅜	2734	76	—	280
South African Rys. (Cape Section)	3 6	328	1 in 40	4-8-0	3 6¼	(2) 17 × 23	1000	45·1	29·16	206
South African Rys. (Natal Section)	3 6	300	1 in 30	4-8-0	3 9½	(2) 20½ × 24	2228	68·75	37·95	—
Darjeeling Ry. (Himalayas)	2 0	70	1 in 28	0-4-0	2 2	(2) 11 × 14	355	13·75	—	35
Anatolian Ry. (Ottoman)	4 8½	670	1 in 39	2-8-0	4 1	(4) 20½ & 30¾ × 24¾	1710	61	31½	200
La Guaira & Caracas (Venezuela)	3 0	140	1 in 27	2-6-0	3 0	(2) 15½ × 20	872	33·75	—	68
Callao Oroya Ry. (Peru)	4 8½	394	1 in 25	—	4 1	(2) 18 × 24	1066	45	20	75
Landquart-Davos (Switz.)	3 3⅜	328	1 in 22·2	0-6-2	3 3	(2) 13·4 × 19·7	667	30	—	45
Madison & Indianapolis, U.S.A.	4 8½	—	1 in 16·5	0-8-0	3 6	(2) 20¼ × 24	1378	47	—	128
Indian State Rys.	5 6	500	1 in 15·5	0-8-0	4 0	(2) 18 × 26	1244	59	—	54
Cantagallo Ry. (Brazil)	3 $7\frac{5}{16}$	131	1 in 12	2-6-0	3 3	(2) 18 × 20	—	40	—	40
Mediterranean Ry. (Italy)......	4 8½	—	1 in 67	4-8-0	4 7⅛	(4) 21¼ & 31½ × 26¾	1718	73·3	33	250

EXAMPLES OF HEAVY GRADE WORKING.

II.—ADHESION ENGINES. SPECIAL TYPES.

	Gauge.	Curves. Ft. Rad.	Grade.	E Type.	Coup. Wheels.	Cylinders.	H. S. Sq. Ft.	E Weight. Tons.	T Weight. Tons.	Load. (Ex. E & T) Tons.
	ft. in.				ft. in.	in. in. in.				
"Fairlie," Mexican Ry.	4 8½	328	1 in 25	0-6-6-0	3 6	(4) 16 × 22	1712	92¼	—	175
Do., Bolivian Ry.	2 6	230	1 in 35	0-6-6-0	2 6	(4) 12½ × 16	1046	52	—	—
"Mallet," St. Gothard Ry.	4 8½	983	1 in 37	0-6-6-0	4 0	(4) 15¾ & 22¾ × 25¼	1660	84	—	200
Do., Landquart-Davos Ry.	3 3⅜	328	1 in 22·2	0-4-4-0	3 3	(4) 13 & 19.3 × 21·7	863	40	—	70
Do., Yverdon-St. Croix Ry	3 3⅜	328	1 in 22	0-4-4-0	3 3½	(4) 11 & 16¾ × 19¾	731	34	—	60
Do., Argentine C.N. Ry...	3 3⅜	—	1 in 40	0-6-6-0	3 7⅜	(4) 13 & 20½ × 21⅜	1612	46	32	150
"Meyer,"-Du Bosquet, Northern of France	4 8½	—	1 in 83	0-6-2 + 2-6-0	4 9¼	(4) 15¾ & 24¾ × 26¾	2630	102	—	1000
"Fell," Rimutaka, New Zealand	3 6	330	1 in 15	0-4-2	{ 2 8 1 10½	(2) 14 × 16 (2) 12 × 14 }	974	36	—	63
"Garratt," Tasmanian Govt. ..	2 0	99	1 in 25	0-4-4-0	2 7½	(4) 11 & 17 × 16	628	33·5	—	—
"Shay Geared," Tidaghton, U.S.A.	4 8½	191	1 in 16·6	8	Gear 1:2	(3) 12 × 10	—	35	—	—
Do., St. Louis Exbn. 1904	4 8½	100	1 in 16·6	12	19:42	(3) 12 × 15	986	58 (Mn.)	—	122

EXAMPLES OF HEAVY GRADE WORKING.

III. COMBINED RACK AND ADHESION ENGINES.

	Gauge.	Curves.	Grade.	E Type.	Coup. Wheels.	Cylinders. Adhesion.	Cylinders. Rack.	H. S.	E Weight.	Load. Ex. E.
	ft. in.	ft.			ft. in.					
Hartz Ry., Brunswick	4 8½	656	1 in 16·6	0-6-2	4 1	17·7 × 23·62	11·82 × 23·62	1463	56	120
Mostar-Serajeyo Ry., Bosnia	2 6	410	1 in 16·6	0-6-2	2 7½	13⅜ × 17¾	11⅞ × 14¼	763	30·5	70
Benguella Ry., W. Africa	3 6	500	1 in 16	0-6-2	3 4	17·13 × 18·9 (H.P.)	17·13 × 18·9 (L.P.)	1044	45·34	160
Eisenerz-Yordernberg, Styria	4 8½	590	1 in 14·7	0-6-2	3 5	18·89 × 19·68	16·54 × 17·71	1560	59	110
Oertelsbruch Ry., Saxe-Meiningen	4 8½	492	1 in 12·5	0-4-2	2 11 7/16	11·81 × 19·68	11·81 × 15·75	517	23·2	50
Transandine Ry., Argentine	3 3⅜	330	1 in 12·5	2-6-4	2 11½	15¼ × 19¾	15¼ × 17¾	1340	57	110
Visp Zermatt Ry., Switz.	3 3⅜	262	1 in 8	0-4-2	3 0	12·6 × 17·71	14·17 × 17·71	697	29	45
Diakophto Ry., Greece	2 5½	164	1 in 6·9	0-6-2	1 11⅝	9·45 × 13·39	8·66 × 19·69	308	15·6	16

EXAMPLES OF HEAVY GRADE WORKING.

IV. RACK ENGINES.

	Gauge.		Curves.	Grade.	Cylinders.		H. S.	Weight. E	Load. Ex. E.
	ft.	in.	ft.						
Puerto-Cabello Valencia Ry.	3	6	410	1 in 12·5	11¼	×14	1167	40·3	67
Padang Ry., Sumatra	3	6	492	1 in 12·5	17	×19·7	863	26·25	60
Nova de Gaya Ry., Portugal	5	6	—	1 in 8	14⅛	×19⅜	624	29	45
Montserrat Ry., Spain	3	3⅜	213	1 in 6·6	12	×22	355	17	24
Rudesheim-Neiderwald, Germany	3	3⅜	984	1 in 5	12·2	×19·7	500	16·75	14·2
Revard Ry., France	3	3⅜	246	1 in 4·76	12	×20	—	17	10
Generoso Ry., Switz.	2	7½	197	1 in 4·5	11·81	×21·65	344	14·5	9
Pike's Peak, Colorado, U.S.A.............	4	8½	377	1 in 4	17	×20	—	23·8	18·7
Ruthhorn Ry., Switz.	2	7½	197	1 in 4	11·81	×21·65	400	17·5	8·5
Vitznau Righi, Switz.	4	8½	590	1 in 4	10⅝	×15¾	517	16	10·5
Salzburg-Gaisberg, Austria	3	3⅛	492	1 in 4	12·2	×19·7	678	23·84	12·8
Schafberg Ry., Austria	3	3⅛	262	1 in 3·9	—		—	17·3	10

BRITISH STANDARD SPECIFICATIONS.

"Locomotive Material" Abstract.

STEEL.	Tensile in Tons per sq. in.	Elongation per cent.
Crank Axles	32 min.	..22 min.
Straight Axles	35-40	..25-20
Tyres, Class C	30-55	..13-11
Do. do. D	56-62	..10-8
Do. do. E	63-69	..10-8
A Forgings, special casehardening	27 max.	..25
B do. ordinary	25-32	..27-20
C do. special without wearing surfaces	32-37	..25-20
D do. special with wearing surfaces	40-45	..20-15
E do. Boiler parts	26-32	..28-22
Steel castings with wearing surfaces	35 min.	..10 min.
Do. wheel centres and general	26	..15
Boiler plates and angles	26-30	..22
General do. do.	28-32	..20
Rivet Bars	24-28	..27

A. Flat test-piece.

For thicknesses under 3/8 inch, 2½ inch max. width, gauge length 8 inches.

For thicknesses 3/8-7/8 inch, 2 inch max. width, gauge length 8 inches.

For thicknesses over 7/8 inch, 1½ inch max. width, gauge length 8 inches.

B.	Round test-piece	Gauge length not less than 8 times the diameter.
C.	,, ,,	Area ¼ sq. in. gauge length 2 inches.
D.	,, ,,	,, ½ ,, ,, 3 ,,
E.	,, ,,	,, ¾ ,, ,, 3½ ,,
F.	,, ,,	Gauge length not less than 4 times the diameter.

Crank axles, straight axles, and forgings	Test-pieces C or
Tyres	,, C.
Steel castings	,, D.
Boiler plates, miscell. plates, copper plates	,, A.
Copper rods	,, B.

For full particulars of above tests see British Standard Specification, No. 24 (revised 1911): Materials used in the Construction of Railway Rolling Stock.

TRACTIVE POWER OF LOCOMOTIVES.

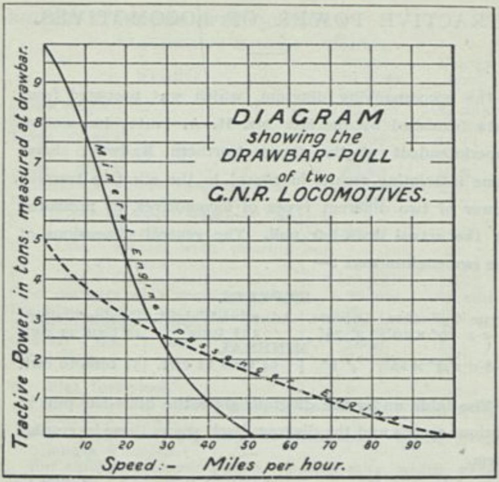
The accompanying diagram, which was prepared from data furnished by the late Mr. H. A. Ivatt, locomotive superintendent of the Great Northern Railway, shows some interesting results in regard to the effective tractive power of two different types of locomotives, as measured by the actual draw-bar pull. The general dimensions of the two engines were :—

Type.	Cylinders.	Drivers.	Adhesive Weight.	Engine Weight.
		EXPRESS.		
4-2-2	19" × 26"	7' 7½"	17½ tons	48 tons 11 cwt.
		MINERAL.		
0-8-0	19¾" × 26"	4' 8"	54 tons 12 cwt.	54 tons 12 cwt.

The table under the diagram gives the draw-bar pull at various speeds and the diagram itself shows these in graphic form.

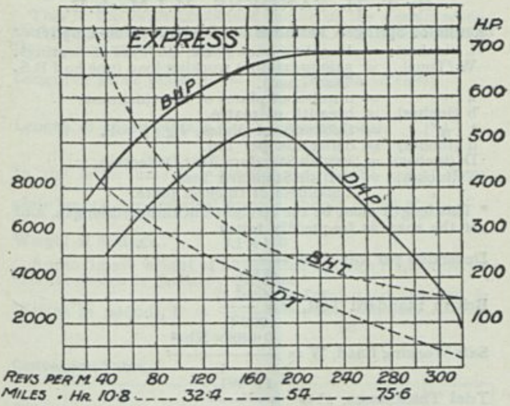
Two further diagrams, on bases of the speeds referred to **revolutions per minute** of the drivers, on the following page, show the power "characteristics." The curves marked DT are in each case identical with that given in the "Drawbar pull diagram." The curve marked DHP shows, in horse-power, the values of these **drawbar pulls** at their respective speeds, by the formula $HP=\frac{TM}{375}$

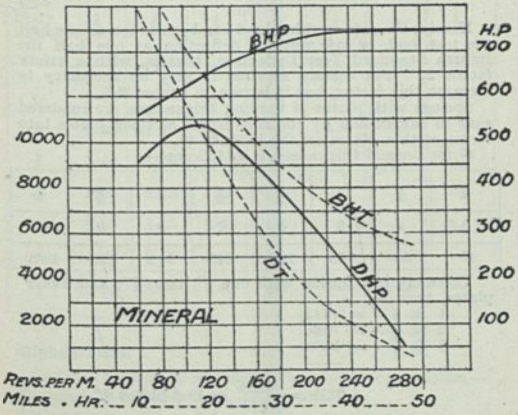
The curve BHP shows the approximate boiler horse-power, as found by the rates (+10%) given in Table XIII., for an assumed heating-surface of 1,270 sq. ft. for the "Express," and 1,439 sq. ft. for the "Mineral." The curve BHT shows, as derived from the **boiler power**, the tractive force at various speeds.



APPROXIMATE DRAWBAR PULL IN LBS. AT VARIOUS SPEEDS.

	Single Wheel. Express Locomotive.	Eight-coupled Mineral Locomotive.
10 miles per hour ..	8,400 lbs.	17,136 lbs.
20 „ „ ..	6,832 „	10,192 „
30 „ „ ..	5,712 „	4,816 „
40 „ „ ..	4,704 „	2,016 „
50 „ „ ..	3,763 „ ...	224 „
60 „ „ ..	2,844 „	—
70 „ „ ..	1,948 „	—
80 „ „ ..	1,164 „	—
90 „ „ ..	436 „	—
100 „ „ ..	—	—


EXPRESS
H.P.
700
600
500
400
300
200
100
8000
6000
4000
2000
BHP
DHP
BHT
DT
REVS PER M. 40 80 120 160 200 240 280 300
MILES . HR. 10·8 ---- 32·4 ----- 54 ---- 75·6


H.P
700
600
500
400
300
200
100
10000
8000
6000
4000
2000
BHP
BHT
DT
DHP
MINERAL
REVS. PER M. 40 80 120 160 200 240 280
MILES . HR. __ 10 ---- 20 ---- 30 ---- 40 ---- 50

LAMINATED BEARING SPRINGS

By T. H. SANDERS, M.I.Mech.E.

Laminated Springs. Formulæ for Design. (Semi-Elliptic)

*L (inches)	=	length of back plate, c.c. eyes or bearings.
W (Tons)	=	safe maximum working load (one half B.S. Test Load).
n	=	number of plates of one thickness.
b (inches)	=	breadth of plates.
t ($\frac{1}{16}''$)	=	thickness of plates, *e.g.* $\frac{1}{2}''=8$.
d (inches)	=	deflection per ton.
D (inches)	=	British Standard Test Deflection.
T (inches)	=	British Standard Test. Thickness of thickest plate.

* This length must be the straight uncambered length, and *not* the span as frequently taken.

Deflection per ton, $d = \dfrac{0 \cdot 1 \times L^3}{t^3 bn}$

British Standard Test, $D = \dfrac{L^2}{900T}$

Safe Working Load, $W = \dfrac{0 \cdot 088 \times Nbt^2}{L}$

Trial Thicknesses, $t^2 = \dfrac{11\ WL}{bn}$

Herein, the safe working load has been taken as one half the test load, or safe working deflection as one half the British Standard Test Deflection, that is, with a safety factor 2. For certain services it may be necessary to increase this factor, but it is rare to exceed 2·5.

Springs with plates of varying thicknesses are rendered easy of calculation by the conversion of thick plates into terms of thin plates on the basis of t^3.

t^3 for normal thicknesses is as follows :—

T	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
t($\frac{1}{16}''$)	4	5	6	7	8	9	10
t^3	64	125	216	343	512	729	1000

Therefore in a spring with one $\frac{1}{2}''$, two $\frac{7}{16}''$, and five $\frac{3}{8}''$ plates, thus :—

$1 @ \frac{1}{2} = 512$
$2 @ \frac{7}{16} = 686$
$5 @ \frac{3}{8} = 1080$

$$2278 = \frac{2278}{216} \text{ or } 10 \cdot 5 \text{ plates } \tfrac{3}{8}''$$

Length of Short Plate.

This is the most important factor in the design when the plate section has been settled, and can be determined thus :—h= width of loop.

Length of short plate, $S = \frac{L}{n} + h$ (speared ends)

Length of short plate, $S = \frac{L}{n}$ (square ends).

In the latter case if $\frac{L}{n}$ is less than h, the actual short plate length, for practical reasons, should be h + 2".

Weight of Springs.

Approximate weight of Laminated Springs P (pounds) of normal design is given by formula.

$$\text{Weight in pounds, } P = \frac{(L+S) \times \text{Total thickness} \times b}{6}$$

Conversion Table.

One plate below	¼	5/16	⅜	7/16	½	9/16	⅝
¼	1·00	—	—	—	—	—	—
5/16	1·95	1·00	—	—	—	—	—
⅜	3·40	1·70	1·00	—	—	—	—
7/16	5·40	2·75	1·60	1·00	—	—	—
½	8·00	4·10	2·35	1·50	1·00	—	—
9/16	11·40	5·80	3·35	2·10	1·40	1·00	—
⅝	15·65	8·00	4·60	2·90	1·95	1·40	1·00

Brinnell Tests.

Carbon Spring Steel gives the following results:—
As rolled—4·2 to 4·0 mm., 45 to 50 tons.
Spring temper 3·5 to 3·2 mm., 66 to 79 tons.

Designing Hints.

a. Springs of plates of uniform thickness are the only perfect type, both theoretically and practically. They reduce the number of sections to be stocked for repairs purposes.

b. The ends of spring plates should either be left square cut or speared (tapered in width). For springs with less than 3" offset between plate and plate the former is recommended.

c. The offsets of spring plates should be uniform throughout.

d. Two, at the most three, full-length plates are sufficient practically for all types.

e. Rib and groove steel is a good section, universal on the Continent. Studs and slits as side play checks are unnecessary on springs under 3' 0" long.

f. All qualities and treatments of steels give the same deflection per ton, as the modulus of elasticity (E) remains constant.

g. If the spring be correctly designed, ordinary water hardening carbon steel will be found quite satisfactory.

h. In designing centre fastenings, never employ an upward nib. The most efficient of the centre fastenings in general use is the downward nib. Relative efficiencies are as follows, compared with solid plate :—

Solid plate	100 %
*Side flat	95 %
Downward nib	85 %
Side notch	80 %
Cotter hole	75 %
Round hole	70 %
Upward nib	60 %

* Patents of Brown, Bayley's Steel Works, Ltd., Sheffield and Wm. Griffiths & Son, Ltd., Sheffield.

i. Every endeavour should be made to avoid the use of welded back or top plates. These are more expensive and obviously more liable to failure than non-welded backs, of the plain, jumped, or rolled-eye patterns.

j. In designing band loops, if at all possible, arrange for them to be of the same thickness on all the four sides.

k. Steel hoops, machined from the solid block, and therefore non-welded, are now nearly universal in British and Continental locomotive practice.

l In specifying the testing of completed springs, adhere to the requirements of the British Standard Specification. This is now adopted as a rule of testing by all leading spring makers and railway engineers, and has proved agreeable from both points of view.

Resiliency of Springs.

The developed plan of the theoretically perfect spring is a rhombus, one axis of which is equal to the straight length of the spring, centre to centre, and the other axis of which is equal to "bn," the number of plates of one thickness multiplied by the width of one plate.

The resiliency of a spring is the amount of work absorbed over a definite range, for each unit weight of the spring. Taking units as pounds and inches, the work absorbed over a given deflection (say the D of the British Standard Test) is D" × W (pounds, the weight required to produce this deflection) ÷ 2. A standard R. C. H. 14-plate buffing spring should deflect 10" for a load of 6½ tons (14,560 lbs.). The Standard Test is 11", or 7·1 tons. The work done on this deflection is therefore 11 × 15,900 ÷ 2 = 87,500 inch-pounds. The weight of the spring without the hoop is about 204 lbs. which gives a resiliency figure of 364.

The resiliency of all theoretically perfect springs of the shape and dimensions given in the first paragraph is a constant, and at the British Standard Test Deflection is 395, inch lbs. per pound weight. Comparison of actual design with this, gives an idea of the efficiency of the type. For instance, the standard buffing spring referred to has an efficiency of 92 per cent. This is rendered possible by its generally simple design, but it is not easy to get a better figure than 75 per cent. for locomotive springs. Much room for improvement is possible in usual designs, however, which not uncommonly give no better figure than 55 per cent. It is clear that the resiliency efficiency turns upon all material in the spring being uniformly stressed, which is not the case when plates of varying thicknesses are employed, as the thickest plate provides the testing limit.

Skin Stress.

The skin stress per square inch attained by the B. S. Test Deflection is as follows :—

Based on fibre extension	..	58 tons.
Based on weight carrying	..	68 ,,

As the elastic limit of ordinary spring steel when treated is only about 55 tons, the above figures, which are based on standard formulæ, would appear to require investigation.

Tables giving deflections per ton of one plate of given width, thickness and length are set forth in The Railway and Wagon Builder's Pocket Book.

AXLE JOURNALS.

The load, in pounds, resting on the journal, stated as pounds per square inch of projected area (diameter × length) may be taken as under, *viz.* :— m

Coupled Axles	.. ..	224 lbs. per sq. in.
Bogie ,,	.. ..	150 ,, ,, ,,
Tender ,,	.. ..	224 ,, ,, ,,

The following tables contain some examples from engines and tenders in service :—

BRITISH RAILWAYS.
JOURNALS OF AXLES FOR COUPLED WHEELS.

		Journal.	Projected Area.	Load.	
Cylinders.	Coupled Wheels.	Dia. × Length.	Sq. Ins.	Total Lbs.	Lbs. per sq. in.
17 × 22	50	7 × 9	63	13,220	210
19 × 26	68	7½ × 7	52·5	16,800	320
18 × 26	73	7½ × 8½	63·75	15,620	245
18½ × 26	63	7½ × 9	67·5	18,225	270
18 × 26	75½	8 × 7½	60	13,440	224
18 × 26	54	8 × 7¾	62	15,400	250
18 × 26	55½	8 × 8	64	16,000	250
19½ × 26	72	8 × 8½	68	13,600	200
21 × 26	56	8 × 9	72	15,840	220
20 × 26	78	8¼ × 12	99	18,414	186
19 × 26	69	8½ × 8½	72·25	18,062	250
21 × 28	56	8½ × 9	76·5	16,371	214
19½ × 26	60	8½ × 10	85	17,000	200
(3) 15½ × 26	82	9 × 10	90	18,000	200
20 × 26	68	9½ × 11	104·5	17,765	170

GENERAL PRACTICE.
JOURNALS OF AXLES FOR COUPLED WHEELS.

		Journal.	Projected Area.	Load.	
Cylinders.	Coupled Wheels	Dia. × Length.	Sq. Ins.	Total Lbs.	Lbs. per sq. in.
11 × 18	42	5 × 6½	32·5	6,727	207
12 × 16	30	5½ × 6¾	37	7,234	195
13½ × 16	30	5½ × 7	38·5	6,160	160
16½ × 22	42	6 × 7	42·0	11,200	266
16 × 20	42	6 × 7½	45·0	10,080	224
16½ × 22	57	6¼ × 8	50·0	8,950	179
18 × 22	42	7 × 8	56·0	11,760	210
16 × 24	49	7 × 9	63·0	13,860	220
17 × 22	48	7¼ × 9	65·25	12,388	190
22 × 26	51	7¼ × 10¼	74·3	14,560	196
19 × 26	55½	7½ × 9	67·5	11,760	174
20 × 26	68	7¾ × 9	69·75	13,950	200
19¾ × 25½	69¼	7⅞ × 10¼	80·7	14,560	180
22 × 26	56½	8 × 9	72	15,120	210
23¼ × 25½	56⅝	8¼ × 9⅞	81·45	15,120	185
19½ × 26	60	8½ × 10	85	16,800	197
16½/25 × 25¾	76	8 11/16 × 9½	82·6	15,120	183

TRAILING TRUCK AXLE JOURNALS.

Journal.	Projected Area.	Load.	
Dia. × Length	Sq. Ins.	Total Lbs.	Lbs. per sq. in.
6 × 10¼	61·5	8,960	145
6 × 12¼	73·5	12,880	175
7 × 12	84·0	11,200	133
7 × 13⅝	95·37	15,120	158

BOGIE AXLE JOURNALS.

Journal.	Projected Area.	Load.	
Dia. × Length.	Sq. Ins.	Total Lbs.	Lbs. per sq. in.
3¾ × 7	26·25	2,240	85
4½ × 6	27	3,920	145
4¾ × 8	38	5,046	133
5½ × 8½	46·75	7,860	168
5⅞ × 9 13/16	57·6	9,520	165
6 × 9	54	7,280	135
6 × 10	60	7,280	121
6¼ × 9	56·25	7,280	128
6½ × 10	[illegible]5	10,080	154
8 × 9	72	11,200	155

TENDER AXLE JOURNALS.

Journal.	Projected Area.	Load.	
Dia. × Length.	Sq. Ins.	Total Lbs.	Lbs. per sq. in.
3¼ × 8	25	3,360	133
4 × 8	32	7,280	227
4 × 9	36	9,520	264
4½ × 9	40·5	11,760	290
5⅛ × 9½	48·7	12,320	250
5¼ × 9	47·25	12,320	260
5½ × 10	55	12,320	224
7 × 12	84	13,440	160

PISTON RODS.

Piston rods are usually made of steel ("Class D" British Standard Specification, Report No. 24, Specification 8) having a tensile breaking strength of 40 to 45 tons per square inch; with 25 to 20 per cent. elongation, and a yield point of not less than 50 per cent. of the ultimate tensile strength.

Representative figures for the tapers of the joints to the piston and crosshead may be taken as 1 in 6 and 1 in 12 respectively, but there is a very great variation in general practice, *viz.:* at the piston 1 : 3, 1 : 4, etc., 1 : 3, 1 : 4, 1 : 5, 1 : 6 and 1 : 8, and at the crosshead 1 : 12, 1 : 16, 1 : 20 and 1 : 24.

To allow for subsequent re-machining to take up wear, which tends to make the rod oval, and also for a liberal working surface on the rod and in the cylinder glands, the diameter of the rod is greater than is otherwise necessary; the stress due to the piston load at the boiler working pressure being usually under 3 tons per sq. in. of the area. The strength at the screw and nut attachment to the piston, at the cotter hole at the crosshead attachment, and at the cotter is usually taken at a maximum of 5 tons per sq. in.

The table on the following page gives some examples from rods in service. The area of the screw, as stated, is the area due to the diameter at the bottom of the thread. The area at the cone is the minimum area at the cotter hole, and the area of the cotter is that of a cotter with half-round ends (in double shear).

CRANK PINS.

Crank pins are usually made of open hearth acid steel (British Standard Specification Report No. 24, Specification No. 8, Class C), having a tensile strength of 32 to 38 tons per sq. in., with 25 to 20 per cent. elongation and a yield point of not less than 50 per cent. of the ultimate tensile strength.

The part fitting into the wheels may be finished parallel in diameter, but in general practice it is tapered 1 in 50.

The hydraulic pressure for forcing the pin into its seat is about 8 tons per inch of diameter.

Pins suitable for rods with adjustable bushes have solid collars at their outer end; for rods with solid circular bushes the end of the crank pin is fitted with a nut, secured by a taper pin (with the head of the pin pointing to the centre of the axle).

In practice, the load per sq. in. of the projected area of the main crank pin (connecting rod bearing) varies between 1,300 lbs. in the smaller bearings, and 2,000 lbs. in the larger; the total load being taken as the piston load at full boiler pressure. Instances will be found in the accompanying table, in which the latter figure is exceeded.

The table on page 140 is compiled from particulars of engines in service, and gives, in addition to the sizes of the main bearing, the sizes also of the bearings for the *coupling rods* on the main crank pin and on those of the other wheels. It will be noted that the examples cover 4, 6 and 8 coupled engines.

Cylinder.	Load.	Piston Rod.		Screw.		Cone.		Cotter.	
Dia. inches.	Lbs.	Dia. inches	Lbs. per sq. in.	Area. sq. in.	Lbs. per sq. in.	Area at Cotter Hole. sq. in.	Lbs. per sq. in.	Section.	Lbs. per sq. in.
11	14,250	2	4,384	2·51	5,700	1·75	8,250	1¾ × 7/16	9,800
12	20,358	2⅛	5,750	2·51	8.100	1·39	14,600	1⅝ × ½	13,400
13	23,886	2¼	6,000	1·66	11,000	2·4	9,900	2 × ½	12,600
14	21,546	2¼	5,420	1·99	10,790	3·69	6,000	1 5/16 × 5/16	27,000
15	31,706	2⅜	7,100	3·53	9,000	3·2	9,910	2⅜ × ⅝	11,300
16	32,160	2⅝	5,960	3·27	9,540	3·91	8,200	2 3/16 × ⅝	12,500
17	36,320	2⅞	5,600	6·49	5,600	6·04	6,000	2¼ × ¾	11,600
18	43,248	3	6,180	5·06	8,700	3·8	11,400	2 × ⅝	18,600
18½	48,384	3¼	5,830	5·07	9,600	2·48	19,500	2 × 9/16	23,000
19	46,777	3¼	5,640	6·24	7,500	4·88	9,600	2¾ × 13/16	11,200
19½	53,748	3½	5,600	6·51	8,250	4·86	11,060	3 × 13/16	11,700
20	53,407	3¼	6,440	5·55	9,600	—	—	—	—
20½	57,750	3½	6,000	6·11	9,450	5·04	11,450	3¼ × 1	9,530
21	62,534	3¾	5,600	5·55	11,300	5·0	10,507	3 × 13/16	13,700
22	70,518	3¾	6,390	6·65	10,600	3·4	21,030	2⅝ × 1	14,600
24	83,694	3¾	7,570	7·23	11,600	6·99	11,900	2¾ × 1	16,700

NOTE.—In the examples here given, 6 threads per inch is common in the majority of the screws from 1⅞ dia. to 3½ outside dia. For the remainder practice varies from 3½ to 10.

CRANK PINS AND CROSSHEAD PINS.
Outside Cylinder Engines.

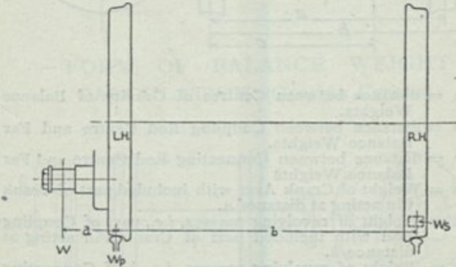
Cylinders. d. × s.	Boiler Press. Lbs. per sq. in.	Wheels. dia.	Crosshead Pin. d. × l.	Driving Con. Rod d. × l.	Driving Coup. Rod. d. × l.	Front. d. × l.	Inter. d. × l.	Hind. d. × l.
Inches.		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
11 × 14	140	26	2 × 2¼	2½ × 3	3¼ × 3½	2¾ × 2½	—	—
12 × 16	180	30	2¼ × 2⅜	3¼ × 3½	4 × 3⅜	3 × 2½	3 × 2½	—
14½ × 18	170	34	2½ × 2 7/16	3½ × 4¼	4¾ × 4½	3¼ × 2¾	3¼ × 3¼	3¼ × 3¼
15½ × 22	180	57	3 × 2¾	4½ × 4	5 × 4	3¾ × 2¾	—	3¾ × 2¾
16 × 18	150	42	2½ × 2½	3¾ × 4⅛	4¾ × 4⅛	3¼ × 3¼	—	3¼ × 2¾
16½ × 22	160	57	3 × 2¾	4½ × 4	5 × 4	3¾ × 2¾	—	3¾ × 2¾
17 × 24	160	54	2¾ × 3	4½ × 5	4¾ × 4½	3 × 4	—	3 × 4
18 × 23	160	42¾	3¼ × 3½	4¼ × 5	4¾ × 4	4 × 3¼	4 × 3½	4 × 3½
19 × 26	160	55½	3½ × 3½	5 × 5	6½ × 4½	3½ × 3½	4 × 3¾	3½ × 3½
19½ × 26	170	69	3½ × 3¼	6½ × 5½	7½ × 3¼	6 × 3¼	—	6 × 3¼
19 11/16 × 25 13/16	180	69¼	3 11/16 × 3½	5 11/16 × 6¼	6¼ × 4⅞	3 13/16 × 3 13/16	—	3 13/16 × 3 13/16
20 × 26	180	51	3½ × 3¾	6 × 6	6¾ × 6	5 × 3½	5 × 4¾	5 × 3½
20 × 26	170	68	3½ × 3¼	5 × 5½	6 × 4¼	4¾ × 4	—	3½ × 4¼
20 × 24	175	48	3¾ × 3½	6 × 6¼	6½ × 4¾	4½ × 3½	5 × 4	4½ × 3½
21 × 26	180	56	3½ × 3	6 × 5	6¾ × 3¼	5¼ × 3½	5¼ × 3½	5¼ × 3½
21 × 26	180	56	3½ × 3¼	5½ × 5½	6½ × 4¼	4 × 5	4 × 5	4¾ × 3½
21 × 28	180	81	3½ × 3½	6 × 5½	6¾ × 3¼	5½ × 3¼	—	—
21½ × 26	160	73½	3½ × 3¾	5½ × 5	6½ × 5⅜	5½ × 3¾	—	5½ × 3¾
22 × 26	160	56½	3½ × 3¾	6 × 5½	6¾ × 5½	5½ × 3½	5½ × 4⅜	5½ × 3
22 × 26	150	51	4½ × 3¼	5½ × 6	6½ × 5¾	4½ × 4	4½ × 5⅛	4½ × 4
22 × 26	180	60	4 × 4¼	6 × 6	7 × 4¾	5 × 4	—	5 × 4
22 × 24¾	170	52⅜	3 11/16 × 3¼	5½ × 5½	6 11/16 × 4	3 13/16 × 3 5/16	3 11/16 × 3 5/16	3 13/16 × 5¼
23⅝ × 25 13/16	180	69¼	4⅛ × 4⅛	5 11/16 × 5⅞	6 11/16 × 5 5/16	4 13/16 × 2¾	—	4 13/16 × 2¾

WHEEL BALANCE-WEIGHT CALCULATIONS.

Forms are given herewith for general reference in calculations of Balance-weights on the wheels of locomotive engines.

Revolving Parts. The weight of all revolving parts should be balanced in the wheels, respectively, on which these parts are hung.

Reciprocating Parts. The weight of the reciprocating parts is divided for balancing purposes over all the coupled wheels, but not necessarily in equal quantities. The proportion of total weight of these parts is usually arbitrarily selected at from 40 to 66%. On heavy narrow gauge engines 80% has been found experimentally to give the best result.

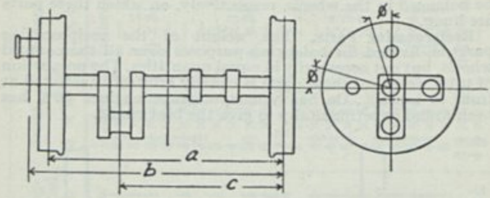


Primary and Secondary Balance-Weights. The use of these terms is relative to the adjustment of the amount and position of the balance-weight so as to include transverse balancing. For example, Fig. 1 herewith shows the driving wheels for an outside cylinder engine. The weight " W " in lbs. representing that of, say, the connecting rod on the left-hand crank-pin has an overhang from the centre of the rail of " a " inches and requires for cross balance a secondary weight Ws to be placed in the right hand wheel. If the distance of the centre of the weight Ws from the centre of the L.H. rail is " b " inches, then $W \times \frac{a}{b} = Ws$ and the primary weight Wp on the L.H. wheel will be $W + Ws$.

The secondary weight Ws, as here determined, has a position on the R.H. wheel directly opposite to the L.H. crank and, therefore, at a right angle to the crank on that wheel, but it will be evident that a similar secondary weight will be required on the L.H. wheel (at a right-angle to the L.H. crank) to balance the R.H. connecting rod.

(In the " forms " it will be noted that the moments of the weights are taken round the centre of the balance-weight and not of the rail as in the above example.)

FORM OF BALANCE WEIGHT CALCULATION.



Let a = distance between Centres of Gravity of Balance Weights.

b = distance between Coupling Rod Centre and Far Balance Weights.

c = distance between Connecting Rod Centre and Far Balance Weights

W_1 = Weight of Crank Arm with included part of Crank Pin acting at distance *a*.

W_2 = Weight of revolving masses, *i.e.*, part of Coupling Rod with included part of Crank Pin acting at distance *b*.

W_3 = Weight of revolving masses, *i.e.*, half Connecting Rod with included part of Crank Pin and Crank Arms at distance *c*.

W_4 = Weight of reciprocating masses to be balanced in each wheel and acting at distance *c*, in all cases.

W_P = Primary balance weights.

W_S = Secondary " "

C = Combined " "

DRIVING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

$W_{P3} = W_3 \frac{c}{a}$

$W_{S3} = W_{P3} - W_3$

$W_{P4} = W_4 \frac{c}{a}$

$W_{S4} = W_{P4} - W_4$

$W_P = W_{P3} + W_{P4} - W_{P1} - W_{P2}$

$W_S = W_{S2} + W_{S3} + W_{S4}$

$C = \sqrt{(W_P)^2 + (W_S)^2}$

$\frac{W_S}{W_P}$ = tan. of angle of convergence ϕ

LEADING OR TRAILING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

$W_{P4} =$ } as found for
$W_{S4} =$ } driving wheels.

$W_P = W_{P1} + W_{P2} + W_{P4}$

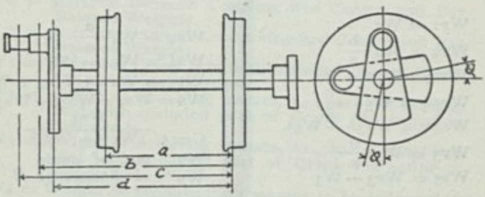
$W_S = W_{S2} + W_{S4}$

$C = \sqrt{(W_P)^2 + (W_S)^2}$

$\frac{W_S}{W_P} =$ tan. of angle of divergence ϕ

NOTE.—All weights are taken at Crank Pin radius, *i.e.*, inch pounds, and are to be reduced in ratio according to balancing moment of crescent found.

FORM OF BALANCE WEIGHT CALCULATION (Outside Cranks).



Let a = distance between Centres of Gravity of Balance Weight.

b = distance between Coupling Rod Centre and Far Balance Weight.

c = distance between Connecting Rod Centre and Far Balance Weight.

d = distance between Crank Arm Centre and Far Balance Weight.

W_1 = Weight of Crank Arm acting at distance *d* and balanced by tail on Crank.

W_2 = Weight of revolving masses, *i.e.*, part of Coupling Rod with included part of Crank Pin acting at distance *b*.

Let W_{3A} = Weight of revolving masses, *i.e.*, part of Connecting Rod with included part of Crank Pin acting at distance *c* and balanced by tail on Crank.

NOTE.—No part of Coupling Rod or Pin should be balanced by tail on crank, but as much as possible of half the Connecting Rod and Pin.

Let W_3 = Weight of revolving masses, *i.e.*, half Connecting Rod (less W_{3A}) with included part of Crank Pin acting at distance *c*.

W_4 = Weight of reciprocating masses to be balanced in each wheel and acting at distance *c* in all cases.

W_P = Primary balance weights

W_S = Secondary ,, ,,

C = Combined ,, ,,

DRIVING WHEELS (with tail on Crank)

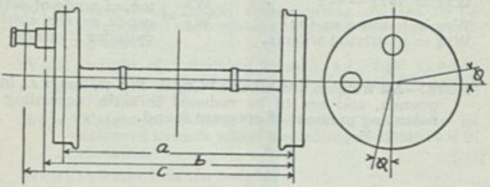
$$W_{P1} = W_1$$
$$W_{P2} = W_2 \frac{b}{a}$$
$$W_{S2} = W_{P2} - W_2$$
$$W_{P3A} = W_{3A} \frac{c}{d}$$
$$W_{S3A} = W_{P3A} - W_{3A}$$
$$W_{P3} = W_3 \frac{c}{a}$$
$$W_{S3} = W_{P3} - W_3$$
$$W_{P4} = W_4 \frac{c}{a}$$
$$W_{S4} = W_{P4} - W_4$$
$$W_P = W_{P2} + W_{P3} + W_{P4}$$
$$W_S = W_{S2} + W_{S3A} + W_{S3} + W_{S4}$$
$$C = \sqrt{(W_P)^2 + (W_S)^2}$$
$$\frac{W_S}{W_P} = \text{tan. of angle of divergence } \phi$$

LEADING OR TRAILING WHEELS.

(No tail on Crank.)

$$W_{P1} = W_1 \frac{d}{a}$$
$$W_{S1} = W_{P1} - W_1$$
$$W_{P2} = W_2 \frac{b}{a}$$
$$W_{S2} = W_{P2} - W_2$$
$$W_{P4} = W_4 \frac{b}{a}$$
$$W_{S4} = W_{P4} - W_4$$
$$W_P = W_{P1} + W_{P2} + W_{P4}$$
$$W_S = W_{S1} + W_{S2} + W_{S4}$$
$$C = \sqrt{(W_P)^2 + (W_S)^2}$$
$$\frac{W_S}{W_P} = \text{tan of angle of divergence } \phi$$

FORM OF BALANCE WEIGHT CALCULATION.



Let a = distance between Centres of Gravity of Balance Weights.
b = distance between Coupling Rod Centre and Far Balance Weights.
c = distance between Connecting Rod Centre and Far Balance Weights.
W_1 = Weight of Crank arm with included part of Crank Pin acting at distance *a*.
W_2 = Weight of revolving masses, *i.e.*, part of Coupling Rod with included part of Crank Pin acting at distance *b*.
W_3 = Weight of revolving masses, *i.e.*, half Connecting Rod with included part of Crank Pin acting at distance *c*.
W_4 = Weight of reciprocating masses to be balanced in each wheel and acting at distance *c* in all cases.
W_P = Primary balance weights.
W_S = Secondary " "
C = Combined " "

DRIVING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

$W_{P3} = W_3 \frac{c}{a}$

$W_{S3} = W_{P3} - W_3$

$W_{P4} = W_4 \frac{c}{a}$

$W_{S4} = W_{P4} - W_4$

$W_P = W_{P1} + W_{P2} + W_{P3} + W_{P4}$

$W_S = W_{S2} + W_{S3} + W_{S4}$

$C = \sqrt{(W_P)^2 + (W_S)^2}$

$\frac{W_S}{W_P}$ = tan. of angle of divergence θ

LEADING OR TRAILING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

$W_{P4} =$ } same as for
$W_{S4} =$ } driving wheels.

$W_P = W_{P1} + W_{P2} - W_P$

$W_S = W_{S2} + W_{S4}$

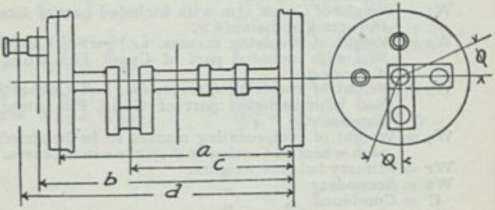
$C = \sqrt{(W_P)^2 + (W_S)^2}$

$\frac{W_S}{W_P} =$ tan. of angle of divergence as for outside cylinder Engines.

NOTE.—All weights are taken at Crank Pin radius, *i.e.*, inch pounds, and are to be reduced in ratio according to balancing moment of crescent found.

FORM OF BALANCE WEIGHT CALCULATION.

FOUR-CYLINDER ENGINES (on one axle)



Let a = distance between Centres of Gravity of Balance Weights.

b = distance between Coupling Rod Centres and Far Balance Weights.

c = distance between Inside Con. Rod Centres and Far Balance Weights.

d = distance between Outside Con. Rod Centres and Far Balance Weights.

W_1 = Weight of Crank Arm with included part of Crank Pin acting at distance *a*.

W_2 = Weight of revolving masses, *i.e.*, part of Coupling rod with included part of Crank pin acting at distance *b*.

W_3 = Weight of revolving masses, *i.e.*, half Inside Con. Rod with included part of Crank Pin and Crank Arms at distance *c*.

W_4 = Weight of Inside reciprocating masses to be balanced in each wheel and acting at distance *c* in all cases.

W_5 = Weight of revolving masses, *i.e.*, half Outside Con. Rod with included part of Crank Pin acting at distance *d*.

W_6 = Weight of Outside reciprocating masses to be balanced in each wheel and acting at distance *d* in all cases.

W_P = Primary balance weights.

W_S = Secondary " "

C = Combined " "

DRIVING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

$W_{P3} = W_3 \frac{c}{a}$

$W_{S3} = W_{P3} - W_3$

$W_{P4} = W_4 \frac{c}{a}$

$W_{S4} = W_{P4} - W_4$

$W_{P5} = W_5 \frac{d}{a}$

$W_{S5} = W_{P5} - W_5$

$W_{P6} = W_6 \frac{d}{a}$

$W_{S6} = W_{P6} - W_6$

$W_P = W_{P1} + W_{P2} + W_{P5} + W_{P6} - W_{P3} - W_{P4}$

$W_S = W_{S2} + W_{S3} + W_{S4} + W_{S5} + W_{S6}$

$C = \sqrt{(W_P)^2 + W_S)^2}$

$\frac{W_S}{W_P}$ = tan. of angle of divergence Φ

LEADING OR TRAILING WHEELS.

$W_{P1} = W_1$

$W_{P2} = W_2 \frac{b}{a}$

$W_{S2} = W_{P2} - W_2$

W_{P4}, W_{S4}, W_{P6}, W_{S6} } same as for driving wheels.

$W_P = W_{P1} + W_{P2} + W_{P6} - W_{P4}$

$W_S = W_{S2} + W_{S4} + W_{S6}$

$C = \sqrt{(W_P)^2 + (W_S)^2}$

$\frac{W_S}{W_P}$ = tan. of angle of divergence as for outside cylinder Engines.

FORM OF BALANCE WEIGHT CALCULATION.

FOUR-CYLINDER ENGINES
(on separate axles.)

The calculations are made as for independent Inside and Outside cylinder Engines except that the Primary and Secondary weights are summed up as follows:—

INSIDE DRIVING WHEELS.

$$W_P = W_{P1} + W_{P2} - W_{P3}$$

$$W_S = W_{S2} + W_{S3} + W_{S4}$$

$$C = \sqrt{(W_P)^2 + (W_S)^2}$$

$$\frac{W_S}{W_P} = \text{tan. of angle of divergence } \phi$$

OUTSIDE DRIVING WHEELS.

$$W_P = W_{P1} + W_{P2} + W_{P3} + W_{P4} - W_{P4}^1$$

$$W_S = W_{S2} + W_{S3} + W_{S4}$$

$$C = \sqrt{(W_P)^2 + (W_S)^2}$$

$$\frac{W_S}{W_P} = \text{tan. of angle of divergence } \phi$$

NOTE.—W_{P4}^1 is the primary for inside reciprocating masses and, as shown, is used as a negative quantity in outside calculation. This introduces a slight additional stress on Coupling Rod, which can only be avoided by treating the Inside and Outside masses as entirely independent and consequently using the maximum amount of balance weight.

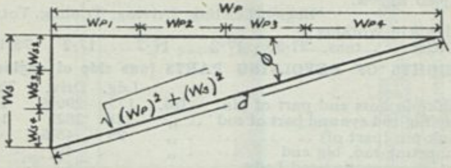
GRAPHIC SOLUTION OF BALANCE WEIGHT CALCULATION.

The calculations solved arithmetically in the forms given on other pages may be checked by a graphic construction as follows:—

1.—Let *a*, *b* and *c* represent the distances already given. Then, if the length *a* is taken to represent to any scale of pounds the weights W_1, W_2, W_3 and W_4 alternately, the corresponding primary weights, W_{P1}, W_{P2}, W_{P3} and W_{P4} will be represented to the same scale of pounds by the lengths of *a*, *b* and *c* respectively. The secondary weights are represented by the amounts these lengths are longer or shorter than *a*.

(NOTE.—When a primary weight equals *a*, no secondary is required.)

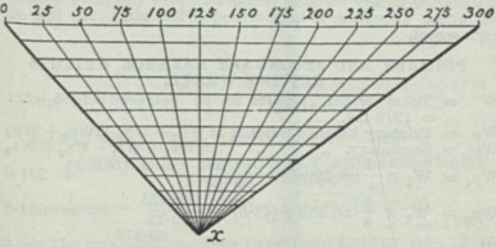
2.—With the various primary and secondary weights lay off a triangle as shown below.



Then the length *d* represents the Combined balance weight required, and as indicated is the graphic solution of the formula noted, while the angle θ is obtained direct without the necessity of consulting a table of tangents, etc.

Note.—For inside cylinder engines the various subtractions of negative weights or lengths must be made before the line *d* is drawn to close the triangle.

3.—The scale of pounds may be drawn on a piece of tracing cloth in the form here given.



The point *x* may be anywhere in relation to the scale divisions. The horizontal lines must be parallel. The divisions of the scale may be subdivided according to range of scale adopted.

Example showing application of Wheel-balancing Form for

OUTSIDE CYLINDER LOCOMOTIVE.

4-6-0 Type locomotive with $21\frac{1}{2}'' \times 26''$ cylinders and 74″ coupled wheels.

	Bogie.	Leading.	Driving.	Trailing.	Total.
Weights in Working Order .. tons.	21·55	17·2	17·2	17·2	73·15

WEIGHTS OF REVOLVING PARTS (one side of engine).

	Ldg.	Driv.	Trg.
Crank-pin boss and part of pin ..lbs.	177	290·5	177
Coupling-rod eye and part of rod .. ,,	118	282	118
Crank-pin (part of) .. .. ,,	35	45·5	35
Connecting-rod, big end .. .. ,,		40	
Part of connecting-rod body .. ,,		347	
Ecc. crank and part of ecc. crank-pin ,,		53	
	330	1058	330

All revolving weights are to be balanced where they occur on each wheel.

WEIGHT OF RECIPROCATING PARTS.

Connecting-rod (small end and part of Gudgeon pin)	lbs.	181
Crosshead complete with arm, connecting link and part of combination-lever	,,	310
Piston with rings and piston-rod, complete	,,	502
Total	,,	993

Two-thirds (2/3) of the weight or 662 lbs. of the reciprocating parts are to be balanced. The balance weights may be distributed in any suitable proportion over the three wheels. An equal allocation is here arranged for, *viz.*: 221 lbs. on each wheel.

PRIMARY AND SECONDARY BALANCE WEIGHTS DRIVING WHEEL.

W = Total weight of parts to be balanced = 1058 + 221 = 1279 lbs.

W_p = Primary balance weights $= W_{p_1} + W_{p_2} + W_{p_3} + W_{p_4}$

W_s = Secondary ,, ,, $= W_{s_1} + W_{s_2} + W_{s_3} + W_{s_4}$

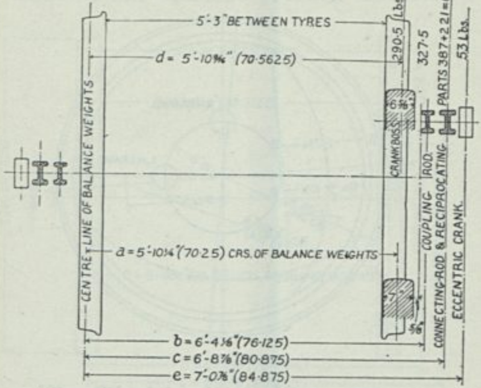
$$W_{p_1} = W_1 \times \frac{d}{a} = 290{\cdot}5 \times \frac{70{\cdot}5625}{70{\cdot}25} = 291{\cdot}6$$

$$W_{p_2} = W_2 \times \frac{b}{a} = 282 + (45{\cdot}5) \times \frac{76{\cdot}125}{70{\cdot}25} = 354{\cdot}8$$

$$W_{p_3} = W_3 \times \frac{c}{a} = (40 + 347 + 221) \times \frac{80{\cdot}875}{70{\cdot}25} = 699{\cdot}9$$

$$W_{p_4} = W_4 \times \frac{e}{a} = 53 \times \frac{84{\cdot}875}{70{\cdot}25} = 64{\cdot}3$$

$$W_p = 1410{\cdot}6$$



$$
\begin{aligned}
Ws_1 &= Wp_1 - W_1 = 291{\cdot}6 - 290{\cdot}5 &&= 1{\cdot}1\\
Ws_2 &= Wp_2 - W_2 = 354{\cdot}8 - (282 + 45{\cdot}5) &&= 27{\cdot}3\\
Ws_3 &= Wp_3 - W_3 = 699{\cdot}9 - (40 + 347 + 221) &&= 91{\cdot}9\\
Ws_4 &= Wp_4 - W_4 = 64{\cdot}3 - 53 &&= 11{\cdot}3\\
& && Ws = 131{\cdot}6
\end{aligned}
$$

or

$$Wp = \frac{(290 \times 70{\cdot}5625) + (327{\cdot}5 \times 76{\cdot}125 + (608 \times 80{\cdot}875)}{70{\cdot}25} = 1410.$$

$$Ws = Wp - W = 1410{\cdot}6 - 1279 = 131{\cdot}6$$

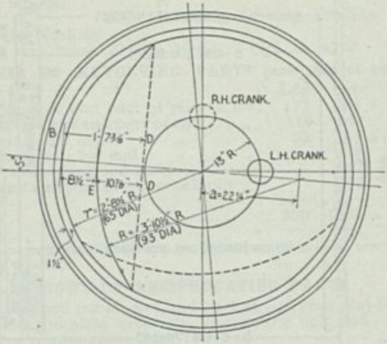
COMBINATION OF PRIMARY AND SECONDARY BALANCE WEIGHTS.

$$\text{Resultant} = \sqrt{Wp^2 + Ws^2} = \sqrt{1410{\cdot}6^2 + 131{\cdot}6^2} = 1416{\cdot}7 \text{ lbs.}$$

The crank-pin on which this weight revolves is at 13 inches radius from the centre of the wheel and thus the Moment of Balance Weight required is $1416{\cdot}7 \times 13 = 18{,}417$ inch lbs. The angle of the Balance weight=

$$\frac{1410{\cdot}6}{131{\cdot}6} = 1 \text{ in } 10{\cdot}7 \text{ or } 5^\circ \text{ approx.}$$

CRESCENT BALANCE-WEIGHT ON DRIVING WHEEL.



Versed sine DE = $10\frac{7}{8}$. Versed sine DB = $19\frac{3}{8}$.
Radius R = $46\frac{1}{2}''$; dia. = 93″. Radius r = $32\frac{1}{2}''$; dia. 65″.
Distance a = 22·25.

For $x = \frac{10\frac{7}{8}}{93} = 0{\cdot}117$ the value of y is 0·051446 (see table).

Area of small segment = $93^2 \times 0{\cdot}051446 = 445$ sq. ins.
Balancing moment = 445 × a = 445 × 22·25 = 9901.
Balancing moment in inch lbs. (at 0·283 lbs. per cubic inch) and a thickness of seven inches (7″) = 9901 × 7 × ·283 = 19600.

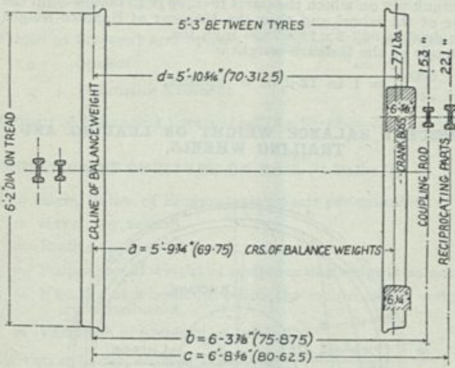
For $x = \frac{19\frac{3}{8}}{65}$ the value of y is 0·196337 (see table).

Area of large segment = $65^2 \times 0{\cdot}196337 = 829{\cdot}5$ sq. ins.
Area of Crescent = 829·5 — 445 = 384·5 sq ins.
Distance of centre of gravity of Crescent from centre of wheel

$$= \frac{9901}{384{\cdot}5} = 25{\cdot}72 \text{ ins.}$$

Weight of Crescent and Spokes = $\frac{19600}{25{\cdot}72}$ = 762 lbs.
,, Spokes 44·4 lbs.
,, Balancing Crescent = 762—44·4 = 717·6 lbs.
Moment of Balancing Crescent = 717·6 × 25·72 = 18455 inch lbs.

PRIMARY AND SECONDARY BALANCE WEIGHTS LEADING AND TRAILING COUPLED WHEELS.



W = Total weight of parts to be balanced 330+221= 551 lbs.

Wp = Primary Balance-weight $= Wp_1 + Wp_2 + Wp_3$.

Ws = Secondary Balance-weight $= Ws_1 + Ws_2 + Ws_3$.

$$Wp_1 = W_1 \times \frac{d}{a} = 177 \times \frac{70{\cdot}3125}{69{\cdot}75} = 178{\cdot}4$$

$$Wp_2 = W_2 \times \frac{b}{a} = (118+35) \times \frac{75{\cdot}875}{69{\cdot}75} = 166{\cdot}4$$

$$Wp_3 = W_3 \times \frac{c}{a} = 221 \times \frac{80{\cdot}625}{69{\cdot}75} = 255{\cdot}5$$

$$Wp = 600{\cdot}3$$

$$Ws_1 = Wp_1 - W_1 = 178{\cdot}4 - 177 = 1{\cdot}4$$

$$Ws_2 = Wp_2 - W_2 = 166{\cdot}4 - (188+35) = 13{\cdot}4$$

$$Ws_3 = Wp_3 - W_3 = 255{\cdot}5 - 221 = 34{\cdot}5$$

$$Ws = 49{\cdot}3$$

$$\text{or } Wp = \frac{(177 \times 70{\cdot}3125) + (153 \times 75{\cdot}875) + (221 \times 80{\cdot}625)}{69{\cdot}75} = 600{\cdot}3 \text{ lbs.}$$

or $Ws = Wp - W = 600{\cdot}3 - 551 = 49{\cdot}3$ lbs.

COMBINATION OF PRIMARY AND SECONDARY WEIGHTS.

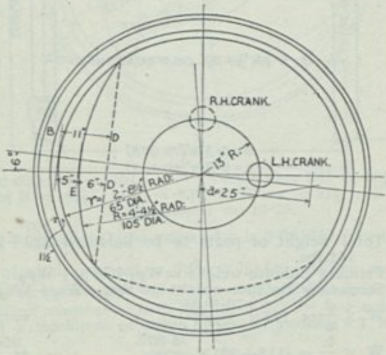
Resultant $= \sqrt{Wp^2 + Ws^2} = \sqrt{600{\cdot}3^2 + 49{\cdot}3^2} = 602{\cdot}3$ lbs.

The crank pin on which the parts revolve is 13 inches from the centre of the wheel and thus the Moment of Balance-weight required is $602{\cdot}3 \times 13 = 7830$ inch lbs.

The angle of the Balance-weight=

$$\frac{600{\cdot}3}{49{\cdot}3} = 1 \text{ in } 12{\cdot}2 \text{ or } 6^\circ \text{ approx.}$$

CRESCENT BALANCE WEIGHT ON LEADING AND TRAILING WHEELS.



Versed sine DE = 6″. Versed sine DB = 11″
Radius R = 52½ ; Dia.=105. Radius r = 32½ ; Dia. = 65.
Distance a = 25″.

For $x = \frac{6}{105} = {\cdot}057$ the value of y is 0·017831 (see table).

Area of small segment $= 105^2 \times 0{\cdot}017831 = 196{\cdot}586$ sq. ins.
Balancing moment $= 196{\cdot}586 \times a = 196{\cdot}586 \times 25 = 4914{\cdot}65$.
" " in inch lbs. (at 0·283 lbs. per cu. in.) and a thickness of 6¼ inches $= 4914{\cdot}65 \times 6{\cdot}25 \times 0{\cdot}283 = 8692{\cdot}78$

For $x = \frac{11}{65} = 0{\cdot}169$ the value of y is 0·087785 (see table).

Area of large segment $= 65^2 \times 0{\cdot}087785 = 370{\cdot}891$ sq. ins.
Area of Crescent $= 370{\cdot}891 - 196{\cdot}586 = 174{\cdot}305$ sq. ins.
Distance of centre of gravity of Crescent from centre of wheel

$$= \frac{4914{\cdot}65}{174{\cdot}305} = 28{\cdot}194.$$

Weight of Crescent and Spokes	$= \frac{8692{\cdot}78}{28{\cdot}194}$	$=$	308 lbs.
„ Spokes		$=$	29 „
„ Balancing Crescent			279 „

Moment of Balancing Crescent $= 279 \times 28{\cdot}194 = 7866$ inch lbs.

VARIATION OF PRESSURE ON RAIL (" Dalby ").

M = Mass, in lbs. of Reciprocating parts per cylinder.
n = Revs. per second.
r = Radius in feet of crank.
Q = Proportion of weight of reciprocating weights balanced.
C = Number of wheels on which the reciprocating weights are distributed.
V = Variation of pressure on rail in lbs.

For two cylinder, outside type $V = \frac{1{\cdot}38\ Mn^2r \times Q}{C}$

For two cylinder, inside type $V = \frac{0{\cdot}93\ Mn^2r \times Q}{C}$

EXAMPLE.

For the two cylinder outside type dealt with above

$Q = 2/3$ and $C = 3$.

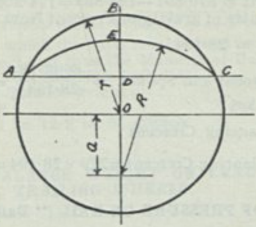
$$V = \frac{1{\cdot}38\ Mn^2r \times 2/3}{3} = {\cdot}31\ Mn^2r.$$

For $M = 993$.
and $n = 4$ (corresponding to 52·8 m.p.h. for 74" wheel).
and $r = 13/12 = 1{\cdot}08$.

$V = {\cdot}31\ Mn^2r = {\cdot}31 \times 993 \times 4^2 \times 1{\cdot}08 = 5320$ lbs. $=$ 2·19 tons.

The load per axle is 17·2 tons or 8·6 tons per wheel.
At 52·8·m.p.h. the maximum load per wheel $= 8{\cdot}6 + 2{\cdot}37 =$ 10·97 tons.
At 52·8 m.p.h. the maximum load per axle $= 21{\cdot}94$ tons.
At 52·8 m.p.h. the minimum load per wheel $= 8{\cdot}6 - 2{\cdot}37 =$ 6·23 tons.
At 52·8 m.p.h. the minimum load per axle $= 12{\cdot}46$ tons.
For 60 and 65 m.p.h. the variation will amount respectively to 6870 lbs. (3·06 tons) and 8075 lbs. (3·6 tons) per wheel.

AREA AND BALANCING MOMENT OF CRESCENTS



Area of Crescent A B C E A = Area of Segment A B C D A — Area of Segment A E C D A

Balancing Moment of Crescent = Its area × distance of its Centre of Gravity from O.
= Area of Segment A E C D A × distance *a*.

NOTE.—This geometrical equivalent is exact and is to be used in preference to any trial and error method of suspension of templets.

$$\frac{\text{Balancing Moment of Crescent}}{\text{Area of Crescent}} = \text{distance of its Centre of Gravity from O.}$$

CENTRE OF GRAVITY OF A SEGMENT.

$$\text{Distance of Centre of Gravity from Centre} = \frac{\text{Chord}^3}{12\ \text{Area}}$$

CENTRIFUGAL FORCE.

W = weight in lbs.
R = radius in inches.
D = diameter of wheel in inches.
M = speed in m. p. h.
C = centrifugal force in lbs.

$$C = 3{\cdot}2\ W R \left(\frac{M}{D}\right)$$

PISTON SPEED AND REVOLUTIONS PER MINUT

S = stroke in inches.
P = piston speed in feet per minute.
R = revolutions per minute.

$$P = 56\ S\ \frac{M}{D} \qquad R = 6\ \frac{P}{S}$$

$$R = 336\ \frac{M}{D}$$

AREA OF SEGMENTS OF A CIRCLE.

$\frac{\text{Versed Sine}}{\text{Diameter}} = x.$ Diameter² × y = Area.

x	y	x	y	x	y	x	y
·001	·000042	·039	·010148	·077	·027821	·115	·050165
·002	·000119	·040	·010537	·078	·028356	·116	·050804
·003	·000219	·041	·010931	·079	·028894	·117	·051446
·004	·000337	·042	·011330	·080	·029435	·118	·052090
·005	·000470	·043	·011734	·081	·029979	·119	·052736
·006	·000618	·044	·012142	·082	·030526	·120	·053385
·007	·000779	·045	·012554	·083	·031076	·121	·054036
·008	·000951	·046	·012971	·084	·031629	·122	·054689
·009	·001135	·047	·013392	·085	·032180	·123	·055345
·010	·001329	·048	·013818	·086	·032745	·124	·056003
·011	·001533	·049	·014247	·087	·033307	·125	·056663
·012	·001746	·050	·014681	·088	·033872	·126	·057326
·013	·001968	·051	·015119	·089	·034441	·127	·057991
·014	·002199	·052	·015561	·090	·035011	·128	·058658
·015	·002438	·053	·016007	·091	·035585	·129	·059327
·016	·002685	·054	·016457	·092	·036162	·130	·059999
·017	·002940	·055	·016911	·093	·036741	·131	·060672
·018	·003202	·056	·017369	·094	·037323	·132	·061348
·019	·003471	·057	·017831	·095	·037909	·133	·062026
·020	·003748	·058	·018296	·096	·038496	·134	·062707
·021	·004031	·059	·018766	·097	·039087	·135	·063389
·022	·004322	·060	·019239	·098	·039680	·136	·064074
·023	·004618	·061	·019716	·099	·040276	·137	·064760
·024	·004921	·062	·020196	·100	·040875	·138	·065449
·025	·005230	·063	·020681	·101	·041476	·139	·066140
·026	·005546	·064	·021168	·102	·042080	·140	·066833
·027	·005867	·065	·021659	·103	·042687	·141	·067528
·028	·006194	·066	·022154	·104	·043296	·142	·068225
·029	·006527	·067	·022652	·105	·043908	·143	·068924
·030	·006865	·068	·023154	·106	·044522	·144	·069625
·031	·007209	·069	·023659	·107	·045139	·145	·070328
·032	·007558	·070	·024168	·108	·045759	·146	·071033
·033	·007913	·071	·024680	·109	·046381	·147	.071741
·034	·008273	·072	·025195	·110	·047005	·148	·072450
·035	·008438	·073	·025714	·111	·047632	·149	·073161
·036	·009008	·074	·026236	·112	·048262	·150	·073874
·037	·009383	·075	·026761	·113	·048894	·151	·074589
·038	·009763	·076	·027289	·114	·049528	·152	·075306

AREA OF SEGMENTS OF A CIRCLE.

$$\frac{\text{Versed Sine}}{\text{Diameter.}} = x \qquad \text{Diameter}^2 \times y = \text{Area.}$$

x	y	x	y	x	y	x	y
·153	·076026	·191	·104685	·229	·135642	·267	·168430
·154	·076747	·192	·105472	·230	·136465	·268	·169315
·155	·077469	·193	·106261	·231	·137307	·269	·170202
·156	·078194	·194	·107051	·232	·138150	·270	·171089
·157	·078921	·195	·107842	·233	·138995	·271	·171978
·158	·079649	·196	·108636	·234	·139841	·272	·172867
·159	·080380	·197	·109430	·235	·140688	·273	·173758
·160	·081112	·198	·110226	·236	·141537	·274	·174649
·161	·081846	·199	·111024	·237	·142387	·275	·175542
·162	·082582	·200	·111823	·238	·143238	·276	·176435
·163	·083320	·201	·112624	·239	·144091	·277	·177330
·164	·084059	·202	·113426	·240	·144944	·278	·178225
·165	·084801	·203	·114230	·241	·145799	·279	·179122
·166	·085544	·204	·115035	·242	·146655	·280	·180019
·167	·086289	·205	·115842	·243	·147512	·281	·180918
·168	·087036	·206	·116650	·244	·148371	·282	·181817
·169	·087785	·207	·117460	·245	·149230	·283	·182718
·170	·088535	·208	·118271	·246	·150091	·284	·183619
·171	·089287	·209	·119083	·247	·150953	·285	·184521
·172	·090041	·210	·119897	·248	·151816	·286	·185425
·173	·090797	·211	·120712	·249	·152680	·287	·186329
·174	·091554	·212	·121529	·250	·153546	·288	·187234
·175	·092313	·213	·122347	·251	·154412	·289	·188140
·176	·093074	·214	·123167	·252	·155280	·290	·189047
·177	·093836	·215	·123988	·253	·156149	·291	·189955
·178	·094601	·216	·124810	·254	·157019	·292	·190864
·179	·095366	·217	·125634	·255	·157890	·293	·191775
·180	·096134	·218	·126459	·256	·158762	·294	·192684
·181	·096903	·219	·127285	·257	·159636	·295	·193596
·182	·097674	·220	·128113	·258	·160510	·296	·194509
·183	·098447	·221	·128942	·259	·161386	·297	·195422
·184	·099221	·222	·129773	·260	·162263	·298	·196337
·185	·099997	·223	·130605	·261	·163140	·299	·197252
·186	·100774	·224	·131438	·262	·164019	·300	·198168
·187	·101553	·225	·132272	·263	·164899	·301	·199085
·188	·102334	·226	·133108	·264	·165780	·302	·200003
·189	·103116	·227	·133945	·265	·166663	·303	·200922
·190	·103900	·228	·134784	·266	·167546	·304	·201841

AREA OF SEGMENTS OF A CIRCLE.

$\frac{\text{Versed Sine}}{\text{Diameter.}} = x.$ Diameter$^2 \times$ y = Area.

x	y	x	y	x	y	x	y
·305	·202762	·343	·238319	·381	·274832	·419	·312055
·306	·203683	·344	·239268	·382	·275804	·420	·313042
·307	·204605	·345	·240219	·383	·276776	·421	·314029
·308	·205528	·346	·241170	·384	·277748	·422	·315017
·309	·206452	·347	·242122	·385	·278721	·423	·316005
·310	·207376	·348	·243074	·386	·279695	·424	·316993
·311	·208302	·349	·244027	·387	·280669	·425	·317981
·312	·209228	·350	·244980	·388	·281643	·426	·318970
·313	·210155	·351	·245935	·389	·282618	·427	·319959
·314	·211083	·352	·246890	·390	·283593	·428	·320949
·315	·212011	·353	·247845	·391	·284569	·429	·321938
·316	·212941	·354	·248801	·392	·285545	·430	·322928
·317	·213871	·355	·249758	·393	·286521	·431	·323919
·318	·214802	·356	·250715	·394	·287499	·432	·324909
·319	·215734	·357	·251673	·395	·288476	·433	·325900
·320	·216666	·358	·252632	·396	·289454	·434	·326891
·321	·217600	·359	·253591	·397	·290432	·435	·327883
·322	·218534	·360	·254551	·398	·291411	·436	·328874
·323	·219469	·361	·255511	·399	·292390	·437	·329866
·324	·220404	·362	·256472	·400	·293370	·438	·330858
·325	·221341	·363	·257433	·401	·294350	·439	·331851
·326	·222278	·364	·258395	·402	·295330	·440	·332843
·327	·223216	·365	·259358	·403	·296311	·441	·333836
·328	·224154	·366	·260321	·404	·297292	·442	·334829
·329	·225094	·367	·261285	·405	·298274	·443	·335823
·330	·226034	·368	·262249	·405	·299256	·444	·336816
·331	·226974	·369	·263214	·407	·300238	·445	·337810
·332	·227916	·370	·264179	·408	·301221	·446	·338804
·333	·228858	·371	·265145	·409	·302204	·447	·339799
·334	·229801	·372	·266111	·410	·303187	·448	·340793
·335	·230745	·373	·267078	·411	·304171	·449	·341788
·336	·231689	·374	·268046	·412	·305156	·450	·342783
·337	·232634	·375	·269014	·413	·306140	·451	·343778
·338	·233580	·376	·269982	·414	·307125	·452	·344773
·339	·234526	·377	·270951	·415	·308110	·453	·345768
·340	·235473	·378	·271921	·416	·309096	·454	·346764
·341	·236421	·379	·272891	·417	·310082	·455	·347760
·342	·237369	·380	·273861	·418	·311068	·456	·348756

AREA OF SEGMENTS OF A CIRCLE.

$\frac{\text{Versed Sine}}{\text{Diameter}} = x.$ Diameter² × y = Area.

x	y	x	y	x	y	x	y
·457	·349752	·468	·360721	·479	·371705	·490	·382699
·458	·350748	·469	·361719	·480	·372764	·491	·383699
·459	·351745	·470	·362717	·481	·373703	·492	·384699
·460	·352742	·471	·363715	·482	·374702	·493	·385699
·461	·353739	·472	·364713	·483	·375702	·494	·386699
·462	·354736	·473	·365712	·484	·376702	·495	·387699
·463	·355732	·474	·366710	·485	·377701	·496	·388699
·464	·356730	·475	·367709	·486	·378701	·497	·389699
·465	·357727	·476	·368708	·487	·379700	·498	·390699
·466	·358725	·477	·369707	·488	·380700	·499	·391699
·467	·359723	·478	·370706	·489	·381699	·500	·392699

SIZES OF DRAWING & WRITING PAPERS.

" Emperor "	72 × 48	Demy	20 × 15½
" Antiquarian " ..	53 × 31	Extra Large Post	22½ × 17½
" Double Elephant	40 × 26¾	Large Post	21 × 16½
" Atlas "	34 × 26	Post	19 × 15¼
" Colombier " ..	34½ × 24	Pinched Post ..	18½ × 14¾
" Elephant "	28 × 23	Double Foolscap .	26½ × 16½
" Imperial "	30 × 22	Foolscap	16¾ × 13¼
" Super Royal " .	27¼ × 19¼	Copy	20¼ × 16
Royal	24 × 19	Pott	15 × 12½
Medium	22 × 17½		

EXPANSION OF WATER (D. K. CLARK).

From 32° to 390° Fahr.

Temp. Fahr.	Weight per cub. ft.	Temp. Fahr.	Boiler pressure. lbs. per sq. ft.	Weight per cub. ft.
32°	62·418 lbs.	298°	50	57·27 lbs.
62°	62·355 ,,	338°	100	56·14 ,,
100°	62·022 ,,	366°	150	56·29 ,,
212°	59·76 ,,	390°	205	54·54 ,,

Note.—Locomotive engines are usually weighed with cold water in the boiler. If the water thus weighed amounts, for example, to 4 tons at 62° it will be found, as per the values in above table, that the weight of water at the same level (*i.e.*, same volume) but at a boiler steam pressure of 205 lbs. per sq. in. would be

$$4 \times \frac{54{\cdot}54}{62{\cdot}355} = 3\tfrac{1}{2} \text{ tons.}$$

THE BOILER.

The function of the boiler is to effect a heat-transfer from fuel to water and, thereby, the conversion of water into high-pressure steam. The dispositions for effecting this transfer, which include the combustion of the fuel, the provision of heat-absorbing surfaces in contact with the water and of water and steam reservoirs, constitute the mechanical structure of the boiler.

The type of mechanical structure, in which is incorporated the rectangular firebox (with open bottom) and the multitubular barrel, as first adopted by Stephenson in "The Rocket" and almost universally used ever since for the locomotive, is known as the "locomotive type." Under that name it has been adopted for torpedo boats, etc.

The locomotive-type boiler is distinguished in relation to many other types by one special feature, consequent on its furnace being controlled by the blast from the engine exhaust steam, *viz.*, the large quantity of fuel which can be dealt with on a fire-grate of limited area.

Apart altogether from differences in size and general proportions, there are many variations in design of this type of boiler, but these variations as a rule are due either to special arrangements for a particular kind of fuel or water, peculiarities of the road, or adaptation to suit the general design of the engine—the latter being usually the dominating reason.

In the earlier days of the locomotive's history very considerable attention had to be given to the smoke problem, Coke was the only permissible fuel, and on this account, says Colbourne, "attempts were occasionally made between 1833 and 1840 to burn coal in locomotive engines without the production of smoke." For this same purpose, we have, further, among many curious experiments, the very interesting cases of, in 1845, Dewrance's firebox with transverse division into furnace and combustion chambers; in 1855 McConnell's firebox with combustion chamber projecting into the barrel (an anticipation of "up-to-date" U.S. practice); in 1853-1855 Beattie's firebox with mid-feather and combustion chamber (barrel), and in 1857 Cudworth's twin firebox (longitudinal division) with very steeply inclined grate—a form which was still being fitted in new boilers as late as 1874. The original form of firebox has, for use with coal, survived all these and many other experiments, the only notable additions being the "Brick-arch" whose introduction, ascribed to Markham, dates as far back as 1858, and the "Air deflector" at the firing hole of the same period. It is virtually a two-chamber box, the lower part of which, *viz.*, the part below the brick-arch, forms the furnace chamber and is supplied with air through the grate, the upper part forming the combustion chamber with air supply through the firehole. Combustion of the solid fuel is effected on the grate, and thorough combustion of the volatile gases should be effected in the upper chamber before these gases undergo any cooling operation by contact with the water-contact-surfaces of the flue tubes.

For a low rate of firing, say, 30 lbs. per square foot of grate, the evaporation has been found (see page 50, Table VI.) to be 9 lbs., as compared with 6 lbs. at 160 lbs. per sq. ft., the loss at the higher rate being thus 33⅓ per cent. This loss is probably due to the higher velocity of the gases carrying off unconsumed carbon, and to a shortening of the time of contact of the hot gases with the heat-absorbing surfaces. The heat-absorption of the firebox (see page 52, Table IX.) under similar ratios of firebox surface to grate area varies from 43 per cent. at 90 lbs. per sq. ft. to 34 per cent. at 130 lbs. per sq. ft., indicating that the loss referred to above, as from a much lower rate of combustion to a higher, may be taken as fully accounted for in the firebox alone.

The deduction from these results seems then to be that, for a given grate area, it is desirable to have greater volume of firebox, with an extension of the flame-way. In this connection reference may be made to two systems now in extensive use, which should give increased efficiency. The first may be termed the "McConnell" system, *viz.*, the combustion chamber extension into the barrel.

Practically introduced in the United States by Wootton as a necessity for his wide firebox with very shallow furnace, it has obtained there a considerable popularity for all classes of work. (It has, of course, an additional recommendation in the case of very long boiler barrels in that it shortens the length of the tube.) The second method is a modification in structure of the "Dewrance," *viz.*, the division of the firebox by a transverse brick arch, into two chambers, a furnace chamber with the usual grate and a front chamber with closed bottom. This system has had several applications on Colonial and Foreign Railways, is known in the U.S. as the "Gaines," and has, up till now, only been applied to shallow type fireboxes.

An interesting experiment illustrating the value of firebox-volume and fuel-bed area (radiation surface) as affected by variations in the area of the grate (air-supply area) is quoted by Mr. Fry (Instn. Mech. Engineers, March, 1908) as having been made by Mr. A. W. Gibbs on the Pennsylvania Railway. The plant used was a locomotive of the "Atlantic" type with 20½" × 26" cylinders and 6'-8" drivers; its boiler had a heating surface of 2,319 sq. ft. composed of 157 sq. ft. firebox surface, and 2,162 sq. ft. tube surface (215 tubes 2" diam. and 15' 0" long), and had a grate area of 55·5 sq. ft. (9'-3" × 6'-0"). The ratio of heating surface to grate area was thus 41·7 to 1. It had no brick arch. The coal used had 57·2 fixed carbon, 35 volatile combustible, 6·7 ash and 1·1 moisture.

Twelve tests were made. All other conditions being the same, the area of the grate was tested under three variations, *viz.* :—(1) At full area of 55·5 sq. ft., (2) with front end cut off and leaving 39·5 sq. ft. available, (3) with front end further cut off and leaving 29·76 sq. ft. available. A set of four tests was made for each variation, *viz.* :—(1) With the engine running at 80 revs., per min., and 15 per cent. "cut off"; (2) at 120 revs. per min., and 20 per cent. "cut off"; (3) at 160 revs. per min., and 25 per cent. "cut off"; (4) at 160 revs. per min. and 32 per cent. "cut off."

The coal fired in each test amounted to from 1,000 lbs. to 5,000 lbs. per hour.

The result of the tests showed that, for a given quantity of coal the boiler efficiency was, *within this limit*, independent of the grate area, *i.e.*, for a quantity of 4,000 lbs. burned in a grate of 55·5 sq. ft. at the corresponding rate of 72 lbs. per sq. ft. per hour, or on a grate of 29·76 sq. ft. at 134 lbs. The firebox volume, adds Mr. Fry, seems here to be the controlling feature.

Furnace capacity comprises the grate area and the depth of the fuel bed. The extent of grate area is dealt with under "Boiler power." For the depth of the fuel bed it is convenient to take as a representative dimension, the distance between the surface of the grate-bars and the brick arch, as at the tube-plate face. In general practice this dimension varies between 18 inches and 32 inches. For bituminous coal the latter figure has, on British railways, been preferred as providing for a furnace which, as regards stoking, required less careful attention, but for many types of engines, and particularly for those designed for narrow gauge railways, it is not attainable.

The relative merits of depths of 32" and 18" were subjected to an exhaustive test on the London and North-Western Railway (C. J. B. Cooke, Instn. Mech. Engineers, March, 1908), and a few particulars are herewith given. The principal dimensions of the engines were :—

	"Precursor." Class.		"Experiment." Class.
Type of locomotive	4-4-0	..	4-6-0
Cylinders	19" × 26"	..	19" × 26"
Coupled wheels	81"	..	75"
Boiler pressure	175	..	185
Heating surface, Tubes ..	1848.4	..	1908
Do. Firebox ..	161.3	..	133
Do. Total ..	2009.7	..	2041
Grate area	22·4	..	25
Firebox depth from centre of brick arch to firebox ..	41¾"	..	28"
Distance from arch to bars at tube-plate	32"	..	18"
Weight (E. & T.) in working order, tons	96¾	..	102¾

The tests, which were taken on the Euston-Crewe run, 316 miles, covered a period of five months (October-February). The loads averaged about 350 tons exclusive of engine and tender, and the speeds from 47 to 58 miles per hour. The results were as under, *viz.* :—

"Precursor," 34,828 miles at 57·53 lbs. coal per mile.
"Experiment," 34,013 ,, at 52·25 do.

The engine with the shallower box and larger grate area thus made a gain of 5·28 lbs. per mile or about 10 per cent.

Note by Mr. Cooke.—"With the shallower box the fireman must handle his shovel carefully and constantly watch the condition of the fire in order to keep the bars from drawing air.

"The minimized space under the firehole door and beneath the brick arch renders it imperative to fire frequently and a little at a time, whilst with the deeper firebox and consequently thicker fire, careful firing is not so necessary."

In the case of the "Experiment" special notice must also be taken of the larger grate area. Taking an average speed of 50 miles per hour the coal consumption per square foot of grate area per hour is :—

$$\frac{52{\cdot}25 \times 50}{25} = 104 \text{ lbs.}$$

For the "Precursor," the corresponding consumption is :—

$$\frac{57{\cdot}53 \times 50}{22{\cdot}4} = 130 \text{ lbs.}$$

A reference to Prof. Goss' experiments, shows that about 7 per cent. of the saving might be due to the larger grate area alone.

Grate.—For hand-firing, the length of the grate, in fireboxes of normal type, is not usually allowed to exceed 10′ 0″. The width of the grate is determined either by the constructional arrangement of the framing and the wheel positions or by the limitations of the "loading-gauge."

The Narrow Firebox, using the term as descriptive of one whose width, over the outside of the shell, is such as to allow it to be placed between the frames and the wheels, may have its maximum width of grate thus defined, *viz.* :—

For the 4′-8½″ gauge the transverse distance between the wheels is 4′-5⅝″. Allowing for ⅞″ clearances between the wheels and the frame, and for 1⅛″ thick frame-plates, the distance between the frames is 4′-1⅛″. Allowing for clearances of ½″ (including the provision for stay and rivet heads), the width of the firebox shell is 4′-0⅛″ and, if the shell plates and firebox plates are each $\frac{9}{16}$″ thick and the width of the foundation-ring (or water space) is 3″, then the maximum width of the grate is 3′-4⅞″. By the use of a 2″ water space, which is not uncommon in British practice in districts where good water is available, this dimension can be increased to 3′-6⅞″ but 3″ is the more generally recognised space and U.S. practice now seems to aim at 4″ to 4½″.

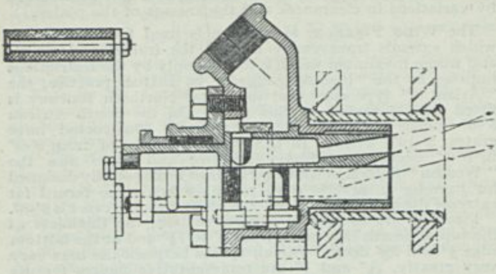
For the other gauges, the width of the grate will vary in accordance with the greater or lesser gauge dimension, *i.e.*, for the 5′-6″ gauge the width can be increased by 9½″, for the 5′-3″ gauge by 6½″, and for the 3′-6″ the width must be decreased by 1′-2½″ except, in each case, as it may be modified by variations in clearances and thicknesses of the plates.

The Wide Firebox, as a term, is used to describe one which extends transversely beyond the frames and wheels and whose maximum width is limited only by the restrictions imposed by the "loading gauge." In British practice, the "Atlantic" type engine of the Great Northern Railway is fitted with a firebox of this type. On the South African 3′-6″ gauge railways, engines recently constructed have grates 5′-10″ wide. In U.S. boilers, widths of from 6′-0″ to 8′-0″ occur in ordinary practice and there also the "Wooten" firebox, a wide and shallow box specially designed for burning anthracite coal, probably holds the record for extreme dimensions of grate—the width in some cases is 9′-6″.

Fire-bars are usually of a taper section, the thickness at the top or hearth face being from ¾″ to 1¼″ and at the bottom edge ⅜″ and 3½″ deep. The air spaces between the bars vary very greatly, $\frac{5}{16}$″ and ⅜″ are representative figures for use with British coal and ¾″ to 1½″ for Indian coal. In rocking-grates for use with "caking" or "clinkering" coal the fingers are usually from 4½″ to 5″ long and about $\frac{15}{16}$″ thick, and 3″ to 3½″ pitch. Rocking or shaking grates with "dump" sections are practically universal in U.S. For large grates steam-operated shaking gear has been installed.

Grates with power stokers are now in extensive experimental use in America and among these may be mentioned those by "Street," "Hanna" and "Crawford," which comprise underfed grates and both "Conveyor" and "Crushing" type stokers.

The Diamond Blower.—One of the most practical cleaning blowers is known as the "Diamond." As will be seen from the illustration, two steam orifices are provided in the nozzle, one arranged to blow parallel with the axis and the other oppcsed at an angle to it. The supply of steam to the jet is controlled by a "ring" valve, which travels backwards and forwards across the ports in the body of the nozzle. The valve is moved by rotation of the hand-wheel, and in one extreme position it fully closes the inlet to the angular jet, leaving the parallel one full open, and at the other end of its travel the reverse is the case. In mid-position both inlet ports are partly open and at all times a constant amount of steam is passing through either a single or combined jet, the intensity of the blast not varying. The turning of the handle, in addition to actuating the valve, also rotates the nozzle. It will be seen that after commencing with a simple jet projected directly on the tubes in the centre of the boiler, the opposing jet comes into operation gradually, increasing in strength, and deflecting the blast until it is at its widest angle and the whole of the tubes have been swept. The jet is concentrated, and takes effect on only a few tubes at a time, but it travels over the whole of the tube plate in the form of a spiral; about ten complete revolutions of the hand wheel are required, taking about one minute.



"DIAMOND" AUTO-GYROIDAL TUBE BLOWER.

Oil Burning.—Many systems are in use, both as to construction of the furnace-chamber and as to apparatus. With the ordinary construction of firebox in "locomotive type" boilers, most of these systems involve the protection of the walls by firebricks and the addition of a firebrick hearth.

The evaporative power of oil is approximately 1¾ times that of coal.

BOILER SHELL.

For purposes of comparison, a standard locomotive type boiler-shell, *i.e.*, the boiler-barrel and firebox envelope or casing, may be taken as having the following features, *viz.*: The barrel is constructed of two or more rings of uniform diameter and is fitted with a dome. The firebox casing is "flush" with the barrel, its front, back and side plates are vertical. The bottom is horizontal. The smokebox tube-plate is extended and flanged to make joint with the smoke-box, and the attachment to the barrel is made with an L ring.

Variations in practice are as under, *viz.* :—

Conical Barrel. This is in considerable use in the United States and has been adopted in one, at any rate, of our home railways. It effects a diminution of weight at the front end of the boiler; the evaporating surface of the water at the front end is also diminished, but the evaporation is there at a minimum, and the effect of this is therefore inappreciable; on the other hand, the construction is a more costly one.

Dome. If sufficient steam space is allowed within the barrel, the dome is merely a convenient place for the regulator steam-valve.

Firebox Shell. The round-top shell, "flush" with, or slightly raised above the level of the barrel, represented common practice in connection with a girder-stayed firebox crown and still obtains to an increasing extent with direct stays, *i.e.*, screwed rods between shell and crown. The flat-top or "Belpaire" type is more representative of modern practice. It gives a full thickness of the plates for connection with the stay screws, greater evaporating surface and steam space at the part of maximum evaporation and lends itself more readily to the arrangement of proper conveniences for the inspection and cleaning of the crown sheet. Inclinations of the throat or back plates are arranged usually to suit weight considerations. At the throat plate an inclination may effect a shortening of the barrel and of the flue tubes and at the back a saving of material and a lessening of the water carried. The width of the shell is governed by the general design of the framing, etc.

Smokebox Tube-plate. The extended or horseshoe plate has been much used in this country as it was considered more suited to inside cylinders, giving a direct connection between boiler and cylinder flange. This form of construction is, however, rapidly giving way to the drumhead type, which facilitates the maintenance of an air-tight smokebox.

FIREBOX.

Relative to features of shell-construction, as above described, the standard firebox may be assumed to be formed with a horizontal roof, and with the sides, the back (door plate) and the lower part of the front (tube plate) inclined from the vertical so as to allow for a wider water-space at the top than at the bottom. The upper part (tube-hole section) of the front plate is always vertical, in order that all tubes may be made of the same length.

Variations in practice are as under, *viz.*:—

The width of the upper part of the box is increased to admit of a greater number of tubes being provided. This is generally necessary but especially so with narrow-grate boxes. If at all possible the outside width (measured over rivet heads) should not exceed that of the opening inside the shell at the bottom, in order that the firebox may be inserted after the shell is riveted together, and to facilitate the removal and replacement of the firebox (in repair work).

The roof of the box is inclined, longitudinally, particularly on long boxes, *i.e.*, lower at the back than at the front, so that on steep grades the water may be maintained at a sufficient depth above the plate.

The provision of a "combustion-chamber" is a special arrangement to ensure more thorough combustion of the fuel (see under "The Boiler").

The provision of a "Midfeather," *i.e.*, a water chamber across the box at the position usually occupied by the Brick

Arch, or a water channel across the roof of the box (as in former Midland Railway practice) has been discarded. These were fitted in order to increase the direct heating surface, or to promote circulation.

In U.S. practice it is usual to fit "Arch tubes" so called because they are used to support the Brick Arch, between the front water-leg and the back end of the roof.

At the fire-hole openings, in the shell and firebox plates, the joint is formed by a solid ring, interposed and riveted to the plates. Owing to troubles experienced with the rings, even when forged, without weld, various methods of direct junction of the plates are in use of which perhaps the "Webb" is the best known example.

BOILER FLUES.

"**Brass Tubes**" was, until recently, the term used in boiler specifications embodying British locomotive practice, but **steel** or **charcoal-iron** tubes are now also in general use.

The quality of the material, etc., as prescribed for tubes in the British standard specifications is as under, *viz.* :—

Brass Tubes. Two qualities are given. (1) 70/30 Alloy in which not less than 70% must be metallic copper and there must not be more than a total of 0·75% of materials other than copper and zinc. (2) 2/1 Alloy in which not less than 66·7% must be metallic copper, and there must not be more than a total of 0·75% of materials other than copper and zinc. The tubes must be annealed at both ends and tested to a hydraulic pressure of at least 750 lbs. per sq. inch.

Copper Tubes. These must contain not less than 99% of copper and 0·35% to 0·55% must consist of arsenic. The hydraulic test is the same as for Brass tubes.

Charcoal-Iron Tubes. These tubes are to be lapwelded and made from genuine Swedish puddled iron of best quality. The tensile strength is to be between the limits of 19 and 24 tons per sq. inch, inclusive, with a contraction of not less than 45%. They must be annealed at both ends. The hydraulic test is to be the same as for Brass tubes.

Steel Tubes. These tubes are to be cold drawn and weldless and made from steel of the best quality by the Open Hearth process. They must not contain more than 0·03% of sulphur or of phosphorus. They must be annealed throughout their length. The tensile strength is to be not more than 24 tons per sq. inch, with an elongation not less than 28% in 8 inches. The hydraulic test is 1000 lbs. per sq. inch.

In general practice, the size of tubes varies between 1½ in. and 2½ in. outside diameter. Tubes of 1½ in. and 1⅝ in. diameter are now seldom used, and then only in the smallest boilers. 1¾ in. diameter may be taken as standard practice for tubes up to 15 ft. long ; 2 in. from 15 to 18 ft. and 2¼ in. for the longest tubes now in use.

For the thickness of the tube the following figures may be taken as representative, *viz.*:—

		Thickness
Brass or Copper,	1¾" dia.	12 W.G. tapering to 14 W.G.
"	2" "	11 " " 13 "
"	2¼" "	10 " " 12
Steel or Ch. ir.	1¾" "	12 "
"	2" "	11 "
"	2¼" "	10 "

Relative to the above tapering thicknesses of brass and copper tubes, it will be understood that the tubes are parallel on the outside, and that the taper is on the inside. Also that the thicker end is fitted into the firebox tubeplate, the allowance being in respect of the greater wear which takes place at that end. The front or smokebox end of the tube is usually made $\frac{1}{16}$ in. larger in diam. for about 3 in. of its length to allow for withdrawal of the tube after being in service and having its surface coated with a slight deposit. The firebox end of the tube is, in many cases, made ⅛ in. smaller in diam. to permit of a stronger bridge between the tube holes in the plate.

As an example of practice based on extensive experience, the following particulars of a 1¾-in. diam. Brass tube as employed in the locomotive boilers of the Indian State Railways, may be of interest, *viz.*:—The tube is increased $\frac{1}{16}$ in. in diameter for 3 ins. at its front end, and reduced ⅛ in. in diameter for 6 ins. at its firebox end. Its thicknesses are:—11 W.G. for 12 ins. at the firebox end, thence tapering to 13 W.G. in the next 12 ins., and thence of a uniform thickness of 13 W.G. to the smokebox end. The reduction at the firebox end, for a length of 6 ins., fulfils the double function of giving greater water space between the tubes at the part of maximum evaporation and of (as referred to above) giving more material in the plate bridges.

The tubes are expanded into the tube plates at both ends and fitted with ferrules at the firebox end. The ferrules are about 1¼ in. long and 11 W.G. thick and are tapered 1 in 20; the outer edge at the small end is rounded so as to avoid its cutting the tube in process of being driven home.

For steel tubes fitted into copper tubeplates it has been found advantageous not to ferrule the tubes until the boiler has been in service for a short period.

For steel tubes fitted into steel firebox tubeplates it is usual to fit on the tube-end a thin copper sleeve of sufficient length only to make the joint and to avoid the possibility, when expanding, of the tube being cut by the sharp edge of the steel plate.

STAYING POWER OF BOILER TUBES.

J. Holden (Proceed., M.I.M.E., 1906).

The following table gives for a cold condition, the force required to pull either a 1¼" thick copper firebox tube plate or a ¾" thick steel smokebox tube plate, over a single steel-tube expanded into the plates but **without ferrule.** In tests Nos. 1-3 the tubes were expanded in **parallel** holes and were not beaded. In tests Nos. 4-6 they were expanded in **taper** holes and were not beaded. Tests 7-9 were similar to 1-3, and tests 10-12 were similar to 4-6 but in 7-12 the tubes were **beaded over** at the copper plate.

In the second set of tests, the end previously pulled through the plate was flattened and held in dies.

The tube used in the test was 1¾" outside diam., 13 S.W.G. thick, with smokebox end 1⅞" outside diam and firebox end 1⅝" diam.

In all the first tests with the exception of Nos. 2, 3, 4 and 6 the joint was **started** in the steel plate and with the exception of No. 3 the tube was **pulled** through the steel plate. In Nos. 2 and 4 it started in both plates, and in 3 and 6 in the copper plate. The load is given in tons.

First Test.			Second Test.	
No. of test.	To start joint.	To pull.	To start joint.	To pull.
1	4·64	5·95	5·95	6·4
2	5·1	5·77	5·1	6·6
3	3·5	3·9	5·45	6·75
4	5·9	5·99	5·9	9·3
5	5·86	7·5	6·9	8·5
6	5·8	6·45	5·8	7·9
7	6·7	6·7	9·0	12·35
8	3·7	3·7	9·2	13·4
9	4·5	8·16	10·3	11·95
10	5·44	6·75	8·1	13·0
11	6·1	7·9	9·4	13·4
12	4·55	4·85	9·1	11·5

SMOKEBOX AND BLAST-PIPE.

The Smokebox or, as in American phraseology "The Front End," forms, with its contents and the chimney, the apparatus for inducing the air to enter the furnace, appurtenant to providing for the discharge into the atmosphere of the exhaust steam from the cylinders and of the waste gases from the furnace. It also accommodates the conduit for the steam from the boiler head to the cylinders, including the superheater header, the spark arrester and the Blower Nozzle or Ring. Except as regards the chimney orifice, the smokebox is an air-tight box and is fitted with an air-tight jointed door, which is sufficiently large to give access for cleaning the tubes, etc., remaking the joints of steam and exhaust pipes and to permit, in case of repair, of the flues being withdrawn and replaced in the boiler.

With inside cylinder engines, the length of the smokebox was at one time determined by the length of the cylinder barrel, but is now usually extended; the smokebox-tubeplate and the front or door-plate being attached to flanges at the back and front ends, respectively, of the barrel casting; the width at the bottom is similarly determined by the attachment of the side covering plates to the main frame plates and the contour of the roof and sides by that of the tube-plate itself. The construction is similar on "outside cylinder" engines, with the exception that the tube and front plates are connected to the frame cross-stretchers at the cylinders.

With a "drum-head" tubeplate in the boiler barrel, the smokebox generally also takes the cylindrical form, its covering or barrel plate being either directly connected to an extension, beyond the tubeplate, of the front plate of the boiler, or with a bar-ring interposed of sufficient thickness to bring the outer surface of the smokebox flush with the clothing sheets. With this construction, the smokebox is bedded on and attached to a saddle which also forms the frame stay at the cylinders, and the length of the smokebox is usually fixed by making the front or door plate, flush with the front face of the saddle.

These constructions, which may be termed "short" smokeboxes, became standard practice after the publication of R. Peacock's "successfully conducted" experiments in 1850 on the Manchester, Sheffield and Lincolnshire Railway. (It may be noted here that these experiments demonstrated on "The Sphynx" that it was beneficial to reduce a normal volume of smokebox of 40 cubic feet to 30 cubic feet.)

In the United States and Canada with their extensive open lines and with wood for fuel, early attention had to be given to "spark arresting." The short smokebox for this reason was fitted with a "balloon" or "diamond" smokestack containing a spark deflecting cone, a wire gauze baffle and an ash reservoir. This type of chimney, while fairly meeting the case of light engines, was in recent times found to be neither efficient nor convenient in the case of heavier machines.

The **extended** Smokebox is now in general use in most countries. It enables, as compared with the balloon chimney, a much greater area of spark arrester netting to be provided and in a more suitable position, *viz.*, **between** the flues and the blast nozzle. It has a much greater capacity for ash deposit and has easy access for the removal of same.

Blast. The system of the blast or air-inducing apparatus is similar to that of an ordinary ejector. The exhaust steam nozzle represents the steam cone, the chimney being the delivery cone and the smokebox space between these parts being the mixing chamber. The function of this apparatus is to eject the exhaust steam and waste gases, and thus to create a partial vacuum in the smokebox, and thus again to induce the products of combustion to pass through the flues, and air to pass through the grate and fuel bed into the furnace. Under various conditions this partial vacuum in the smokebox amounts to from 4 to 10 inches of water, and the back pressure on the piston, due to this work of passing the exhaust steam through the nozzle, may be taken at from 2 to 3 lbs. per square inch.

The position of the blast nozzle relative to the flues and chimney has been the subject of much experimental work. Previous to Peacock's tests (above referred to), in 1848, the nozzle was located either within the chimney-barrel or at the level of the smokebox-roof. The result of these experiments showed that greater efficiency was obtained with the nozzle placed eighteen inches from the base of the chimney, and this is approximately in accordance with the "High position" in modern practice, *viz.*, about 2 inches above the top row of flues.

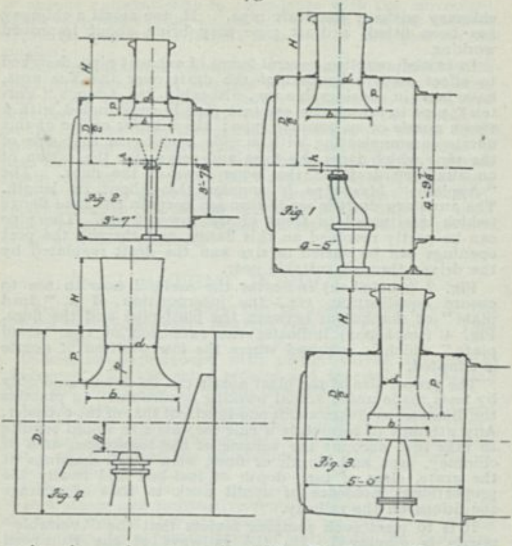
In main line work, however, with boilers of large diameter, highly pitched relative to the rail level, and with the same maximum height ("Loading gauge" restriction) the available length of chimney barrel above the smokebox has been reduced. In such cases it has been found necessary to provide an extension of the chimney inside the smokebox, with a resultant lowering of the blast-pipe nozzle. Three outline sketches herewith, Figs. 1 to 3, are representative of the positions on engines in extensive use, *viz.*, Figs. 1 and 2 show the position as for the Standard Indian Locomotives for the 5′-6″ and Metre Gauge Railways, and Fig. 3 shows the position as for one of our important Home Railways.

The principal dimensions for the positions, etc., on these smokeboxes are as under, *viz.* :—

	D	d	h	b	P	p
Fig. 1	69″	17″	3″	25″	12¾″	9″
„ 2	51½″	13¼″	1″up	18″	4″	10½″
„ 3	67⅝″	14″	—	24″	24″	10″

With a much lower position of nozzle a "petticoat pipe" or draught pipe was usually interposed between the nozzle and the chimney. The earliest record of such an arrangement is considered to be that of Ross-Winans in 1848. A few years later, with the object of more thoroughly equalizing the draught over the flue area, the general practice in the U.S. had introduced a number of these petticoat pipes or draft cones, in place of the single cone.

Fig. 4 shows the low position of the nozzle, and the flared extension of the chimney barrel, representative to a considerable extent of the U.S. practice of the present time. It embodies the recommendation following on the extensive



series of experiments conducted by Dr. Goss at the Purdue University, with the view of determining the most suitable dimensions for the chimney. For these dimensions, he gives the following equations, *viz.* :—

Let D=diam. of smokebox; d=diam. of chimney at throat; h=distance of nozzle below centre line of smokebox; b=diam. of chimney flare; P=extension of chimney inside smokebox, and p=distance from throat to face of flare; all in inches ("h" should be as great as possible),

then, $d = {\cdot}21D + {\cdot}16h$
$b = 2d \text{ or } {\cdot}5D$
$P = {\cdot}32D$
$p = {\cdot}22D$

It will be observed that, in Dr. Goss' suggestion, there are no proposals for "petticoat" or draft pipes (U.S. term). A very thorough series of tests relative thereto was, however, included in his experiments, and it was found that no possible combination of single or double draft pipes and chimney could be found which would give a better draft than could be obtained by the use of a properly proportioned chimney without the draft pipe. If too small a chimney has been fitted, a draft pipe may bring about improved working.

In British practice, several forms of exhaust pipe, designed to effect an equalization of the draft over the flue area, have been in considerable use. Notably, the Adam's "Vortex" pipe in which the exhaust pipe is constructed with a steam nozzle of an annular type; the interior orifice of this nozzle communicating with a wide opening in that side of the pipe which faces the flues and serves for the action of an auxiliary draft on the lower rows of the flues. The "Appleby" blast-pipe is annular throughout its length. The auxiliary draft is made through ports in the base flange (which is situated in front of the lower flues). The pipe can be partly revolved on this flange, and thereby the port openings can be varied in size and the draft regulated by the driver through suitable gear.

Fig. 2 (smokebox) indicates the method now in use to ensure equalization, *viz.*, the interposition of a "dead plate" or diaphragm between the blast-pipe and the flues. Fig. 4 (smokebox) indicates the extension of the "dead plate," which is required where the low position of nozzle is adopted.

The proper size of the blast nozzle can be determined only by tests made under actual working conditions. In practice the diameter averages about one-fourth of that of the cylinder. Any attempt to formulate a rule for this size would require to take into account the volume of the smokebox, area of chimney, area and length of flues, area of air-openings at the grate, class of fuel, depth of fuel-bed and finally the proportional incidence of uphill work to that of average conditions on the railway.

It is to meet such complex factors that the "variable" nozzle is employed. On the railways of the European Continent, it has maintained its position for half a century, but elsewhere it has gained merely a bare recognition. Two types of variable nozzle are in use. The older form employs a vertical spindle, passing through the exhaust pipe, with a coned head so placed in the nozzle-orifice that the movement of the cone increases or diminishes the area of the orifice. The form now probably in greater use is that in which the nozzle-orifice is, for its smallest area, formed in two hinged flaps. By a movement of these flaps the area can be increased.

A third type is that introduced by Macallan, of the G.E. Railway, and limited the variation to two sizes. The small size was attached to a lay shaft in such a manner that it could be swung over and superimposed on the large nozzle.

In these systems the variations of the size are regulated from the footplate and the chief objection to their installation is that, if not constantly in use, they become unworkable, due to smokebox conditions. For types 1 and 2 it is, therefore, worthy of note that they have also been arranged to change automatically in accordance with the movement of the reversing handle, *i e.*, in full working gear the variable nozzle is open for its largest area and in mid gear for its smallest.

Another method of varying the draught is that which retains the simple nozzle but arranges for relieving excess of pressure in the exhaust pipe. Earlier applications of this type provided for a bye-pass valve (controlled from the footplate) on the exhaust pipe, through which part of the steam could be discharged to the atmosphere, or be utilized either to heat the feed water in the tank, or for working an exhaust steam injector. A more recent application, which has now several years of good work to its credit, is that on G.W.R. locomotives, in which the ordinary nozzle has a "lift" which acts automatically under excess pressure, and permits of an auxiliary exhaust.

LENTZ PATENT POPPET VALVES.

This type of Poppet Valve can be operated by any of the several well-known valve motions generally employed. (See p. 201 also p. 203.)

Difficulties experienced with piston valves are usually concerned with extensive repairs and renewals of packing rings and liners and to carbon deposits.

Lentz Valves are said to overcome all these troubles and provide a valve which will remain perfectly steam tight; being balanced they require little effort to operate, and also but a small part of the oil required for piston or ordinary slide valves.

Poppet Valves are well adapted for high pressure superheated steam and locomotive requirements in general. On the Lentz system they are arranged in a steam chest casting which may be separate from or cast with the cylinders. There are four valves in each steam chest, and they are made of mild steel machined out from the solid. They are mounted on spindles of special hardened steel and are disposed in the horizontal plane, two valves at each end of the casing, one for steam and one for exhaust. The adjacent valves are side by side and parallel, and having their axis opposite those of the valves and at the other end of the valve chest. At right angles in the centre of the valve chest is a cam shaft having two hardened cams, one for the two steam valves and one for the two exhaust. A rocker arm is fitted to the cam shaft at its outer extremity to which connection to the valve gear is made. A reciprocating motion thus provided oscillates the cams, which impart motion to the spindles through a system of intermediate levers opening and closing the valves as desired. Restricting the swing of the rocker arms shortens the movement of the valve spindles and the valve openings being less they close earlier, thus providing a shorter cut off. In this respect and as regards reversal the valve equipment resemble ordinary piston valves.

BOILER BARREL PLATES.

The formula for the thickness is as under :—

$$T = \frac{P \times D \times 100}{2f \times \%}$$

T = Thickness of plate in inches.
D = Diameter of barrel in inches.
P = Working pressure of boiler in lbs. per sq. in.
S = Tensile strength of plate in lbs. per sq. in.
F = Factor of safety.

$$= \frac{S}{F} = \text{Working stress on plate.}$$

% = Joint efficiency per cent.

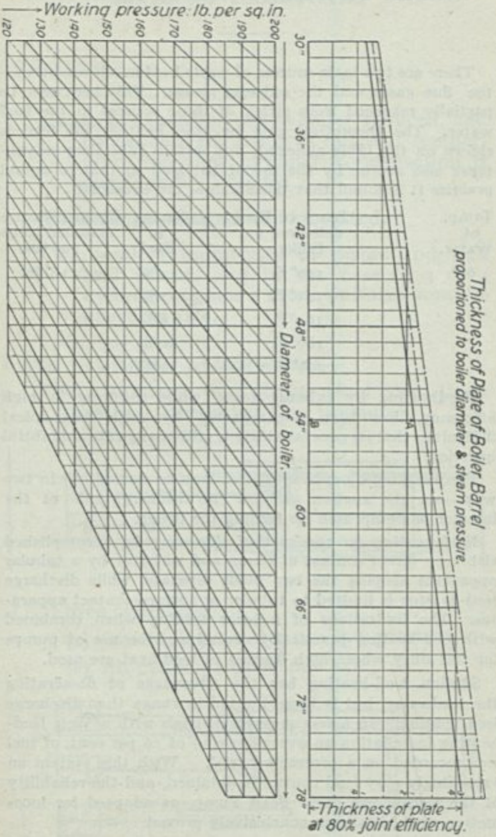
Example. Plate thickness required for barrel 60 in. diam. 180 lbs. pressure, 28 tons tensile, and a factor of 5 and joint efficiency of 80%

$$\text{Stress} = \frac{28}{5} = 5 \cdot 6 \text{ tons} = 12544 \text{ lbs.}$$

$$\text{Thickness of plate} = \frac{180 \times 60 \times 100}{2 \times 12544 \times 80} = \cdot 538 \text{ or } \frac{17}{32} \text{ in.}$$

The results from this formula are graphically shown on the next page for pressures of 120 to 216; diameters of 30 in. to 78 in.; joint efficiencies of 70%, 75% and 80%; for plate, having a tensile strength of 28 tons, and for a factor of 5, *i.e.* a working stress of 12,544 lbs.

Example. Taking particulars as per above example, from 180 follow the horizontal line till it touches the diagonal for 60 in., the vertical line measured from A to B gives the required thickness in full size. To the lower inclined line gives the thicknesses for 80%, the mid line for 75% and the top line for 70%.


Working pressure: lb. per sq.in.
120
130
140
150
160
170
180
190
200
Diameter of boiler.
30"
36"
42"
48"
54"
60"
66"
72"
78"
Thickness of Plate of Boiler Barrel proportioned to boiler diameter & steam pressure.
Thickness of plate at 80% joint efficiency.

NOTES ON FEED-WATER HEATING.

There are two main sources of waste heat in a locomotive—the flue gases and the exhaust steam. This heat can be partially returned from either of those sources in the feed water. The theoretical gain by thus heating the feed is shown on the table annexed, but certain subsidiary advantages also accrue by the use of hot feed so that in actual practice it is found that those values are exceeded.

Temp. of Water.	Temp. of Feed delivered to Boiler.	Saving in Fuel.	Boiler pressure assumed to be 200 lbs.
60°	120° F.	4%	per sq. in.
	140° F.	5%	
	160° F.	8%	
	180° F.	10%	
	200° F.	12%	

Feedheating by exhaust gases, while resulting in high efficiency, has been accompanied by such mechanical difficulties that its general utility is still at any rate a doubtful question.

Feed-heating by exhaust steam may be carried out in two ways—on the suction and on the discharge side of the injector or pump used for feeding the boiler.

Feed-heating on the suction side may be accomplished either by direct contact of steam and water or by a tubular apparatus keeping the two fluids separate, while discharge feed-heating is limited to tubular or surface-contact apparatus. The limitations of injector feeding when combined with feed-heating practically necessitate the use of pumps for this duty where high degrees of feed-heat are used.

Suction feed-heating has the advantage of de-aërating the feedwater, but is more limited in range than discharge feed-heating. In a recent series of trials with a Weir feed-heating installation an overall saving of 16 per cent. of fuel was recorded on a protracted trial. With this system an exceedingly easy feed control is obtained, and the reliability of the well-known Weir Feed Pump, as adapted for locomotive work, has been conclusively proved.

COMPOUND LOCOMOTIVES

—:—

ADVANTAGES :—

Economical use of steam.

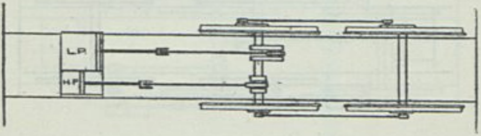
Range of expansion per cylinder reduced, and consequent reduction of range of temperature, so that cylinder condensation is considerably lessened.

Total range of expansion increased.

Comparative uniformity of piston rod pull and thrust, and in the case of 3 or 4 cylinder engines a more uniform rotative effect on axle.

TYPES :—Cylinder Arrangements—

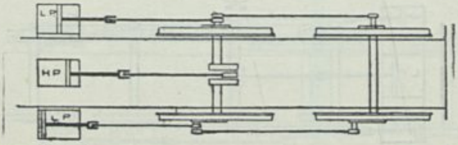
I. Two cylinders, one about usual size (high pressure), one larger (low pressure).



II. Three cylinders.

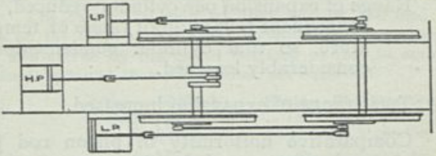
(1) One high pressure, two low pressure.

(*a*) All cylinders drive one axle.



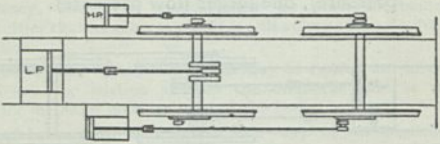
II. Three cylinders (*continued*).

(1) (*b*) Cylinders drive separate coupled axles.

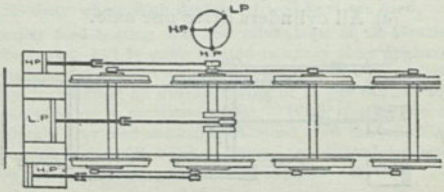


(2) Two high pressure, one low pressure.

(*a*) Cylinders drive separate uncoupled axles.

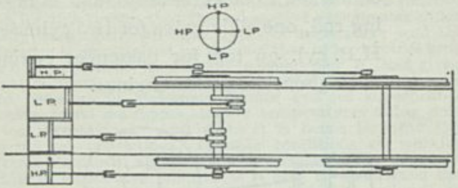


(*b*) All cylinders drive one axle.

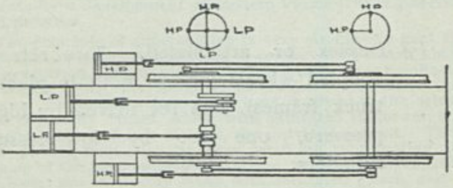


III. Four cylinders.

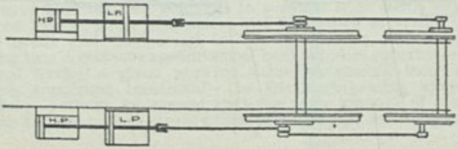
(1) Balanced. All cylinders drive one axle. Also with low pressure cylinders outside.



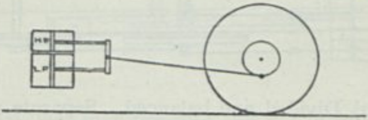
(2) Divided and balanced. Separate coupled axles driven.



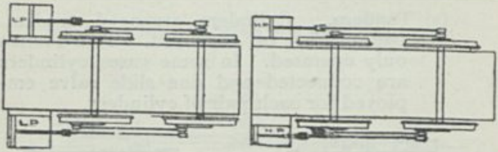
(3) Tandem. Cylinders arranged tandem, two pistons on each rod. Two cranks only operated. In some cases cylinders are connected and one slide valve employed for each pair of cylinders.



(4) Superimposed cylinders. Two piston rods connected to one crosshead and connecting rod, one slide valve for two cylinders. H.P. cyl. on top for passenger engines, L.P. above for goods engines.



(5) Duplex or articulated. Two sets of coupled wheels (one or both in pivoted truck frames), one set driven by high-pressure, one set by low-pressure cylinders.



LOCOMOTIVE SUPERHEATING.

Although superheating is, and has been for a long period, a standard feature of stationary steam engineering, it is essentially a modern development as applied to locomotive engines, by reason of the fact that conditions are so different from those which apply to other branches of steam practice. It is for this reason that the locomotive superheater differs vitally from nearly all other types of apparatus; and this difference is emphasized by the fact that in locomotive practice high superheat, ranging up to about 260° F., and giving steam temperature of from 650° to 680° F., is now standard, whereas in stationary plants 150° of superheat is about a usual maximum, higher temperatures being more or less exceptional. And when it is borne in mind that dimensional restrictions, variable conditions of working, extreme demands, simplicity and reliability are governing factors in locomotive practice, it is easy to understand that the development of a superheater expressly designed for locomotive purposes has been necessary before superheating could be accepted as a practicable proposition for adaptation to every-day locomotives. Trial equipments of one kind or another have been numerous, some of them dating to very early days; but modern superheating apparatus is essentially a development of modern locomotive engineering and progress.

The principle of superheating is very simple—to heat the steam, after it has ceased to be in contact with water, above its generation temperature. By this means three results are attained. First the water of saturation is converted into steam. Secondly, a reserve of heat is given to the steam, whereby many causes, which with saturated steam result in condensation and loss of heat, are provided against. These two phases may also be considered as representing the raising of the heat value of the steam, thereby compensating for losses which readily occur with saturated steam, and in this way adding to its working value. The low thermal conductivity of the steam is another factor against ready condensation; though it also militates against the free transmission of heat to the steam while being superheated. The third aspect is that of volumetric increase, whereby a given volume of saturated steam becomes, when superheated, a greater volume of superheated steam.

There are various ways of regarding the actual conditions which apply in the case of superheated steam, but it is thought that the best course is to consider it as steam produced by two-stage generation, the first stage occurring in the boiler and the second in the superheater, the result being that a certain expenditure of heat supplies superheated steam having a given working value, volumetric increase being concerned incidentally in the superheating stage. It may, perhaps, be argued that the same amount of heat when applied only to steam generation will produce a volume of steam which should have the same heat value, and that this should give the same working value. In practice, however, this is not the case, as saturated steam is always peculiarly liable to condensation on the slightest provocation, the saturation water is not eliminated nor is it usefully employed, and the conditions are such that the heat value is not equivalent to the working value. With superheated steam, largely in proportion to the degree of superheat, there is a nearer approximation to equality of heat and working value, many sources of loss are reduced or eliminated, the steam is in a condition to give greater efficiency, and economic criticism shows that a given expenditure of heat can be utilised to greater advantage if applied to steam generation and steam superheating, than if used only to produce saturated steam.

This view of the matter is in close accordance with practice, in that locomotives equipped with high degree superheaters, as is usual now, rarely provide an equivalent to non-superheater practice, unless generation and superheating are considered together on the two-stage basis. A smoke-box superheater is an addition to the boiler, and allows of superheating being separated from generation. But it does not allow of any very high degree of superheat being attained, because if there is much heat available for utilisation when the furnace gases reach the smoke-box, it follows that the boiler itself is not utilising its proper proportion. And if the superheater is allowed to monopolize a proportion of the heat in this way in order to give reasonably high superheat, there are better methods of effecting the same result. Smoke-box superheaters, such as the Baldwin, Phœnix and other designs, have indeed given fairly satisfactory results up to a point, and in this respect they may be regarded as more or less equivalent to superheaters used in stationary practice; but they have not gone far enough—hence the general favour of high degree apparatus. As a rule they will not give more than about 150° of superheat, and in most cases about 100° may be regarded as the maximum.

High superheat entails the conversion of all the water into steam, reserve of heat and volumetric increase. The two former aspects are of importance, but the latter is the controlling factor. A superheater boiler of given steam generative heating surface—usually less than that of a corresponding non-superheater—produces from a given weight of water a volume of superheated steam which is from 25 to 35 per cent. larger than that actually generated; and, by virtue of the superior condition of the steam, largely increased working value is realized. It may be argued that the heat value per unit of volume should be nearly the same, whether the heat be devoted solely to generation or partially to generation and partially to superheating; but in practice it is found that highly superheated steam is able to show superior steam efficiency, water goes further, and in various ways the results given are very strongly in favour of superheated steam, not only in respect of water consumption, but also as regards fuel consumption and the capabilities of the engines. The fact that given boiler dimensions provide a larger volume of steam when fitted with a superheater has also enabled pressures to be reduced and cylinders enlarged, while providing the same or greater haulage capabilities in the engine as a whole.

The case for superheating may therefore be set forth as:

(1) Saturation water is evaporated.

(2) A heat reserve is given to the steam.

For high degree superheating it becomes stronger:—

(3) Substantial volumetric increase is realized;

(4) The steaming value of a given boiler is raised, thus enabling a more powerful engine to be produced without seriously increasing its dimensions.

(5) The use of standard locomotive designs can be continued, if adapted for superheating, whereas otherwise it would be necessary to introduce larger classes;

(6) Steam pressures can be lowered and cylinders enlarged to give the same tractive effort as with saturated steam;

(7) Superheated steam can sometimes be utilised to greater advantage as regards the steam cycle in the cylinders than is possible with saturated steam.

Against these can be set the following factors:—

(a) The superheater usually entails modification of the boiler, and may require, if for high superheat, the use of piston valves, special packings, mechanical lubricators and other adjuncts.

(b) Its first cost has to be taken into account as well as other aspects of expense covered by (a).

These can, however, be simply answered by stating (1) that the cost of the superheater and other special fittings are all associated with the economics of superheating, which require to take account of these aspects as well as of fuel and water savings; (2) piston valves and other details are considered good practice apart from superheating and are equivalent to parts which must be used in any case; (3) if an engine is enabled to show greater efficiency or becomes equivalent to an otherwise larger engine these aspects cease to count; and (4) standard superheaters are now so efficient and free from liability to failure, that apart from first cost—in itself a very moderate factor—the expenses of maintenance are very small.

Taking the situation as a whole, therefore, it must be admitted that the high degree superheater has abundantly justified itself, has shown its economic and operating value in a marked degree, and the fact that it is now used for many thousands of engines of all classes, in virtually every country and on almost every railway of importance in the world, is proof that it satisfies economic, maintenance and operating requirements and does indeed realize notable economics in fuel and water consumption besides materially adding to the capabilities of locomotives to which it is fitted.

As indicated, the smoke-box superheater is not now largely used. The Phœnix and Baldwin designs were in most favour, with a few other superheaters or steam-dryers (such as the Drummond apparatus formerly used on some British Railways and the Buck-Jacobs apparatus used for large articulated engines in the United States. Most other superheaters are of fire-tube type, with U-tubes extending from a header in the smoke-box into large tubes in the boiler, well towards the firebox.

In the well-known Robinson superheater the elements are of double-looped type, giving a four-fold steam path, and are attached to the chambered header by flanges permitting of ready removal and attachment. The tubes are expanded into the header casting, access being obtained by means of a removable cover plate. On the London, Midland and Scottish Railway, Mr. Hughes employed a design with separate headers for saturated and superheated steam, to which the respective lengths of superheater tubing are connected. The Superheater Company have introduced a special valve to allow of steam being passed through the superheater while the engine is standing and thus overcome the difficulty that, on starting, an engine has not usually been able to raise its superheat. This also permits of the damper mechanism being dispensed with. On the L.M.S. the Fowler-Anderson valve is employed, whereby superheat can be raised while standing to meet the conditions of goods and stopping train working.

THE CONSTRUCTION OF A "LOCOMOTIVE TYPE" BOILER.

Boiler Shell.—The boiler-barrel plates are lined off to finished sizes, position of rivet-holes marked where necessary, machined on edge and a few "tacking" holes in each plate drilled ($\frac{1}{8}$ in. smaller than the rivet size). The circumferential rivet-holes are marked on the outside of plates which are to form the outer ring. The dome-opening is partly knife drilled out and the rivet-holes for dome-joint are drilled $\frac{1}{16}$ in. smaller than rivet size. The plates are next passed through the bending rolls and bent true to the required diameter. Barrel-joint-strips, dome-liner, angle-bars, etc., are machined to size and all rivet-holes are drilled in the outside joint-strips. A few "tacking" holes are drilled $\frac{1}{8}$ in. smaller than rivet size in other pieces. These pieces are where necessary then next bent to diameter. The angle-ring at smokebox tube-plate is turned to size and barrel-joint rivet-holes marked. The holes for the attachment of tube-plate are drilled to templet. The smokebox tube-plate is flanged to shape, machined on edges and all holes drilled to templet. The holes in dome-base are marked from shell-plate and drilled, separate from shell to finished size. Firebox-back and throat-plates are flanged to shape and machined on edges. A few "tacking" holes only, $\frac{1}{8}$ in. smaller than rivet sizes, are drilled in the flanges. The stay-holes are drilled $\frac{1}{32}$ in. smaller than tapping size. The rivet-holes at bottom ring are drilled $\frac{1}{8}$ in. smaller than rivet size. The holes for firedoor-ring are drilled with ring used as a jig. Firebox-shell wrapper-plates are machined on edges and all holes are drilled except at corners of bottom-ring and at top corners in the case of "Belpaire" boxes. Stay-holes are drilled $\frac{1}{32}$ in. smaller than tapping size and holes for bottom-ring $\frac{1}{8}$ in. smaller than rivet size. The plate is then bent to shape.

Boiler Shell, Assembling and Drilling.—All parts of boiler and outer firebox-shell are assembled in position and secured by "tacking" bolts. The complete shell is then centred on the trunnion carriage of the boiler-shell drilling machine and all rivet-holes "position drilled" through the solid plates and the holes previously drilled in the wrapper-plate and in the outside joint-strips act as jigs for holes through shell and inner strips. The plates are taken apart and all burrs removed.

Inner Firebox.—The door and tube plates of the inner firebox are flanged to shape and machined on edges. All stay and rivet holes are drilled $\frac{1}{32}$ in. smaller than tapping or rivet sizes. Tube-holes are drilled to templet. The covering plate is machined to size and all holes drilled except at corners of bottom-ring and top corners of box. All stay and rivet holes are drilled $\frac{1}{32}$ in. smaller than tapping and rivet. The prepared plate is next bent to shape.

Inner Firebox, Assembling and Drilling.—The parts of inner firebox are assembled in position and all rivet-holes reamed to size. The box is placed in the boiler shell and the bottom and firedoor rings inserted. The rivet-holes through rings form jig-holes for reaming.

Boiler Riveting, Staying and Mounting.—The boiler shell with inner firebox after being separately riveted up, are assembled with firedoor and bottom-rings in position. The various parts are riveted up, the stay holes are reamed to tapping size, tapped, and stays fitted. The pressure brought upon each rivet is usually 50 tons, but is varied to suit the thickness of the plates and size of rivets. The plates are fullered by a broad faced tool actuated by pneumatic pressure. The boiler is set up on blocks and plumb lines suspended from the barrel and firebox. A straight edge is fastened across the back plate and smokebox tube-plate and squared with the lines previously drawn on the plate. A line is drawn from each straight edge, thus giving the centre line of the boiler. Spirit-levels are used to set the boiler longitudinally and transversely so that the distance from the plumb line to the firebox-side can be checked on either side.

Any twisting due to riveting is at once located and remedied. The screwed stays are now fitted, and the seatings for gauge cocks, injectors and mud plugs are faced up and riveted to the shell. The boiler-tubes are put in from the smokebox end, gauged and then cut to exact length. The firebox ends of the tube are expanded and made tight by driving in a tapered steel ferrule. The smokebox end of the tube is also expanded. The main steam-pipe is put in through the smokebox tube-plate and connected to the regulator at the dome. After the regulator rod and links are connected, and the various steam-supply pipes for mountings put in position, the dome base is jointed and bolted tight to the dome. The mountings are fitted to the boiler, after which it is prepared for testing.

Boiler Testing.—Boilers are usually tested with hydraulic pressure to 50 per cent. over working pressure, and with steam to 10 lbs. per square inch over working pressure.

SAFETY VALVES.

The function of the safety valve is to ensure a discharge of steam from the boiler if the pressure increases above the permissible " working pressure."

The ideal valve would open with the slightest increase and close immediately the working pressure was again reached. In practice an allowance of 3 lbs. per sq. inch above and below can be attained.

As applied to the boiler of a locomotive engine, the valves need only be of a capacity to deal with an evaporation at a *moderately forced rate* as the maximum evaporation is dependent on a blast which has to be maintained by an outflow of steam from the boiler.

In locomotive practice it is, as elsewhere, of the greatest importance that the valves should be proof against being tampered with by the engine crew.

The quantity of steam that will escape, through a square edged orifice, from a boiler into the atmosphere, may be found approximately by Napier's formula, as under, *viz.* :—

Let P = Absolute pressure in lbs. per sq. inch.
A = Area in sq. inches of discharge opening.
F = Flow of steam in lbs. per hour.
Then F = 51·43 P.A.

In ordinary practice, two valves $2\frac{1}{2}$ inches dia. having a lift of 1/16 in. have been found of sufficient capacity for a boiler with 1,500 square feet of heating surface and 22 square feet of grate and working at a pressure of 160 lbs. per sq. inch (*i.e.*, an absolute pressure of 175 lbs.)

Circumference of the two valves $= 2 \times 2\frac{1}{2} \times 3{\cdot}1416 = 15{\cdot}708$.
Area of discharge opening $= 15{\cdot}708 \times 1/16 = {\cdot}98$.
$F = 51{\cdot}43$ P.A. $= 51{\cdot}43 \times 175 \times {\cdot}98 = 8{,}820$ lbs. per hour.

Discharge per sq. ft. of heating surface $= \frac{8{,}820}{1{,}500} = 5{\cdot}8$ lbs. per hour

" " grate area $= \frac{8{,}820}{22} = 400$ " "

Relative to this result for the grate area, the coal burned per square foot of grate at an evaporation of 8 lbs. steam per pound of fuel would be $\frac{400}{8} = 50$ lbs. per hour, and this is much in excess of a moderately forced rate.

Formulating, however, on this as a safe basis where H = heating surface in square feet.

then $\frac{51{\cdot}43 \text{ P.A.}}{\text{H}} = 5{\cdot}8$

$$A = \frac{5{\cdot}8 \text{ H}}{51{\cdot}43 \text{ P.}}$$

Further let D = Diameter of valve in inches.
N = Number of valves.
L = Lift of valve.

$$\text{then} \quad A = 3{\cdot}1416 \text{ D.N.L. and D.N.} = \frac{A}{3{\cdot}1416 \text{ L.}}$$

$$\text{or D.N.} = \frac{5{\cdot}8 \text{ H.}}{3{\cdot}1416 \times 51{\cdot}43 \text{ PL}} = \frac{\text{H}}{27{\cdot}8\text{LP}} = \frac{{\cdot}036 \text{ H.}}{\text{LP.}}$$

This latter formula coincides with the standard of the U.S. Association of Master Mechanics.

It will be evident, in basing the capacity on *heating-surface*, that for the case of the very long boiler tubes, a great part of which (at " moderately forced rates "), have a very low evaporative valve, it may be sufficient to take only the surface due to a length of about 17 ft.

The heating surface to be taken is, in any case, exclusive of superheating surfaces.

Example : Boiler working pressure 185 lbs. (200 absolute). Heating surface 2,000 sq. ft. Valve lift 1/16 in.

$$\text{D.N.} = \frac{{\cdot}036 \text{ H}}{\text{L P}} = \frac{{\cdot}036 \times 2{,}000}{200 = 1/16} = 5{\cdot}76$$

$$\text{D} = \frac{5{\cdot}76}{\text{N.}}$$

For N = 1, the valve is 5·76 dia. say 6 in.
,, N = 2, ,, ,, 2·88 ,, 3 in.
,, N = 3, ,, ,, 1·92 ,, 2 in.

Spring-loaded valves are the only types in use on locomotives. The " Ramsbottom," a duplex valve with the loading spring in tension, was generally adopted in British and Continental practice.

Valves directly loaded with springs in compression are now generally used and in that class are the " Pop " valves mentioned later.

For valves of the " Ramsbottom " type, the formula (modified from D. K. Clarke's) for the strength of springs in tension is as under, *viz.* :—

Let S = Dia. of coil (centres) in inches.
s = Dia. of wire in sixteenths of an inch.
W = Load on spring in pounds.

$$\text{then } s^3 = \frac{\text{W.S.}}{4{\cdot}5} \quad \text{or} \quad W = \frac{4{\cdot}5 \ s^3}{S}$$

For the extension of the spring the formula is :—

Let E = Extension of spring in inches.
C = Number of coils.

$$\text{then} \quad E = \frac{S^3 \text{ W.C.}}{22 \ s^4}$$

or where W is the load as ascertained in the above " strength" formula :

$$E = \frac{9 \ S^2.C.}{44 \ s.}$$

The table herewith gives a few ordinary values from these formulæ :—

Wire diam. In.	Coil centres. In.	Load in lbs.	Number of coils.	Extension per given load. In.	Load per extension of $\frac{1}{16}$ in.
$\frac{3}{8}$	2	490	6	·82	37 lbs.
$\frac{7}{16}$	$2\frac{1}{2}$	620	6	1·09	36 ,,
$\frac{1}{2}$	$2\frac{1}{4}$	920	6	0·96	60 ,,
$\frac{9}{16}$	3	1100	6	1·22	56 ,,
$\frac{5}{8}$	3	1500	6	1·10	85 ,,
$\frac{11}{16}$	3	2000	6	1·0	125 ,,
$\frac{3}{4}$	$3\frac{1}{4}$	2400	6	1·08	140 ,,
$\frac{13}{16}$	$3\frac{1}{2}$	2800	6	1·15	150 ,,
$\frac{7}{8}$	4	3100	6	1·40	140 ,,
$\frac{15}{16}$	$4\frac{1}{4}$	3600	7	1·72	130 ,,
1	$4\frac{1}{2}$	4100	7	1·81	140 ,,
$1\frac{1}{16}$	$4\frac{1}{2}$	5000	7	1·70	180 ,,
$1\frac{1}{8}$	$4\frac{1}{2}$	5800	8	1·84	200 ,,

In the last column, the approx. load is given, which will produce 1/16 inch extension of the spring, or allow for 1/16 inch lift of the valve or valves. Thus, in the case of a "Ramsbottom" safety-valve, with two $2\frac{1}{2}$ in. valves (area 4·9) for 150 lbs. per sq. inch working pressure, the load on the spring (neglecting the weight of the valves and lever) would be $2 \times 4{\cdot}9 \times 150 = 1{,}470$ lbs. A spring suitable for this load is the $\frac{5}{8}$ in. wire given in the table, with 1/16th in. extension for 85 lbs., and this load on the valve-areas is equivalent to a pressure of $\frac{85}{2 \times 4{\cdot}9} = 8{\cdot}6$ lbs. per sq. inch. For a discharge area based on a lift of 1/16th inch this spring would thus involve an increase in the "blowing off" pressure from 150 to 158·6 lbs.

For comparison, take further the case of a "Ramsbottom" with two $3\frac{1}{2}$ inch valves (area 9.62) for 180 lbs. per sq. inch working pressure. The load on the spring (as above) would be $2 \times 9{\cdot}62 \times 180 = 3{,}463$ lbs. A spring suitable for this load would be that with 15/16th inch wire given in the table, with 1/16th inch extension for 130 lbs. and this load on the valve-areas is equivalent to a pressure of $\frac{130}{2 \times 9{\cdot}62} = 6.7$ lbs. per sq. inch. If a spring with $3\frac{1}{2}$ in. centres were substituted (as actually occurs in practice) with the 15/16th in. wire, the load for 1/16th in. extension would be about 300 lbs. and the corresponding pressure equivalent would be $\frac{300}{2 \times 9.62} = 15$ lbs. per sq. inch.

It will not escape attention that the capacities of the valves are not, as usually assumed, proportional to their areas, which are in these examples nearly 1 : 2, but to their diameters, lifts and boiler pressures. For the 2½ in. valves the discharge opening is 0·98 square inches and the capacity at 150 lbs. working pressure is 8,316 lbs. per hour (approx.). For the 3½ in. valve the discharge opening is 1·37 sq. in. and the capacity at 180 lbs. working pressure is 13,782 lbs per hour (approx.).

The "lift" of the valve, as above considered, is that effected by the pressure of the steam on the net area of the valve. This lift can be increased by utilizing the energy of the escaping steam.

Thos. Adams invented the well-known valve, the "Adams'" valve, which attained this object. He added a lip on the valve, directly above its joint face, to intercept the current of steam. It has to be noted, however, that the size of this lip must be such that, while effecting an increase of the lift it should not be so large as to retard the closing of the valve when the pressure falls.

The special feature of the "Pop" valves meets this difficulty. In combination, usually, with the Adams' lip valve, they have an adjustable annular ring (forming with the lip a cavity called the "Huddling Chamber") attached to the valve seat and by means of this ring the outflow can be regulated to ensure a quick and full opening and a closing of the valve at from 1 to 2 lbs. per sq. in. of a fall below the working pressure.

The "Ross Patent Muffled Pop," with similar efficiency, also uses the Adams' lip, but the opening and closing are also affected by a secondary (piston) valve, at the top of the valve casing, which is subjected to the pressure of the escaping steam as controlled by an adjustable outlet.

REGULATOR OR THROTTLE-VALVE.

It has now become general practice to arrange the regulator in the dome. There still exist, however, examples of what may be termed the "Stirling" method in which the valve is fitted on the tube plate inside the smokebox. The Continental method of a special valve-chest fitted on the top of the boiler barrel (involving the use of outside branch steam pipes to the cylinders) is still largely in evidence, but seems to be in process of being discarded.

Preferentially the dome, with the regulator, should be located on the boiler over and near the centre of evaporation—reckoning the evaporation surface at the firebox as having an efficiency of about 40 per cent.

Four types of Regulators are at present in considerable use, *viz.*, (1) Slide Valve. (2) "Double-beat" or double disc seated valve. (3) Single disc with easing valve. (4) "Servo" or fitted with steam assisting gear for operating.

(1) The Slide-valve type is the one best known in British and Continental practice. It consists essentially of

the swan-neck steam pipe with a vertical port-face on which is fitted the main slide. On the back of this main slide is fitted the smaller slide or easing valve. The opening and closing of these valves is effected by the rotary movement of a shaft ("the regulator rod"), which at the front end is connected to the valves by a lever and link and which at the cab end is fitted with the engineer's operating handle.

(2) The "double-beat" valve has also been largely adopted on British locomotives. In the United States it is generally adopted. In this type of regulator the "swan-neck" carries the valve-chest. The valve itself has two disc faces, one of which fits on the top opening and the other on the bottom opening of the chest. The discs and their connecting stem form one casting, and necessarily, to provide for a cover-joint the lower disc (which must be inserted through the top opening) is of smaller diameter than the upper one. This valve, therefore, when under steam pressure is not in equilibrium.

As an example :—If the diameter of the opening under the lower valve is 5" the valve itself over the joint face will be 5¼", the top opening 5¼" full, and the top valve 5½". The unbalanced area is that due to the difference between the areas of the 5" diam. and the 5½" diam. or 4·12 square inches. The unbalanced load with the steam pressure at 180 lbs. per sq. in. would be 742 lbs. The gear for operating these valves, in British practice, is similar to that above described for slide-valve types. For the example here given, if the engineer be supposed to exert a pressure of 26 lbs. on the operating handle, the leverage required in the gear for lifting 742 lbs. would be 742/26, or, say, 25 to 1. This leverage is only necessary for "starting" the valve and is usually arranged for by fixing the short lever on the shaft so that the "shut" position it hangs almost vertically, *i.e.*, as near to the "dead centre" as permits of an allowance for a drop of the valve due to wear of its faces.

In U.S. practice with double-beat valves the gear is arranged to suit a "pull" handle for opening the valve. A bell-crank lever connects the pull rod with the valve link. The steam pressure on the unbalanced area (at the stuffing-box) of the pull rod assists the opening of the valve. In U.S. practice it is also usual to allow a much greater cover-joint lap on the valves than in British, and consequently the unbalanced area is also comparatively greater. As an example :—With an unbalanced area of 9 square inches at 180 lbs. per sq. in. steam pressure, the unbalanced load is 1,620 lbs. If the bell-crank leverage is 6 to 1 and the pull-rod area 1·22 (1¼" diam.) sq. in. there will be a lifting pressure on the valve of $1{\cdot}22 \times 6 \times 180$ or 1,320 lbs. and the nett load to be operated on by the engineer 1,620—1,320 or 300 lbs. can be manipulated by means of a handle leverage of 300/26 or, say, 12 to 1.

The "Lockyer" Regulator is of the double-beat type and effects equilibrium. The top and bottom discs are separate parts united by the centre spindle. The bottom disc is inserted into its position through a door, specially provided for this purpose, in the side of the valve-chest. The discs can thus be made of equal diameters. There is no unbalanced area and the valve can be very easily manipulated.

Another satisfactory regulator of recent design is that known as the Owen Valve, which is a double beat equilibrium valve of simple construction designed to have a minimum clearance of ⅛" at the top valve for expansion, this being made possible by the introduction of a piston type valve which allows the bottom valve to lift a determined distance before the top valve lifts up.

(3) The single-disc with easing valve. This type, though in limited use as a regulator valve, is in very extensive use on the Continent for general purposes such as injector-steam valves, etc. Its application as a regulator consists in a vertical steam pipe, in the dome, with its top end covered by the main valve and with, in the centre of the main valve, a small easing valve. In operating, the smaller or easing valve is first lifted for "starting" purposes and then the main valve for fuller admission of steam. The gear is similar to that employed in British practice, but the engineer's handle must be fitted with a detent to avoid the closing of the valve by the action of the inflowing steam.

The "Zara" type regulator is an improved form of the single disc type and has had a considerable adoption on Continental engines. In its simpler form it resembles the ordinary double-beat, but the extended lower part of the valve is a loosely fitted guide piston and does not serve for steam admission.

(4) The "Servo" type regulator (Hulburd's) has also the swan-neck form of steam pipe (as in the double beat) forming the valve-chest. The main valve is a differential piston, the trunk portion projects into the valve-chest and the part of larger diameter is fitted into a cylinder which forms a lower part of the chest. The cover of this cylinder is perforated with one small hole. Both faces (exclusive of the trunk-face) of the piston are under the boiler pressure, the pressure on the larger area holding the piston valve in its shut position.

The valve is operated by means of a small pilot-valve fitted in the centre of the piston. Steam can, through a movement of the pilot, be allowed to escape into the steam pipe from the cylinder, the pressure in which acts on the large face of the piston. The supply of steam to this cylinder is limited to what can pass through the small hole in the cover. When the pressure therein drops, the piston leaves the valve face and an additional supply of steam enters the steam pipe. By further movements of the pilot the position of the piston or valve opening can be modified to suit the demand. The effort required from the engineer to open this regulator is confined to the opening of the pilot; it is very small and in fact precautions have to be taken to prevent the use of excessive force.

THE FRAME.

In the original locomotives, the Boiler formed the framing for connecting together the cylinders, wheels, etc.

When framing emerged as a separate entity, only iron bars or small iron sheets were obtainable for its construction. The use of bars, although introduced by Bury, one of the most able pioneers in locomotive construction, was only used in a few instances in England. In America, at that time remote from other manufacturing processes, the "country smithy" could ensure its production, and it has there become the standard method of construction. In England the manufacture of iron sheets made steady progress and the plate frame is to-day the standard European method.

In the U.S. practice the manufacture of the bar frame has outgrown the resources of the very extensive smithies, which have been therefor specially organized. For the heavier engines steel castings are now employed. In Great Britain many engines with "bar" frames have been constructed for foreign or Colonial railways, but in these cases the frames have been machined out of rolled steel slabs of the required thickness.

In European practice each main frame plate has been for many years obtainable in steel, solid rolled in one piece of a length suitable for the most powerful engines.

With respect to the relative merits of the two methods of construction, claims have been made as to the one method serving to adapt the engine to respond more readily to irregularities of the road surface, and, as to the other, to greater flexibility in adapting itself to curvature of the road. It may be true, and probably is true, that the bar frame did so respond, but the bar frame was never designed to act as a spring. Portions only of it could so act, with the result of "fatigue" and breakage at the junction of the springing and the stiff portions. Similarly with the claim for the flexibility of the plate frame. With the light engines of earlier days these claims might be asserted. With the engines of to-day it is clearly understood that vertical flexibility is a function to be entirely undertaken by the bearing springs, and horizontal flexibility a function to be entirely undertaken by the flexibility of the wheel base (side play bogies, etc.).

Accessibility to moving parts, for purposes of oiling and repair work, was regarded as an important feature of the bar frame. With the very general adoption of the outside valve gear that claim has lost its force, but it may be noted that the most extensive use of the plate frame occurs where not merely the valve gear, but the main driving gear (piston rods, crossheads, connecting rods) is between the frames.

The **Framing** (or, to borrow a more expressive word from the motor world, the "Chassis") of the locomotive engine has three functions to perform, *viz.*:—to support the boiler, to form the bedplate for the cylinders, axleboxes, bogies, etc., and to transmit the buffing and tractive forces.

The chief stresses to which the framing is subjected may be classified thus, *viz.* :—(1) At all wheel centres, it has to resist the horizontal force due to the pressure of the wheel flanges against the rail. (2) At the part to which the cylinders are attached it has to resist the bending moment due to the steam pressure on the cylinder covers (alternately) at the overhung distance of the cylinder centre from the frame. (3) At the connection between the cylinders and the main axle the alternating tension and compression stress due to steam pressure on the cylinder covers and the resistance at the main axleboxes, and similarly of those due to the action of the "reciprocating parts" of the motion. (4) At the part of the frame on which the axleboxes of the main axle are supported, the transverse stresses due to the alternating pressure on each of the two sides of the engine. (5) The vertical bending moments when the engine is being lifted by chains attached to the extreme ends of the frame, due to the weight of the superstructure (boiler, cab, etc.). (6) The tension and compression stresses due to the transmission of traction and buffing forces.

The constructive arrangements employed as a provision for these stresses may be indicated generally as consisting of a thorough bracing of the frames. With inside cylinders or with outside cylinders each combined with a "half saddle" (as in U.S. practice), the important stresses under (2) are very thoroughly provided for. In the latter case, however, it entails a complex cylinder casting. The provision of a saddle casting with backward extension flanges, or of transverse plates, *viz.*, a horizontal plate at the level of the top of the cylinder flange, extending from the buffer beam to some distance behind the cylinders, and a horizontal plate at the lower flange, extending at least for the length of the flange, and vertical plates at each end of the cylinder connecting the top and bottom plates and the frames. In bogie engines the bottom stay is usually a steel casting which carries the centre pivot. Cross stays are fitted at the slide-bar bracket (in inside cylinder engines the bracket itself forms the stay) also about the main axle and at the pivot centres of the compensating beams of the spring gear. The front buffer beam is an important frame stay. If side buffers are to be fitted, the beam should be stiffened by gusset plates to the outside of the frame, by the platform plates and the latter (reinforced by a strong angle bar on its outside edges) should form a longitudinal stiffening for the main frame. The design of hind draw-box is usually governed by considerations as to the distribution of the weight on the various axles. Where light weight is necessary it is built of plates. Where the "balance" of the engine requires the addition of weight at the hind end, it takes the form of a casting of such weight as to effect the required movement of the centre of gravity of the engine.

Bar Frame. In U.S.A. practice these frames are usually from 4 inches to 4½ inches thick. In recent practice for heavy engines, where steel castings have been adopted, much thicker frames are required. For the Pennsylvania Ry. 2-10-0 type with $30\frac{1}{2}" \times 32"$ cylinders and 250 lb. working pressure, the castings are about 45 ft. long and weigh about 10 tons each. The section of the bar over the horns is $7\frac{1}{2}"$ thick by $9\frac{1}{2}"$ deep. The top member is $7" \times 8"$ and the bottom member $7" \times 6"$. At the cylinders the section is $5\frac{1}{2}" \times 20"$.

In engines with hind trucks the frame is usually jointed behind the coupled axles. In an example of this class, the 2-8-2 type with a main frame section at the horns of $6" \times 7"$, the extension to the rear end is $2\frac{1}{2}" \times 12"$ to 13" deep. With forged frames the bar to which the cylinders are attached is jointed to the main frame in front of the coupled axles. In an example of this class, the 4-4-2 type (Pensylvania Rly.) the main frames are $4\frac{3}{4}" \times 5\frac{1}{2}"$ over the horns; the top rails are $4" \times 6\frac{3}{4}"$, and the bottom rails $4" \times 5\frac{3}{4}"$; the front bar takes slab form $3" \times 15"$ at the cylinders.

Plate Frames. The thickness of the main frame plates varies from $\frac{3}{4}"$ in light engines to $1\frac{1}{4}"$ in the heaviest class now built.

The section of the frame over the horns varies from 12" in light engines to from 18" to 24" in the heavier classes and, especially in the latter class, is reinforced by the horse-shoe type horn-blocks of strong section.

The transverse stays generally take the form of steel castings.

General. The types of framing are known as "Inside Frames," in which the main frame plates are on the inner side of the wheels, and "Outside Frames," in which they are on the outer side. The latter type is now in use only on narrow gauge engines; the main bearings of the axles are on the outer side of the wheels thus involving the use of "outside cranks"; the cylinders are at a wider pitch relative to the rail gauge, and this tends to unsteady running.

In the more powerful engines on narrow gauge railways, a combination of the two types has been successfully adopted. At the coupled axles the main frame plates are on the inner side of the wheels and the hind extension frame plates are on the outer side. The two framings are either directly connected at the front of the firebox or by a transverse steel casting. The advantage of this combination is that it permits a great width of firegrate while retaining the narrow pitch of cylinders.

VALVE GEARS.

The ideal valve-gear should give (1) Full steam admission, with quick opening and closing for all ratios of "cut off." (2) Full opening to exhaust for the whole period before compression begins. (3) Pre-admission of steam before the end of the piston stroke.

Link-motions and radial gears have not, as yet, been able to fulfil these ideal functions. They give high mechanical efficiency, are simple in action and easily kept in good working order. Gears with "cam" or similar action give results more closely approximating to the ideal, but it has yet to be fully demonstrated that in practical working they have the requisite mechanical characteristics.

The systems of link motions associated with the names of "Stephenson," "Allan" and "Gooch" are so well known all over the world, and are dealt with in so many text books, that description of them here is quite unnecessary; especially is this the case with regard to the "Stephenson" which, until about 1908, was the generally recognised gear for locomotives. The "Allan" never attained any great popularity apart from its adoption where its light weight was of sufficient importance. The "Gooch" has long since disappeared from practice except for cases on design for which its special features were a recommondation, as, for example, the Corliss valves in the "Durant-Lencauchez" system.

Similarly the "Walschaerts" or "Heusinger" gear, which since about 1908 has been gradually asserting its supremacy, does not require here more than a general reference. Invented in 1844 by Egide Walschaerts in Belgium, and independently a little later by Heusinger von Waldegg in Germany, it attained to considerable use in these countries, and was also adopted to some extent by British builders on locomotives built for export. With the advent of the large "Mallet" articulated locomotives in the U.S.A. came the necessity there for an entirely outside motion as distinguished from one with inside eccentrics and reversing link with rocking shaft and with outside valve-rod to outside cylinders. Its accessibility on the engine and the light weight of its parts for handling gained for it a quick recognition of its suitability for that general adoption which has taken place.

The dual function of the valve gear mechanism, viz., a constant lap and lead movement with a variable steam admission, is, in the Walschaerts gear, separated. The lap and lead lever (or combination lever) is worked from the crosshead and the reversing link (which gives variation of the cut off as well as reverse) is actuated either from a return crank or an eccentric pulley.

Many modifications of the Stephenson and Walschaerts gears have been proposed and several are in use. Their characteristic feature, patent numbers, or a reference to a publication when a description may be seen are here given.

LINK MOTIONS.

Anderson. A Stephenson gear actuated by a return crank with double driving pins instead of eccentrics.—"Locomotive Cyclopedia," 1922, p. 497. U.S.A.

Younghusband (1897). A double eccentric motion with cross rods. It has a straight link with shifting valve rod. It is stated to give quick openings and constant lead. It was tested on five N.E.Ry. passenger engines for three years with a reported saving of 14·8 per cent. of coal.

J. T. Marshall. A double eccentric motion with cross rods. It has a curved reversing link of the Gooch type with shifting valve-rod. One eccentric is directly opposite the crank and its rod connects to centre of the reversing link and thus controls lap and lead motion. The other eccentric, fixed at about 90° behind crank, actuates a bell-crank lever rocking on the reversing shaft. The horizontal arm of the bell crank lever is connected by a link to a trunnion bracket in the reversing link. Fitted to a G.S. & W. (Ireland) locomotive and reported to have effected a saving of 15 to 20 per cent. of coal.—"Engineer," Vol. c., p. 436.

Durant-Lencauchez. The "Gooch" valve gear is here used and actuates four Corliss valves, two admission and two exhaust per cylinder. The two valve-rods driving these valves work in the same guide, and are connected with each other by the two reversing links. These links are controlled by the same reversing shaft. All valves are double ported. Seventeen express engines were so fitted on the Paris and Orleans Ry. in 1894.—"Engineering," Vol. lxiii., p. 291.

Young. The peculiarity of this gear lies mainly in its application for working two Corliss type valves per cylinder, each valve serving for steam admission and for exhaust, i.e., a valve is arranged on the top of and at each end of the cylinder. The "Stephenson" link motion with rocking shaft is utilised. From the arm of the rocking shaft, the valve-rod connects with a T lever situated between the valve casings. From this lever the movements of the wrist plate are actuated. —"Engineer," Vol. c., p. 380.

Alfree. This is a "Stephenson" link motion with a supplementary gear, actuated from the crosshead. The link motion is of the old U.S.A. type with rocking shaft. The valve-rod pin has an eccentric pin connection to the rocking shaft lever. On the outer end of this eccentric pin a pinion is fixed gearing with a segmented rack which rocks on the main rocking shaft. The double lever actuated by the crosshead is connected by a rod to this segment. The slide valve and cylinder ports are specially constructed to suit this gear. About fifty engines had, in 1905, been fitted.—"Engineer," Vol. c., p. 380.

WALSCHAERTS GEAR.

Kitson. (Patent 4512 of 1879) is a "Walschaerts" in which the drive for the reversing link is taken from the coupling rod to a horizontal arm on that link.

Beames. A modification of the "Walschaerts" gear to suit inside cylinder engines. The combination lever (lap and lead) is driven from an extension on the coupling rod instead of from the crosshead. The lever works through a guide spindle which, in turn, operates the valve rod through a rocking lever. Fitted to a L. & N.W. Ry. locomotive exhibited at the British Empire Exhibition, Wembley, 1924. "Engineer," Vol. cxxxvii., p. 706.

Golsdorf (Austria). Fitted "Walschaerts" valve gears in which the combination lever for the inside cylinder gear is worked from an extension of the coupling rod.—"Engineer," Vol. lxxxviii., p. 318.

Baker (U.S.A.). This is a "Walschaerts" gear in which the reversing link is replaced by a pivoted bell-crank coupled on one member to the valve rod and on the other to a pendulum lever which engages the rod from the return crank. The bracket supporting the bell-crank pivot also on a lower centre supports the swing link for the pendulum lever; an extension on the top end of this swing link connects to the reversing gear.—"Locomotive Cyclopedia" of 1922, p. 48, U.S.A.

Kingan-Ripken. A "Walschaerts" gear in which the combination lever is linked to an arm on the connecting-rod, near its small end, instead of to the crosshead. It is claimed that it causes release, compression and pre-admission to occur later in the stroke with the same cut-off. It has been applied to a number of locomotives on the Minneapolis, St. Paul ans Sault Ste Marie Ry.—"Railway Gazette," Vol. xxiii., p. 590.

Deeley. This gear was fitted to several express locomotives on the Midland Railway. The combination lever is of the "Walschaerts" type driven by the crosshead. The reversing link is driven by the crosshead on the opposite side of the engine as had been done in the Belgian "Stevart" gear. The die block in the link is in top position on the one side of the the engine when that on the other side is at the bottom. —"Engineer," Vol. civ., p. 286.

Young. In this system of "Walschaerts" gear the reversing link is driven from the crosshead. The combination lever on the one side of the engine is driven from the top of the reversing link on the other side of the engine. The combination lever and the radius rod are connected to a lever attached to a double cross shaft, the inner part of which acts for one side and the outer, or tube, acts for the other side.—"Locomotive Encyclopedia," p. 547 of 1927. U.S.A.

Jones. A "Walschaerts" gear with supplementary fitting to give a variable lead, consisting of a link interposed between the top of the combination lever and a secondary rod from the reversing lever. The valve rod connection is taken from an intermediate point on the link. The top end of this link is guided by a quadrant.—"Locomotive Cyclopedia," 1922, p. 495, U.S.A.

Berth (Paris Exhibition, 1910). A modified "Walschaerts" gear driving one admission and one exhaust piston-valve per cylinder. Separate reversing links are provided for admission and exhaust valves. Variations in steam admission are regulated independently.—"Engineering," lxx., p. 3.

Pilliod. This gear is composed entirely of parts having positive pin connection and no loose or sliding parts. Like the "Walschaerts" it has two drives, one from a return crank and one from the crosshead. It was fitted to a 4-6-2 type locomotive on the Chicago & Alton Ry., U.S.A.— "Engineer," Vol. cviii., p. 252.

Baguley. This gear belongs to the class in which the lap and lead movement and the variable valve-travel are combined. The reversing link and valve-rod are similar to the "Walschaerts." The drive is by a rod, direct from the main crank pin, which is connected at its front end to a lever on the reversing link trunnion. The trunnion is eccentric.

From an intermediate point in this driving rod, a vertical link actuates a horizontal arm on the reversing link. For full description see "Engineering," Vol. lix., p. 741.

Bonnefond (Paris Exhibition, 1889). "Walschaerts" system, working two admission and two exhaust valves on each cylinder. The reversing link drive is taken from a cam on the end of the crank pin. The point of cut-off is arranged independently of the reversing link, by a spiral cam the position of which is adjusted through a bevel pinion.—"Engineering," Vol. xlviii., p. 710.

Lentz. In this system, a "Walschaerts" gear actuates a lever on a cam shaft which operates four Poppet valves, two steam and two-exhaust, for each cylinder. The valves and cam gear are enclosed in a valve-chest attached to the top of each cylinder. The valves are double-beat pattern and are arranged horizontally, their centre line being parallel to the piston-rod. An illustration is given of the arrangement of the valves and cam gears. This gear has been fitted to a number of locomotives both in this country and abroad, and is reported to have given successful results. In the older form of the "Lentz" gear, the valves were arranged vertically, and were actuated by a sliding rod with inclined planes. A great number of locomotives were fitted therewith and have been working on Continental railways chiefly in Austria and Germany.

Fidler. "Walschaerts" type. The reversing link has a horizontal arm actuated vertically by a return crank which is set opposite to the main crank pin. On the end of the valve spindle a double lever is pivoted; the valve rod to the reversing link is connected to the top centre of this lever, the bottom centre of the lever is connected by a rod to an intermediate point on the driving rod from the return crank.

"Ouest" Railway (France). A "Walschaerts"-"Joy" gear was applied on this railway system during 1891-6 to some 4-4-0 type express locomotives. The combination lever was worked as usual from the crosshead. The rocking action of the reversing link was obtained from the connection rod through a Joy correcting gear coupled to a horizontal arm on the link. (See "Locomotive Valve Gears and Valve Setting.")

RADIAL GEARS.

In the "Engleman" gear (Patent 2964 of 1859), and "Hackworth" gear, 12,872 of 1849, and "J. W. Hackworth" gears (2448 of 1859, 4240 of 1876 and 877 of 1882) will be found the basic principles of most of the more modern gears.

Strong (Patent 1888), U.S.A. This is a modification of "Hackworth," and illustrates the main feature of the "Bremme," "Marshall" and "Southern." As the "Southern" represents the latest form of this important class of valve gear, a diagram is herewith given, showing its application to New South Wales Ry. locomotives. It has also been fitted to a number of locomotives in the U.S.A. In this later form the gear is driven by a return crank. In the "Strong" locomotive an inside eccentric and rocking shaft was used.

Bremme (Patents 2037 of 1879 and 7886 of 1886). This is a modification of "Hackworth" applied to marine work and has not been adopted for locomotives. Bremme considered the "Strong" gear (see p. 201) to be based on his invention.

Marshall (Patents 2138 of 1879 and 4185 of 1880). The locomotive types are modifications of Hackworth (see "Strong").

Bryce-Douglas (Patent 4958 of 1884). This gear was fitted to a C.R. locomotive which was exhibited at the Edinburgh Exhibition of 1886, but was subsequently removed. It was also tried on the G.E. Ry.

D. Joy (Patent 929 of 1879). This gear is based on "Hackworth," but had a correcting motion for the movement of the connecting rod point connection and had also a curved slide. It belongs to the class in which the "lap and lead" and variable travel are combined. Trouble has been experienced with the main connecting rod at the part where the drive for the Joy gear is engaged. This gear had a great popularity for locomotives on the old L. & N.W.R.

D. Morton (Patent 1490 of 1882). This gear is also based on "Hackworth." It has a further improved correcting gear. The reversing link has only a sliding movement. This gear has been applied chiefly to small locomotives. Its principal success has been on marine engines.

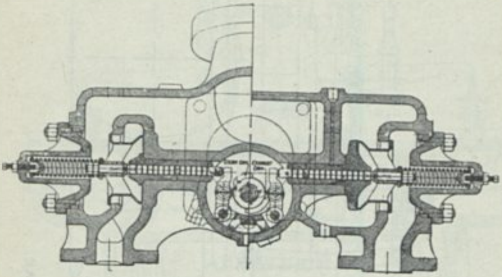
Brown, Switzerland (Patent 5175 of 1878) introduced many forms of "Hackworth" gears, one of which closely resembled the "Joy." His correcting gears are also of great interest. (See "Engineering," Vol. xxx., p. 271).

"CAPROTTI" VALVE GEAR.

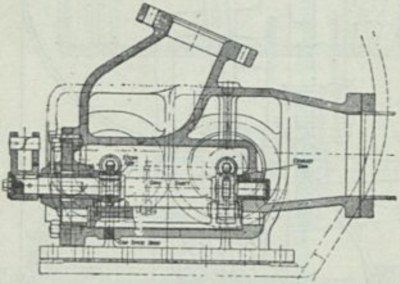
This gear, like the Lentz, works four poppet valves, two steam and two exhaust for each cylinder. These valves are arranged vertically and are actuated by a novel form of cam gear which is enclosed in a gear box on top of the cylinders. The drive of the Caprotti camshaft is taken direct through a spindle and gear wheels from the main axle. There are three cams on the gear box, one pair of which controls the opening and the other the closing of both admission valves and the third cam controls the opening and closing of the exhaust valves. The variation of the admission exhaust and compression and also of the reversing is effected by means of a quick pitch screw, mounted loosely on the cam shaft, which engages with two scrolls which can be moved longitudinally. An illustration is given of the general arrangement of this gear box. The gear has given very successful results on Italian railways, and also on the London, Midland and Scottish Railway.

THREE-CYLINDER VALVE GEAR.

Gresley. Method of actuating the valves of a third cylinder inside the frames by levers actuated by the Walschaerts valve gears of the two outside cylinders. (See "Locomotive Valve Gears and Valve Setting.")

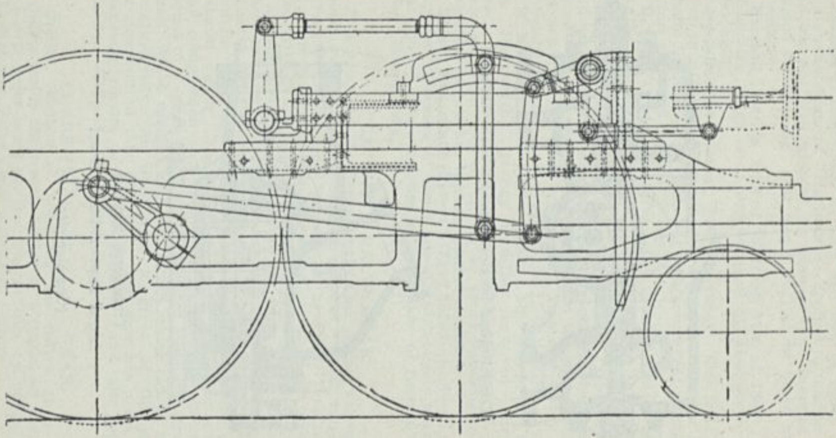


Longitudinal Section through Valve Chest.

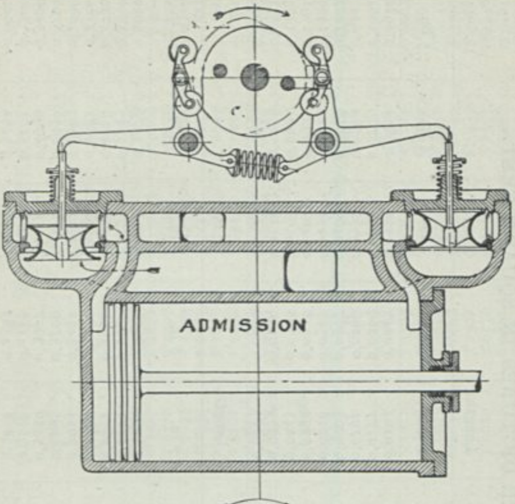


Transverse Section.
Lentz Poppet Valve Gear.

(See also page 175.)



SOUTHERN VALVE GEAR.



Caprotti Valve Gear.

HEATING SURFACE OF TUBES IN SQUARE FEET.

Length.

Outs. Diam.	⅛ in.	¼ in.	⅜ in.	½ in.	¾ in.	1 in.	2 in.	3 in.
1½ ..	0·0041 ..	0·0082 ..	0·0123 ..	0·0164 ..	0·0245 ..	0·0327 ..	0·0654 ..	0·0982
1⅝ ..	0·0044 ..	0·0089 ..	0·0133 ..	0·0177 ..	0·0266 ..	0·0354 ..	0·0709 ..	0·1064
1¾ ..	0·0048 ..	0·0095 ..	0·0143 ..	0·0191 ..	0·0286 ..	0·0382 ..	0·0764 ..	0·1145
1⅞ ..	0·0051 ..	0·0102 ..	0·0153 ..	0·0205 ..	0·0307 ..	0·0409 ..	0·0818 ..	0·1227
2 ..	0·0055 ..	0·0109 ..	0·0164 ..	0·0218 ..	0·0327 ..	0·0436 ..	0·0873 ..	0·1309
2⅛ ..	0·0058 ..	0·0116 ..	0·0174 ..	0·0232 ..	0·0348 ..	0·0464 ..	0·0927 ..	0·1391
2¼ ..	0·0061 ..	0·0123 ..	0·0184 ..	0·0245 ..	0·0368 ..	0·0491 ..	0·0982 ..	0·1473
2⅜ ..	0·0065 ..	0·0130 ..	0·0194 ..	0·0259 ..	0·0389 ..	0·0518 ..	0·1036 ..	0·1554
2½ ..	0·0068 ..	0·0136 ..	0·0205 ..	0·0273 ..	0·0409 ..	0·0545 ..	0·1091 ..	0·1636

Length.

Outs. Diam.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.
1½ ..	0·1309 ..	0·1636 ..	0·1963 ..	0·2290 ..	0·2618 ..	0·2945 ..	0·3272 ..	0·3600
1⅝ ..	0·1418 ..	0·1773 ..	0·2127 ..	0·2481 ..	0·2836 ..	0·3191 ..	0·3545 ..	0·3900
1¾ ..	0·1527 ..	0·1909 ..	0·2291 ..	0·2672 ..	0·3054 ..	0·3436 ..	0·3818 ..	0·4200
1⅞ ..	0·1636 ..	0·2045 ..	0·2454 ..	0·2863 ..	0·3272 ..	0·3682 ..	0·4091 ..	0·4500
2 ..	0·1745 ..	0·2182 ..	0·2618 ..	0·3054 ..	0·3491 ..	0·3927 ..	0·4363 ..	0·4800
2⅛ ..	0·1854 ..	0·2318 ..	0·2782 ..	0·3245 ..	0·3709 ..	0·4172 ..	0·4636 ..	0·5100
2¼ ..	0·1963 ..	0·2454 ..	0·2945 ..	0·3436 ..	0·3927 ..	0·4418 ..	0·4909 ..	0·5400
2⅜ ..	0·2073 ..	0·2591 ..	0·3109 ..	0·3627 ..	0·4145 ..	0·4663 ..	0·5181 ..	0·5700
2½ ..	0·2182 ..	0·2727 ..	0·3272 ..	0·3818 ..	0·4363 ..	0·4909 ..	0·5454 ..	0·6000

HEATING SURFACE OF TUBES IN SQUARE FEET.

Length.

Outs. Diam.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
1½	0·3927	0·7854	1·1781	1·5708	1·9635	2·3562	2·7489	3·1410
1⅝	0·4254	0·8508	1·2763	1·7017	2·1271	2·5525	2·9780	3·4034
1¾	0·4581	0·9163	1·3744	1·8326	2·2907	2·7489	3·2070	3·6652
1⅞	0·4909	0·9817	1·4726	1·9635	2·4544	2·9452	3·4361	3·9270
2	0·5236	1·0472	1·5708	2·0944	2·6180	3·1416	3·6652	4·1888
2⅛	0·5563	1·1126	1·6690	2·2253	2·7816	3·3379	3·8943	4·4506
2¼	0·5890	1·1781	1·7671	2·3562	2·9452	3·5343	4·1233	4·7124
2⅜	0·6218	1·2435	1·8653	2·4871	3·1089	3·7306	4·3524	4·9742
2½	0·6545	1·3090	1·9635	2·6180	3·2725	3·9270	4·5815	5·2360

Length.

Outs. Diam.	9 ft.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.	16 ft.
1½	3·5343	3·9270	4·3197	4·7124	5·1051	5·4978	5·8905	6·2832
1⅝	3·8288	4·2542	4·6797	5·1051	5·5305	5·9559	6·3814	6·8068
1¾	4·1233	4·5815	5.0396	5·4978	5·9559	6·4141	6·8722	7·3304
1⅞	4·4179	4·9087	5·3996	5·8905	6·3814	6·8722	7·3631	7·8540
2	4·7124	5·2360	5·7596	6·2832	6·8068	7·3304	7·8540	8·3776
2⅛	5·0069	5·5632	6·1196	6·6759	7·2322	7·7885	8·3449	8·9012
2¼	5·3014	5·8905	6·4795	7·0686	7·6576	8·2467	8·8357	9·4248
2⅜	5·5960	6·2177	6·8395	7·4613	8·0831	8·7048	9·3266	9·9484
2½	5·8905	6·5450	7·1905	7·8540	8·5085	9·1630	9·8175	10·4720

METRIC MEASUREMENTS AND BRITISH EQUIVALENTS.

Metric Measures of Weight.

	Grammes	British measures.
Milligramme -	0.001	0.0154 grains.
Centigramme -	0.01	0.1543 ,,
Decigramme - -	0.1	1.5432 ,,
Gramme - -	1.0	15.4323 ,,
Kilogramme -	1,000	2.2046 lb. avoir
Tonneau (shipbuilding) or Millier	1,000,000	0.9842 ton.

Metric Solid Measures.

Cubic	Cubic metres.		British measures.
millimetre	0.000000061		0.00091 Cub. in.
centimetre	0.000001	-	0.0610 ,, ,,
metre = Stere	1.0	-	35.3166 Cub. ft.

Metric Measures of Area.

Science and engineering. Square	Land.	Square metres.		British measures.
millimetre		0.000001	-	0.00155 sq. in.
centimetre		0.0001	-	0.15500 ,,
decimetre		0.01	-	15.501 ,,
	Milliare	0.1	-	1.07643 sq. ft.
metre	Centiare	1.0	-	10.764299 ,,
decametre	Are	100	-	10.764,299 ,,
hectometre	Hectare	10,000	-	10,764.299 ,,

Hectare = 2.471 acres.

Metric Measures of Length.

	Metres.		British measures.
Millimetre - -	0.001	=	0.03937 inch.
Centimetre - -	0.01	=	0.39371 ,,
Metre - - -	1	=	3.2809 feet
Kilometre - -	1,000		0.62138 miles.

Metric Measures of Capacity.

	Litres.	Cubic inches.	
Decilitre	=0.1	=6.1027	=0.17608 pint.
Litre (dm 3)	1	61.0271	0.8800 qrt.
Decalitre	10	610.271	2.2010 gal.
Hectolitre	100	6,102.71	22.0100 ,,

Rules for Converting Metric to English Measures and Weights.

Grammes to ounces avoirdupois, multiply by 20 and divide by 567.

Kilogrammes to pounds, multiply by 1,000 and divide by 454.

Litres to gallons, multiply by 22 and divide by 100.

Litres to pints, multiply by 88 and divide by 50.

Millimetres to inches, multiply by 10 and divide by 254.

Metres to yards, multiply by 70 and divide by 64.

BRITISH INCHES AND SIXTEENTHS WITH METRIC EQUIVALENTS.

In.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16
0		1·58	3·17	4·76	6·35	7·93	9·52	11·11
1	25·400	26·98	28·57	30·16	31·74	33·33	34·92	36·51
2	50·799	52·38	53·97	55·56	57·14	58·73	60·32	61·91
3	76·199	77·37	79·37	80·96	82·54	84·13	85·72	87·31
4	101·60	103·19	104·77	106·36	107·95	109·54	111·12	112·71
5	127·00	128·59	130·17	131·76	133·35	134·94	136·52	138·11
6	152·40	153·98	155·57	157·16	158·75	160·33	161·92	163·51
7	177·80	179·38	180·97	182·56	184·15	185·73	187·32	188·91
8	203·20	204·78	206·37	207·96	209·55	211·13	212·72	214·31
9	228·60	230·18	231·77	233·36	234·95	236·53	238·12	239·71
10	254·00	255·58	257·17	258·76	260·35	261·93	263·52	265·11
11	279·39	280·98	282·57	284·16	285·74	287·33	288·92	290·51
12	304·79	306·38	307·97	309·56	311·14	312·73	314·32	315·91
13	330·19	331·78	333·37	334·96	336·54	338·13	339·72	341·31
14	355·59	357·18	358·77	360·36	361·94	363·53	365·12	366·71
15	380·99	382·58	384·17	385·76	387·34	388·93	390·52	392·11
16	406·39	407·98	409·57	411·16	412·74	414·33	415·92	417·50
17	431·79	433·38	434·97	436·55	438·14	439·73	441·32	442·90
18	457·19	456·78	460·37	461·59	463·54	465·15	466·72	468·30

In.	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	12·70	14·28	15·87	17·46	19·05	20·63	22·22	23·81
1	38·09	39·68	41·27	42·86	44·44	46·03	47·62	49·21
2	63·49	65·08	66·67	68·26	69·84	71·43	73·02	74·61
3	88·89	90·48	92·07	93·66	95·24	96·83	98·42	100·01
4	114·30	115·89	117·47	119·06	120·65	122·24	123·82	125·41
5	139·70	141·28	142·87	144·46	146·05	147·63	149·22	150·81
6	165·10	166·68	168·27	169·86	171·45	173·03	174·62	176·21
7	190·50	192·08	193·67	195·26	196·85	198·43	200·02	201·61
8	215·90	217·48	219·07	220·66	222·25	223·83	225·42	227·01
9	241·30	242·88	244·47	246·06	247·65	249·23	250·82	252·41
10	266·70	268·28	269·87	271·46	273·05	274·63	276·22	277·81
11	292·09	293·68	295·27	296·86	298·44	300·03	301·62	303·21
12	317·49	319·08	320·67	322·26	323·84	325·43	327·02	328·61
13	342·89	344·48	346·07	347·66	349·24	350·83	352·42	354·01
14	368·29	369·88	371·47	373·06	374·64	376·23	377·82	379·41
15	393·69	395·28	396·87	398·46	400·04	401·63	403·22	404·81
16	419·09	420·68	422·27	423·85	425·44	427·03	428·62	430·20
17	444·49	446·08	447·67	449·25	450·84	452·43	454·02	455·60
18	469·89	471·48	473·07	474·65	476·24	477·83	479·42	481·00

PROPERTIES OF SATURATED STEAM.

Pressure above the Atmosphere. (Boiler Pressure)	Number of Atmospheres.	Temperature of Steam. Deg. Fahr.	Total Heat in Fahr. Deg. from Water at 32° Fahr.	Weight of one Cu. Ft. of Steam.	Specific Volume.
.0	1.00	212.	1146.1	.0380	1642
5.3	1.36	228.	1150.9	.0507	1229
15.3	2.04	250.4	1157.8	.0743	838
25.3	2.72	267.3	1162.9	.0974	640
35.3	3.40	281.	1167.1	.1202	518
45.3	4.08	292.7	1170.7	.1425	437
55.3	4.76	302.9	1173.8	.1648	378
65.3	5.44	312.	1176.5	.1869	333
75.3	6.12	320.2	1179.1	.2089	298
85.3	6.80	327.9	1181.4	.2307	270
100.	7.80	337.8	1184.4	.2622	238
105.	8.14	340.9	1185.4	.2725	228
110.	8.48	344.	1186.3	.2838	220
115.	8.82	347.	1187.2	.2948	211
115.	9.16	349.9	1188.1	.3054	204
120.	9.50	352.8	1189.	.3156	197
130.	9.84	355.5	1189.8	.3266	191
135.	10.18	358.2	1190.6	.3371	185
140.	10.52	360.8	1191.4	.3478	180
145	10.86	363.3	1192.1	.3584	175
150.	11.20	365.8	1192.8	.3689	170
155.	11.54	368.1	1193.6	.3792	165
160.	11.88	370.6	1194.3	.3893	160
165.	12.22	372.8	1195.	.4003	156
170.	12.56	375.1	1195.7	.4111	152
175.	12.90	377.3	1196.4	.4216	149
180.	13.24	379.5	1197.1	.4321	145
185.	13.58	381.5	1197.7	.4425	142
190.	13.92	383.7	1198.3	.4572	139
195.	14.26	385.8	1199.	.4629	136
200.	14.60	387.8	1199.6	.4733	133
203.	14.94	389.7	1200.2	.4836	130
210.	15.28	391.7	1200.8	.4941	127
215.	15.62	393.6	1201.4	.5046	124

PROPERTIES OF SATURATED AND SUPERHEATED STEAM.

(A few extracts from Marks & Davies' Extensive Tables.)

SATURATED STEAM.					SUPERHEATED STEAM					
					150° Superheat.		200° Superheat.		250° Superheat.	
Pressure	Temp.	Vol.	Heat of Liquid.	Total Heat.	Vol.	Tot. Heat	Vol.	Tot. Heat	Vol.	Tot. Heat
35·3	281·0	8·51	250·1	1173·6	10·48	1247·7	11·11	1271·8	11·74	1295·8
85·3	327·8	4·43	298·3	1186·3	5·47	1264·7	5·80	1289·4	6·12	1313·6
100	338·1	3·88	309·0	1188·8	4·81	1268·2	5·09	1293·0	5·38	1317·3
110	344·4	3·58	315·5	1190·3	4·45	1270·4	4·71	1295·2	4·97	1319·5
120	350·3	3·33	321·7	1191·6	4·14	1272·3	4·38	1297·2	4·63	1321·6
130	355·8	3·12	327·4	1192·8	3·87	1274·2	4·10	1299·1	4·33	1323·6
140	361·0	2·92	332·9	1194·0	3·63	1276·0	3·85	1300·8	4·06	1325·3
150	366·0	2·75	338·2	1195·0	3·43	1277·6	3·64	1302·5	3·84	1327·1
160	370·8	2·6	343·2	1195·9	3·24	1279·1	3·44	1304·1	3·63	1328·7
170	375·4	2·47	348·0	1196·8	3·08	1280·6	3·27	1305·6	3·45	1330·2
180	379·8	2·35	352·7	1197·7	2·93	1282·0	3·11	1307·0	3·29	1331·6
190	384·0	2·24	357·1	1198·5	2·80	1283·3	2·97	1308·3	3·14	1333·0
200	388·0	2·14	361·4	1199·2	2·68	1284·6	2·84	1309·7	3·00	1334·4
210	391·9	2·05	365·5	1199·9	2·57	1285·9	2·72	1310·9	2·88	1335·7

The " Pressure " is in lbs. per sq. in. above the Atmosphere (Boiler Pressure).
The Temp. is Temperature in Fahr. degrees.
The Vol. is the Specific Volume in Cubic Feet per lb.
The Heat of the Liquid (Boiler water) and the Total Heat of the Steam are given in British Thermal Units (B.Th.U.).
The Temperature of the Superheated Steam is 150°, 200° and 250° respectively above that of Saturated Steam.

EQUIVALENT EVAPORATION "FROM AND AT 212° FAHR."

For a given resultant evaporation "from" feed water at a stated temperature and "at" a stated steam pressure it is usual, for comparative purposes, to restate this in terms of the "equivalent evaporation from and at 212° Fahr." Thus, for example, if the stated evaporation per pound on fuel is 7 lbs. of water FROM a feed temperature of 60° Fahr. and AT 160 lbs. per square inch, steam pressure.

Heat in 1 lb. steam at 160 lbs. working pressure with feed at 32° = 1194·3 B.T.
" deducted for higher temp. of feed =60-32 = 28 "

1166·3 "

Heat in 1 lb. steam at 212° .... = 966 "

$$\text{Factor of evaporation} \quad \frac{1166{\cdot}3}{966} = 1{\cdot}208$$

The equivalent evaporation for 7 lbs.=7 × 1·208=8·456.

The table herewith gives the factors for the usual feed water temperatures and steam pressures occurring in locomotive practice.

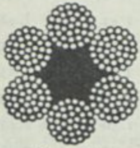
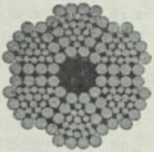
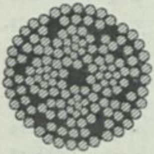
FACTORS OF EVAPORATION.

Temp. of feed water in Deg. Fahr.	Boiler working pressure in lbs. per □".					
	140	160	170	180	200	220
40	1·226	1·229	1·230	1·232	1·234	1·237
50	1·215	1·218	1·220	1·221	1·224	1·226
60	1·205	1·208	1·210	1·211	1·214	1·216
70	1·194	1·197	1·199	1·200	1·203	1·206
80	1·184	1·187	1·189	1·190	1·193	1·195
90	1·174	1·177	1·179	1·180	1·183	1·185
100	1·164	1·167	1·168	1·170	1·172	1·175
120	1·143	1·146	1·147	1·149	1·151	1·154
140	1·122	1·125	1·127	1·128	1·131	1·133
160	1·101	1·104	1·106	1·107	1·110	1·112
180	1·080	1·083	1·085	1·086	1·089	1·09
200	1·059	1·063	1·064	1·065	1·068	1·071
210	1·049	1·052	1·053	1·055	1·057	1·060

WEIGHT PER RUNNING FOOT OF SEAMLESS DRAWN BRASS AND COPPER TUBES.

Diameter Outside.	Thickness.		Weight.	
	B.W.G.	Inches.	Brass.	Copper.
1¼"	12	.109	1.44	1.52
1¼"	13	.095	1.27	1.34
1¼"	14	.083	1.12	1.18
1⅜"	12	.109	1.60	1.68
1⅜"	13	.095	1 41	1.48
1⅜"	14	.083	1.25	1.31
1½"	12	.109	1.76	1.85
1½"	13	.095	1.55	1.63
1½"	14	.083	1.36	1.43
1⅝"	12	.109	1.92	2.02
1⅝"	13	.095	1.68	1.77
1⅝"	14	.083	1.48	1.56
1¾"	12	.109	2.07	2.18
1¾"	13	.095	1.82	1.92
1¾"	14	.083	1.61	1.69
1⅞"	12	.109	2.23	2.35
1⅞"	13	.095	1.96	2.06
1⅞"	14	.083	1.72	1.81
2"	12	.109	2.39	2.51
2"	13	.095	2.10	2.21
2"	14	.083	1.84	1.94
2½"	12	.109	2.71	2.85
2¼"	13	.095	2.38	2.50
2¼"	14	.083	2.08	2.19
2½"	12	.109	3.31	3.18
2½"	13	.095	3.02	2.79
2½"	14	.083	2.65	2.45

ACTUAL BREAKING STRAINS OF STEEL ROPES FOR CRANES, HOISTS, SLINGS, ETC.

Construction of Rope.	Circumference.	Best Patent Steel.	Best Plough Steel.	Extra Special Improved Plough Steel.
	Ins.	Tons.	Tons.	Tons.
	3	24·1	29·8	34·0
	3⅛	26·2	32·4	37·0
	3⅜	29·7	36·7	42·0
	3½	32·2	39·7	45·4
	3¾	37·3	46·0	52·6
	3⅞	40·0	49·4	56·5
	4	42·8	52·9	60·5
	4¼	48·7	60·1	68·8
No: 15.	4½	53·4	65·9	75·4
Round Strand.	4¾	60·0	74·1	84·6
	5	66·9	82·6	94·4
	3	28·60	34·61	39·10
	3⅛	31·20	37·77	42·66
	3⅜	36·77	44·53	50·30
	3½	39·73	48·13	54·34
	3¾	44·91	54·40	61·51
	3⅞	48·21	58·36	65·98
	4	51·56	62·50	70·52
	4¼	57·50	69·56	78·50
	4½	64·93	78·67	88·90
No. 49 K	4¾	71·53	86·63	97·82
Keystone Strand.	5	79·90	96·70	109·30
	3	30·34	37·53	42·88
	3⅛	32·28	39·89	45·55
	3⅜	38·46	47·50	54·29
	3½	41·75	51·51	58·91
	3¾	47·50	58·61	67·03
	3⅞	51·10	63·13	72·09
	4	53·57	66·12	75·59
	4¼	60·04	74·13	84·71
	4½	68·27	84·41	96·44
No. 162.	4¾	75·57	94·19	106·72
Non-Rotating.	5	83·28	102·9	117·62

The aLove tables have been compiled by Wrights Ropes Ltd.

BRITISH MEASURES WITH METRIC EQUIVALENTS.

Miles in Kilometres.

Miles	Kilo-metres.	Miles	Kilo-metres.	Miles	Kilo-metres.	Miles	Kilo-metres.
1	1.609321	26	41.842346	51	82.075371	76	122.308396
2	3.218642	27	43.451667	52	83.684692	77	123.917717
3	4.827963	28	45.060988	53	85.294013	78	125.527038
4	6.437284	29	46.670309	54	86.903334	79	127.136359
5	8.046605	30	48.27963	55	88.512655	80	128.74568
6	9.655926	31	49.888951	56	90.121976	81	130.355001
7	11.265247	32	51.498272	57	91.731297	82	131.964322
8	12.874568	33	53.107593	58	93.340618	83	133.573643
9	14.483889	34	54.716914	59	94.949939	84	135.182964
10	16.09321	35	56.326235	60	96.55926	85	136.792285
11	17.702531	36	57.935556	61	98.168581	86	138.401606
12	19.311852	37	59.544877	62	99.777902	87	140.010927
13	20.921173	38	61.154198	63	101.387223	88	141.620248
14	22.530494	39	62.763519	64	102.996544	89	143.229569
15	24.139815	40	64.37284	65	104.605865	90	144.83889
16	25.749136	41	65.982161	66	106.215186	91	146.448211
17	27.358457	42	67.591482	67	107.824507	92	148.057532
18	28.967778	43	69.200803	68	109.433828	93	149.666853
19	30.577099	44	70.810124	69	111.043149	94	151.276174
20	32.18642	45	72.419445	70	112.65247	95	152.885495
21	33.795741	46	74.028766	71	114.261791	96	154.494816
22	35.405062	47	75.638087	72	115.871112	97	156.104137
23	37.014383	48	77.247408	73	117.480433	98	157.713458
24	38.623704	49	78.856729	74	119.089754	99	159.322779
25	40.233025	50	80.46605	75	120.699075	100	160.9321

METRIC MEASURES WITH BRITISH EQUIVALENTS.

Kilogrammes in Pounds

Kg.	Pounds.	Kg.	Pounds	Kg.	Pounds.	Kg.	Pounds.
1	2.205	26	57.320	51	112.435	76	167.550
2	4.409	27	59.524	52	114.639	77	169.754
3	6.614	28	61.729	53	116.844	78	171.959
4	8.818	29	63.933	54	119.048	79	174.163
5	11.023	30	66.138	55	121.253	80	176.368
6	13.228	31	68.343	56	123.458	81	178.573
7	15.432	32	70.547	57	125.662	82	180.777
8	17.637	33	72.752	58	127.867	83	182.982
9	19.841	34	74.956	59	130.071	84	185.186
10	22.046	35	77.161	60	132.276	85	187.391
11	24.251	36	79.366	61	134.481	86	189.596
12	26.455	37	81.570	62	136.685	87	191.800
13	28.660	38	83.775	63	138.890	88	194.005
14	30.864	39	85.979	64	141.094	89	196.209
15	33.069	40	88.184	65	143.299	90	198.414
16	35.274	41	90.389	66	145.504	91	200.619
17	37.478	42	92.593	67	147.708	92	202.823
18	39.683	43	94.798	68	149.913	93	205.028
19	41.887	44	97.002	69	152.117	94	207.232
20	44.092	45	99.207	70	154.322	95	209.437
21	46.297	46	101.412	71	156.527	96	211.642
22	48.501	47	103.616	72	158.731	97	213.846
23	50.706	48	105.821	73	160.936	98	216.051
24	52.910	49	108.025	74	163.140	99	218.255
25	55.115	50	110.23	75	165.345	100	220.462

BRITISH MEASURES WITH METRIC EQUIVALENTS.

Pounds in Kilogrammes.							
Lbs.	Kilo-grammes.	Lbs.	Kilo-grammes.	Lbs.	Kilo-grammes.	Lbs.	Kilo-grammes.
1	.453593	26	11.793418	51	23.133243	76	34.473068
2	.907186	27	12.247011	52	23.586836	77	34.926661
3	1.360779	28	12.700604	53	24.040429	78	35.380254
4	1.814372	29	13.154197	54	24.494022	79	35.833847
5	2.267965	30	13.60779	55	24.947615	80	36.28744
6	2.721558	31	14.061383	56	25.481208	81	36.741033
7	3.175151	32	14.514976	57	25.854801	82	37.194626
8	3.628744	33	14.968569	58	26.308394	83	37.648219
9	4.082337	34	15.422162	59	26.761987	84	38.101812
10	4.53593	35	15.875755	60	27.21558	85	38.555405
11	4.989523	36	16.329348	61	27.669173	86	39.008998
12	5.443116	37	16.782941	62	28.122766	87	39.462591
13	5.896709	38	17.236534	63	28.576359	88	39.916184
14	6.350302	39	17.690127	64	29.029952	89	40.639771
15	6.803895	40	18.14372	65	29.483545	90	40.82337
16	7.257488	41	18.597313	66	29.937138	91	41.276963
17	7.711081	42	19.050906	67	30.390731	92	41.730556
18	8.164674	43	19.504499	68	30.844324	93	42.184149
19	8.618267	44	19.958092	69	31.297917	94	42.637742
20	9.07186	45	20.411685	70	31.75151	95	43.091335
21	9.525453	46	20.865278	71	32.205103	96	43.544928
22	9.979046	47	21.318871	72	32.658696	97	43.998521
23	10.432639	48	21.772464	73	33.112289	98	44.452114
24	10.886232	49	22.226057	74	33.565882	99	44.905707
25	11.339825	50	22.67965	75	34.019475	100	45.3593

METRIC MEASURES WITH BRITISH EQUIVALENTS.

LITRES IN IMPERIAL GALLONS.							
Litres.	Gallons.	Litres.	Gallons.	Litres.	Gallons.	Litres.	Gallons.
1	.22	26	5.72	51	11.22	76	16.73
2	.44	27	5.94	52	11.44	77	16.95
3	.66	28	6.16	53	11.67	78	17.17
4	.88	29	6.38	54	11.89	79	17.39
5	1.10	30	6.60	55	12.11	80	17.61
6	1.32	31	6.82	56	12.33	81	17.85
7	1.54	32	7.04	57	12.55	82	18.05
8	1.76	33	7.26	58	12.77	83	18.27
9	1.98	34	7.48	59	12.99	84	18.49
10	2.20	35	7.70	60	13.21	85	18.71
11	2.42	36	7.92	61	13.43	86	18.93
12	2.64	37	8.14	62	13.65	87	19.15
13	2.86	38	8.36	63	13.87	88	19.37
14	3.08	39	8.58	64	14.09	89	19.59
15	3.30	40	8.80	65	14.31	90	19.81
16	3.52	41	9.02	66	14.53	91	20.03
17	3.74	42	9.24	67	14.75	92	20.25
18	3.96	43	9.46	68	14.97	93	20.47
19	4.18	44	9.68	69	15.19	94	20.69
20	4.40	45	9.90	70	15.41	95	20.91
21	4.62	46	10.12	71	15.63	96	21.13
22	4.84	47	10.34	72	15.85	97	21.35
23	5.06	48	10.56	73	16.07	98	21.57
24	5.28	49	10.78	74	16.29	99	21.79
25	5.50	50	11.00	75	16.51	100	22.01

BRITISH MEASURES WITH METRIC EQUIVALENTS.

Imperial Gallons in Litres.

Gal.	Litres.	Gal.	Litres.	Gal.	Litres.	Gal.	Litres.
1	4.543	26	118.130	51	231.717	76	345.304
2	9.087	27	122.674	52	236.260	77	349.847
3	13.630	28	127.217	53	240.804	78	354.391
4	18.174	29	131.761	54	245.347	79	358.934
5	22.717	30	136.304	55	249.891	80	363.478
6	27.261	31	140.848	56	254.434	81	368.021
7	31.804	32	145.391	57	258.978	82	372.565
8	36.348	33	149.935	58	263.521	83	377.108
9	40.891	34	154.478	59	268.065	84	381.651
10	45.435	35	159.021	60	272.608	85	386.195
11	49.978	36	163.565	61	277.152	86	390.738
12	54.522	37	168.108	62	281.695	87	395.282
13	59.065	38	172.652	63	286.239	88	399.825
14	63.609	39	177.195	64	290.782	89	404.369
15	68.152	40	181.739	65	295.326	90	408.912
16	72.696	41	186.282	66	299.869	91	413.456
17	77.239	42	190.826	67	304.412	92	417.999
18	81.782	43	195.369	68	308.956	93	422.543
19	86.326	44	199.913	69	313.499	94	427.086
20	90.869	45	204.456	70	318.043	95	431.630
21	95.413	46	209.000	71	322.586	96	436.173
22	99.956	47	213.543	72	327.130	97	440.717
23	104.500	48	218.087	73	331.673	98	445.260
24	109.043	49	222.630	74	336.217	99	449.804
25	113.587	50	227.173	75	340.760	100	454.347

WATER, WEIGHT AND VOLUME.

1 IMP. GAL.=1 1/5 U.S. GAL. U.S. GAL. 5/6 IMP.

Imp. Gallons.	U.S.A. Gallons.	Litres or Kilos.	Cub. Metres M3.	Cub. ft.	Lbs.			
6·2355	7·48	28·315	·02832	1	62·355			
8·333	10·	37·86	·001	1·337	83·33			
220·1	264·2	1000	1·	35·3156	2204·62			
·2201	·2641	1	·001	·0353	2·2046			
·8333	1·	3·786	·00378	·1337	8·333			
1·	1·2	4·544	·00454	·1604	10·			
					T.	C.	Q.	Lbs.
8·33	10	37·86	0·0378	1·337			2	27
10	12	45·44	0·0454	1·604			3	16
41·6	50	189·30	0·1893	6·685		3	2	24
50	60	227·2	0·2272	8·020		4	1	24
83·3	100	378·6	0·178	13·37		7	1	21
100	120	454·4	0·454	16·04		8	0	4
416·6	500	1893	1·890	66·85	1	17	0	21
220·4	264·5	1000	1·000	35·35		19	2	20
224	269	1018	1·018	35·93	1	0	0	0
500	600	2272	2·270	80·20	2	4	2	16
833	1000	3786	3·78	133·7	3	14	1	17
1000	1200	4544	4·54	160·4	4	9	1	4
1666	2000	7572	7·56	267·4	7	8	3	6
2000	2400	9088	9·08	320·8	8	1	8	8
2500	3000	11358	11·34	401·1	11	3	0	23
3000	3600	13632	13·62	481·2	13	7	3	12
3333	4000	15144	15·12	534·8	14	17	2	12
4000	4800	18176	18·16	641·6	17	17	0	16
	5000	18930	18·90	668·5	18	12	0	1
5000	6000	22720	22·70	80·20	22	6	1	20
6000	7200	27264	27·24	962·4	26	15	2	24

METRIC MEASURES WITH BRITISH EQUIVALENTS.

KILOGRAMMES PER SQUARE CENTIMETRE IN POUNDS PER SQUARE INCH.

Kgs. per Sq. Centim.	Lbs. per Sq. In.	Kgs. per Sq. Centim.	Lbs. per Sq. In.	Kgs. per Sq. Centim.	Lbs. per Sq. In.	Kgs. per Sq. Centim.	Lbs. per Sq. In.
1.	14.223	3.6	51.203	6.2	88.183	8.8	125.162
1.1	15.645	3.7	52.625	6.3	89.605	8.9	126.585
1.2	17.068	3.8	54.047	6.4	91.027	9.	128.007
1.3	18.490	3.9	55.470	6.5	92.450	9.1	129.429
1.4	19.912	4.	56.892	6.6	93.872	9.2	130.852
1.5	21.335	4.1	58.314	6.7	95.294	9.3	132.274
1.6	22.757	4.2	59.737	6.8	96.716	9.4	133.696
1.7	24.179	4.3	61.159	6.9	98.139	9.5	135.119
1.8	25.601	4.4	62.581	7.	99.561	9.6	136.541
1.9	27.024	4.5	64.004	7.1	100.983	9.7	137.963
2.	28.446	4.6	65.426	7.2	102.406	9.8	139.385
2.1	29.868	4.7	67.848	7.3	103.828	9.9	140.808
2.2	31 291	4.8	68.270	7.4	105.250	10.	142.230
2.3	32.713	4.9	69.693	7.5	106.673	10.1	143.652
2.4	34.135	5.	71.115	7 6	108.095	10.2	145.074
2.5	35.558	5.1	72.537	7.7	109.517	10.3	146.497
2.6	36.980	5.2	73.960	7.8	110.939	10.4	147.919
2.7	38.402	5.3	75.382	7.9	112.362	10.5	149.341
2.8	39.824	5.4	76.804	8.	113.784	10.6	150.764
2.9	41.247	5.5	78.227	8.1	115.206	10.7	152.186
3.	42.669	5.6	79.649	8.2	116.629	10.8	153.608
3.1	44.091	5.7	81.071	8.3	118.051	10.9	155.030
3.2	45.514	5.8	82.493	8.4	119.473	11.	156.453
3.3	46.936	5.9	83.916	8.5	120.896	11.1	157.875
3.4	48.358	6.	85.338	8.6	122.318	11.2	159.297
3.5	49.781	6.1	86.760	8.7	123.740	11.3	160.720

BRITISH MEASURES WITH METRIC EQUIVALENTS.

Pounds Per Square Inch in Kilogrammes Per Square Centimetre.

Lbs. per Sq. In.	Kgs. per Square Centimetre.	Lbs. per Sq. In.	Kgs. per Square Centimetre.	Lbs. per Sq. In.	Kgs. per Square Centimetre.	Lbs. per Sq. In.	Kgs. per Square Centimetre.
1	·0703	26	1·828	51	3·5857	76	5·3434
2	.1406	27	1.8983	52	3.656	77	5.4138
3	.2109	28	1.9686	53	3.7263	78	5.4841
4	.2812	29	2.0389	54	3.7966	79	5.5544
5	.3515	30	2.1092	55	3.8669	80	5.6247
6	.4218	31	2·1795	56	3.9373	81	5.695
7	.4921	32	2.2498	57	4.0076	82	5.7653
8	.5624	33	2.3202	58	4.0779	83	5.8356
9	.6327	34	2.3905	59	4.1482	84	5.9059
10	.70309	35	2.4608	60	4.2185	85	5.9762
11	.7734	36	2.5311	61	4.2888	86	6.0465
12	.8437	37	2.6014	62	4.3591	87	6.1168
13	.9140	38	2.6717	63	4.4294	88	6.1872
14	.9843	39	2.7420	64	4.4997	89	6.2575
15	1.0546	40	2.8123	65	4.5700	90	6.3278
16	1.1249	41	2.8826	66	4.6404	91	6.3981
17	1.1952	42	2.9529	67	4.7107	92	6.4684
18	1.2655	43	3.0232	68	4.781	93	6.5387
19	1.3358	44	3.0936	69	4.8513	94	6.609
20	1.4062	45	3.1639	70	4.9216	95	6.6793
21	1.4765	45	3.2342	71	4.9919	96	6.7496
22	1.5468	47	3.3045	72	5.0622	97	6.8199
23	1.6171	48	3.3748	73	5.1325	98	6.8902
24	1.6874	49	3.4451	74	5.2028	99	6.9606
25	1.7577	50	3.5154	75	5.2731	100	7.0309

WEIGHTS.

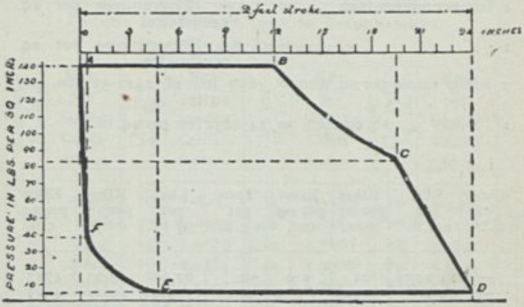
ENGLISH-FRENCH EQUIVALENTS.

1 Pound per square inch	=	0·070377 Kilogramme per sq. centimetre.
1 Ton per square inch	=	1·575 Kilogrammes per sq. millimetre.
1 „ „ „	=	157·5 Kilogrammes per sq. centimetre.
1 Kilogramme per sq. mm.	=	·635 ton or 1422·32 lbs. per sq. in.
1 „ „ sq. cm.	=	14·2232 lbs. per sq. in.

Tons per sq. in.	Lbs. per sq. in.	Kilos per sq. mm.	Kilos per sq. cm.	Tons per sq. in.	Lbs. per sq. in.	Kilos per sq. mm.	Kilos per sq. cm.
—	14·2232	·01	1·0	30	67,200	47·25	4725
—	14·7	·0103	1·035	31·25	70,000	49.21	4921
0.635	1,422·32	1·0	100	32	71,680	50·4	5040
1	2,240	1·575	157·5	34	76,160	53·55	5355
2	4,480	3·15	315	35·714	80,000	56·25	5625
3	6,720	4·725	472·5	36	80,540	56·7	5670
4	8,960	6·3	630	38	85,120	59·85	5985
4·464	10,000	7·03	703	40	89,600	63·0	6300
4	11,200	7·875	787·5	40·18	90,000	63·28	6328
6	13,340	9·45	945	42	94,080	66.15	6615
7	15,680	11.025	1102·5	44	98,560	69·3	6930
8	17,920	12·6	1260	44.643	100,000	70·31	7031
8·928	20,000	14·06	1406	46	103,040	72·45	7245
9	20,160	14·175	1417·5	48	107,580	75·6	7560
10	22,400	15·75	1575	50	112,000	78·75	7875
12	26,880	18·9	1890	53·572	120,000	84.37	8437
13·393	30,000	21·09	2109	55	123,200	86·625	8625
14	31,360	22·05	2205	60	133,400	94.5	9450
16	35,840	25·2	2520	62·5	140,000	98·43	9843
17·857	40,000	28·12	2812	65	144,600	102·375	10237
18	40,320	28·35	2835	70	156,800	110·25	11025·
20	44,800	31·5	3150	71·428	160,000	112·49	11249
22	47,280	34·65	3465	75	168,000	118.125	11812·
22·321	50,000	35·15	3515	80	179,200	126·0	12600
24	53,760	37·8	3780	90	201,600	141·75	14175
26	58,240	40·95	4095	100	224,000	157·5	15750
26·786	60,000	42·18	4218				
28	62,720	44·1	4410				

EXPANSION OF STEAM DIAGRAM.

TAKEN WHEN STEAM IS CUT OFF AT HALF STROKE.



ATMOSPHERIC LINE.

A.B. **is the steam line**, the steam port being open during this portion of the stroke.

B.C. **is the expansion curve**, and shews the fall in pressure after the steam port has been closed at *B*.

C.D. **is the exhaust line**, and shews the further fall in pressure after the steam port has been opened to the exhaust at *C*.

D.E. **is the back pressure line**, and shews the pressure against the piston on its return stroke (the steam port being still open to the exhaust). If there were no back pressure of steam this line would be as low as the atmospheric line.

E.F. **is the compression curve**, and shews the rise in pressure against the piston, due to the compression of the steam left in the cylinder after the steam port has been closed to the exhaust at *E*.

F.A. **is the admission line** and shews the further rise in pressure due to the steam port being opened before the piston is at the end of its stroke.

The amount of opening of the port when the piston is at the end of its stroke is termed "**lead.**"

The amount by which the slide valve covers each steam port when it is in its central position is termed "**lap.**"

FUEL AND FUEL CONSUMPTION.

A locomotive boiler should evaporate 8 lbs. of water per lb. of coal consumed (Yorkshire steam coal of good quality), and 9 lbs. of water per lb. of coal when using Welsh coal.

Its efficiency is about 65%, but may with careful design approach 80%.

The heat value of any fuel can be ascertained from its analysis, and its suitability for locomotive purposes known from the following :—

1 lb. of carbon, perfectly consumed, should evaporate	12.4 lbs. of water.
1 lb. of hydrogen, perfectly consumed, should evaporate	53. ,,
1 lb. of sulphur, perfectly consumed, should evaporate	3.4 ,,

---

A fair sample of	%Carbon	%Hydrogen	%Sulphur
Newcastle steam coal contains	82.4	5.4	1.5
Best Welsh smokeless steam contains	92·3	5.	—
Ordinary ditto.	88.2	4.7	1.7
Lancashire	82.6	5.9	.8
Scotch	80.1	6.5	1.4
S. Staffordshire	82.6	5.9	.4

DRAUGHT.—

When a locomotive is in full gear, cutting off at 75% of stroke, the blast should not create a vacuum in the smokebox of more than 5 ins. of water, measured at centre of tube plate, and when running with a cut-off of 25%, 2 ins. should be ample.

The temperature of the smokebox will average 600°F.

For rough calculations, the fuel consumption of locomotives may be estimated as follows :—

(Engines of modern build ; Coal of average quality.)

Main line express and passenger ..	40 lbs. per mile. or .12 lb. per ton mile.
,, ,, goods and minerals	65 lbs. per mile. or .1 lb. per ton mile.
Suburban tank locomotives	55 lbs. per mile. or .25 lb. per ton mile.

LINEAR MEASURES AND WEIGHTS IN DIFFERENT COUNTRIES.

British Empire generally	1 yard of 3 feet of 12 inches = ·9144 m.
„ „	1 foot=·3048 m., 1 inch=·0254 m.
„ „	1 ton of 20 cwts. of 4 quarters of 28 lbs.=1016·06 kg.
„ „	1 cwt.=4 qrs.=112 lbs. =50·8 kg.

In the United States and Canada the units of length are as in Great Britain, but the U.S. ton is of 2,000 lbs. only.

India. The acknowledged equivalent to a Maund is 84 lbs.

European Countries generally adopt the metrical system, which is also largely used in Great Britain and Dependencies, Mexico, Central and South America, North Africa, etc.	1 metre m.=100 centimetres. cm.=1000 millimetres mm. 1 kilogramme kg. = 1000 grammes g.

Netherlands	metric system. 1 pound (1 kg.) = 10 oncen = 100 looden = 1000 wigtjes.
Denmark	1 alen of 2 fod of 12 tommer of 12 linien=·6277 m.
Russia	1 foot=12 inches=1 foot British=·3048 m.
„	1 pood of 40 pounds of 32 ounces=16·38 kg., 1 pound =409·53 g.

For comparison of weights and volumes see p. 220.

UNIT OF LENGTH IN DIFFERENT COUNTRIES IN BRITISH YARDS.

Belgium	(kilometre)	1,094	yards
Denmark	(mil)	8,238	
England..........	(mile)	1,760	
France	(kilometre)	1,094	
Germany	(kilometre)	1,094	
	(mill.)	7,656	
Holland	(kilometre)	1,094	
Italy	(chilometro)	1,094	
Portugal	(kilometre)	1,094	
Russia	(verst)	1,167	
Spain	(kilometro)	1,094	
Switzerland	(lien)	5,249	
Turkey	(berri)	1,828	

TEMPERATURE BY FAHRENHEIT AND CENTIGRADE :—

$$\text{F. to C.} = 5\frac{(F-32)}{9} = \text{C.}$$

$$\text{C. to F.} = \frac{9C}{5} + 32 = \text{F.}$$

Example :—212° Fahr. 212 less 32 = 180. Divide by 9 = 20. Multiply by 5 = 100.

100° Cent. 9 times 100 = 900. Divide by 5 = 180. Add 32 = 212.

Water boils at 1 degree less temperature (Fahr.) for every 521 feet in height above the sea. This is approximate only, and is corrected by relative barometric and thermometric readings in actual practice.

APPROXIMATE WEIGHT OF METALS.

Cast Iron	—450	lbs. per cubic ft.	·26	lbs. per cubic in.
Wrought ,,	—480	,, ,, ,, ,,	·277	,, ,,
Steel	—490	,, ,, ,, ,,	·283	,, ,,
Tin	—458·3	,, ,, ,, ,,	·265	,, ,,
Zinc	—436·5	,, ,, ,, ,,	·252	,, ,,
Copper	—552	,, ,, ,, ,,	·319	,, ,,
Lead	—710	,, ,, ,, ,,	·41	,, ,,
Aluminium	—166·5	,, ,, ,, ,,	·096	,, ,,

APPROXIMATE WEIGHT OF TIMBERS.

	lbs. per cubic ft.		lbs. per cubic ft.
Poplar	24	Holly	47
Larch	34	Hornbeam	47½
Fir	34¾	Ash	47½
Honduras Mahogany	35	Dark Oak	47½
Willow	36½	Maple	49
Sycamore	37	Yew	50
Cedar	37¼	Spanish Mahogany	53¼
Elm	38	Canadian Oak	54½
Pine	39⅓	Box	60
Pitch Pine	41½	English Oak	60⅝
Walnut	42	Greenheart	62½
Beech	43½	Adriatic Oak	73¼
Birch	44¼	Ebony	83¼
Teak	46½	Lignum Vitæ	83¼

MELTING POINT OF METALS, ETC.

Names.	Fahr.
Platinum	4590°
Antimony	842
Bismuth..	487
Tin	475
Lead	620
Zinc	700
Cast Iron	2100
Wrought Iron	2900
Steel	2500
Copper	2000
Glass	2377
Beeswax	151
Sulphur	239
Tallow	92

EXPANSION OF METALS.

The following table shows the amount of expansion for different materials per foot :—

	Expansion per Degree Fahr.	Expansion from 32° to 212°.
Iron	·0000067	·00122
Steel	·0000069	·00124
Copper	·0000090	·00171
Zinc	·0000160	·00294
Tin	·0000120	·00217

Almost all solid bodies expand equally for each degree between freezing and boiling, or from 32° to 212° of Fahrenheit's thermometer. A bar of iron, therefore, which is 12 feet long, by an increase of 60° of temperature becomes $50 \times 12 \times {\cdot}0000067 = 12{\cdot}0048$ feet in length.

SPECIFIC GRAVITY AND WEIGHTS OF VARIOUS SUBSTANCES.

Name of Substance.	WEIGHTS. Per Cubic Foot.	Per Square Foot, 1 in. Thick.	Per Cubic Inch.	Specific Gravity
Water, Pure	62·3	5·19	·036	1·000
Water, Sea	64·3	5·36	·037	1·028
Platinum	1344	112·00	·777	21·52
Gold	1204	100·33	·697	19·25
Mercury	847	70·58	·490	13·59
Silver	656	54·66	·380	10·51
Bismuth..	618	51·50	·358	9·90
Aluminium	160	13·33	·092	2·56
Arsenic	360	30·00	·208	5·76
Wrought Iron ..	480	40·00	·277	7·70
Cast Iron	450	37·50	·260	7·20
Steel	490	40·84	·283	7·84
Lead	710	59.16	.410	11.36
Copper, Rolled ..	548	45.66	·317	8.80
Brass, Rolled ..	524	43.66	·302	8.40
Tin	453	37.78	·262	7·29
Best Babbitt Metal	497	41·47	·288	8.00
Anti-Friction Metal, Commercial quality	653	54·45	·378	10·50
Antimony	419	34·92	·242	6·71
Zinc	428	35·66	·248	6·86
Sand	98	8·23	·057	1·57
Brickwork, Common and Clay ..	120	10·00	·069	1.92
Brickwork, Close Joints	140	11·66	·081	2·24
Limestone	168	18·00	·124	2·68
Glass	156	13·00	·090	2.49
Concrete	137·5	11·45	·079	2.20
Pine, White	30	2.50	·017	·48
Pine, Yellow.. ..	35	2·91	.019	·56
Hornbeam	47·5	3·95	·027	·76
Lignum-Vitæ ..	83·3	6·94	·048	1·35

LOCOMOTIVE MEMORANDA FROM PRACTICE.

The life of a modern locomotive may be computed at from 20 to 30 years. During this period it will have been rebuilt once, and sometimes twice.

The life of a locomotive boiler will average from 8 to 10 years, during which time the engine will probably have run from 300,000 to 350,000 miles.

Boilers should be thoroughly examined and tested after running from 200,000 to 250,000 miles (5 to 6 years), and if retained in service, a further examination and test should take place when a further mileage equal to half above has been recorded.

Boilers should be primarily tested with hot water under hydraulic pressure and at least 50% above working pressure, and at all subsequent tests at not less than 10% above working pressure.

The life of a copper firebox is approximately about 5 to 9 years, but this must necessarily depend on many local circumstances, service the engine is engaged on, water and fuel used, etc.

The life of a set of steel tubes may be taken at 5 years, if taken out and pieced at the firebox end. When new, the tubes of a boiler should be examined after 6 to 9 months' service, a few of the lower rows being removed, cleaned and replaced; after 12 to 15 months' service, half the set should be removed, cleaned and replaced, and when 2 to 2½ years' working have been recorded the whole set will have to be removed and attended to.

Driving wheel tyres, of good quality steel, will run 50,000 miles before requiring to be re-turned.

Leading bogie wheels	do.	25,000 miles.
Carrying and tender wheels	do.	30 to 40,000 miles.

A shed day should be apportioned for every locomotive once per week, when the boiler should be thoroughly washed out, the firebox, firebars, smokebox cleaned trimmings and bearings attended to, etc.

Six pints of engine oil for general lubrication and 2 pints of cylinder oil per 100 miles run is a fair allowance for a 4-6-0 or 4-4-2 engine on medium duties.

RECORDED LOCOMOTIVE PERFORMANCES. No. 1.

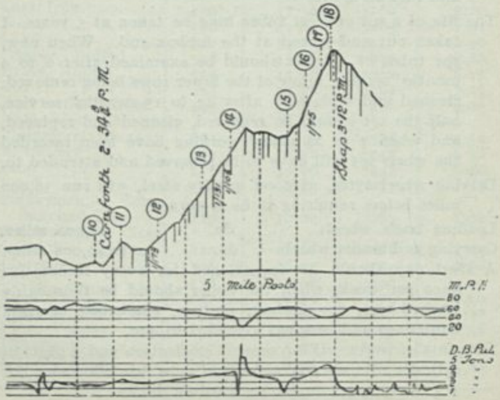
London & North-Western Rly. (now L.M.S.)

Crewe to Carlisle. Scotch Express ex Crewe 1.12 p.m., on 4th Nov., 1913.
Distance, 141 miles.
Train consisting of 10 coaches and one dynamometer car.
Locomotive, " Ralph Brocklebank," No. 1159.
Type 4-6-0 (superheater) with four Cyls., 16″ × 26″.

Coupled wheels	6′ 9″ diam.
Heating surface	1574 sq. ft.
Superheater surface	413·8 sq. ft.
Total	1987·8 sq. ft.
Grate area	30·5 sq. ft.
Boiler working pressure	175 lbs. per sq. in.
Adhesion weight	59 tons.
Train weight	360 tons.
Do., do., including engine & tender	477 tons.

Time occupied in journey, 142½ mins.
Mean speed in miles per hour, 59·4.

Profile of line - Carnforth to Shap



Mean draw-bar pull in tons, 1·83.

Mean draw-bar horse power, 663.

Indicator diagrams were taken at seventeen points. The average I.H.P. at these points was 1387 and the average draw-bar H.P. was 920, *i.e.*, D.H.P./I.H.P.=920/1387=·66.

Climbing the Shap is an interesting part of this journey, occupying 33 miles of the distance, and 37½ minutes of the time.

The profile of the line at this part, with the speeds and draw-bar pulls, is shown on the diagram herewith. At the points marked 10 to 18 indicator diagrams, etc., were taken and the resultant figures are given in the following table. The approach speed at Carnforth was 69½ m.p.p. and the summit speed 37½ m.p.p.

Point No.	Up Grade.	M.P.H.	D.B. pull.	D.H.P.	I.H.P.	D.H.P / I.H.P.
10	1 in 460	69½	$1\frac{7}{16}$ tons	572	1095	·522
11	,, 134	60½	$2\frac{13}{16}$,,	1015	1504	·675
12	,, 173	67	2⅜ ,,	950	1407	·675
13	,, 104	52½	3½ ,,	980	1494	·656
14	,, 131	47	3¼ ,,	996	1526	·652
15	,, 146	69	2⅝ ,,	1082	1669	·648
16	,, 75	58	3⅛ ,,	1082	1606	·673
17	,, 75	42½	$4\frac{5}{16}$,,	1094	1593	·686
18	,, 75	37½	5¼ ,,	1187	1498	·793

RECORDED LOCOMOTIVE PERFORMANCES No. 2.

(" Railway Engineer," April, 1906.)

Great Western Railway.

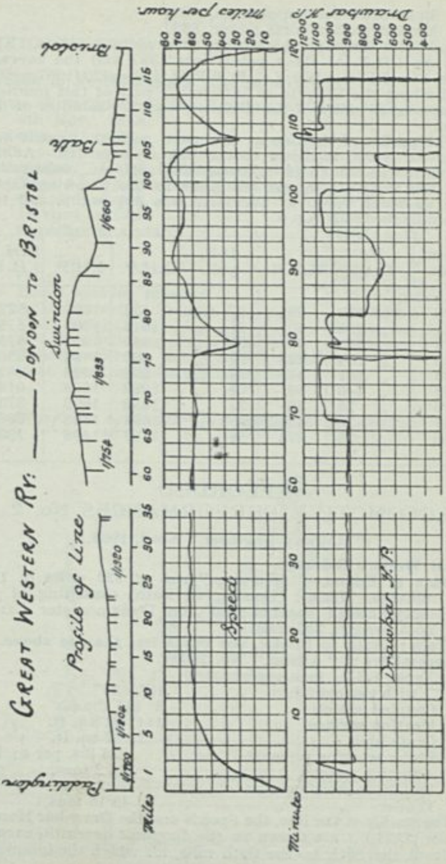
London to Bristol.—" Non-stop " run of 120 miles in 120 minutes. **Train :** London to Bath, consisting of 10 eight-wheeled coaches and one Dynamometer Car—Total weight, 337 tons.

Train : Bath to Bristol, one coach less than as above.

Locomotive : " Albion," No. 2971.

Type 4-6-0 (non-superheater) with two cylinders	18″×30″
Coupled wheels	6′ 8½″ diam.
Heating surface	2142·91 sq. ft.
Grate area	27·07 sq. ft.
Boiler working pressure	225 lbs. per sq. in.
Adhesion weight	54·2 tons.
Weight in working order	70·2 tons
Tender ,, ,,	43·15 tons.

The profile of the line, the Speeds and the Draw-bar Horse-power (D.H.P.) are shown on the diagrams herewith, except at from the 35th to the 60th mile, for which the following


Great Western Ry: —— London to Bristol
Profile of Line
Paddington
Swindon
Bath
Bristol
1/1320
1/1204
1/1754
1/833
1/660
Miles
Speed
Miles per hour
Drawbar H.P.
Minutes

note may suffice. From the 35th to 47th mile the speed was maintained at about 63 M.P.H., falling to 60 m.p.h. at the 60th mile. The D.H.P. was maintained at about 810 to the 44th mile, falling there to about 750 and rising at the 49th to 910 at which is continued to the 60th.

A speed of 60 m.p.h. was maintained over 70 consecutive miles on a rising grade with a maximum incline of 1 in 754. The maximum speed of 76 m.p.h. was attained on a down grade.

The "cut-offs" during the first four minutes, from the start from Paddington with 75·06%, was successively 50, 30·8, 28·6 and 20·8%. For the journey the prevailing notches were 18, 20·8 and 23·4%. At Bath, after lowering the speed in order to "slip" a coach, the notches were 30·8 and 23·4%.

The **Regulator** was "full open" during the run.

It will be noted that the **Accelerations** at starting from Paddington are approximately

0 to 25 m.p.h. in 2 minutes.
25 „ 50 „ „ 4 „
50 „ 60 „ „ 4 „

and from Bath

30 to 56 m.p.h. in 3 minutes.
56 „ 70 „ „ 4 „

The **Resistance per ton** (on the level) behind the tender at 60 m.p.h. is 14 lbs. and at 74 m.h.p. is 18 lbs.

I. Deduction from a series of Test Runs on the Great Western Railway by H. Kelway Bamber, M.V.O. (Proceedings Instn. Locomotive Engineers, 1926). The locomotive employed in these tests was the G.W.R. "Castle" class, 4-6-0 type, with a rated tractive force capacity of 31,629 lb. (14·12 tons).

Section	Miles	Weight.			Time Min.	Speed M.P.H av'age	Resistances.			H.P. mean	Est. Coal Consumpt.		
		E & T tons	Train tons	Total tons			E & T lb.	Train lb.	Total lb.		Total lb.	Per mile lb.	sq. ft. Grate lb.
Pad'dington Westbury	95·5	113	495	608	98	58·48	3,560	6,435	9,995	1,559	4,887	50·65	97·5
Westbury Taunton	47·5	112	423	535	50	56·98	3,416	5,287	8,603	1,310	2,074	43·66	80·0
Taunton Exeter	30·75	111	364	475	32	57·64	3,408	4,680	8,088	1,222	1,238	40·26	81·0
Exeter Plymouth	52·75	110	293	403	67	47·25	2,750	4,130	6,880	855	1,813	34·71	54·3
Total ..	226·5				247						10,012	44	80·02

The H.P. is calculated by the formula H.P. $= \frac{R \times m.p.h.}{375}$ thus $\frac{9995 \times 58{\cdot}48}{375} = 1559$.

The coal consumption from Paddington to Westbury calculated from an allowance of 2 lb. per H.P. less 5 per cent. for coasting, etc., thus $1559 \times 2 \times \frac{98}{60} = 4887$ lbs. or 10,012 lbs. for the whole trip.

The coal consumption per sq. ft. of grate (the grate being 30·28) is calculated from the coal consumption per section, thus $\frac{4887}{30{\cdot}28} = 97{\cdot}5$ lbs. per hour, from Paddington to Westbury.

The actual coal consumption for the whole journey was 10,080 lb. (4·5 tons).

II. Deductions from a series of tests on the London and North Eastern Ry. by H. Kelway Bamber, M.V.O. (Proceedings Instn. Locomotive Engineers, 1926). The locomotive employed, G.W.R. "Castle" class, had the same rated tractive force as that used on the Paddington-Plymouth runs above referred to.

Section.	Miles.	Weight of Train. Tons.	Time. Min.	Speed, M.P.H. average.
King's Cross } Peterboro'	76·25	457	83	54·59
Peterboro' } Grantham	29·25	457	36	48·82
	105·5	—	119	53·19

The coal (best Yorks.) consumption for the out and home journeys was 5·35 tons., or an average of 2·675 tons (5,992 lbs.) for the single run of 105·5 miles.

Section.	Coal Consumption.		
	Per mile. lbs.	Per sq. ft. Grate. lbs. per hr.	H.P. at 2 lbs. per. H.P.
King's Cross } Grantham	56·8	103·5	1567·5

Boiler H.P., on a rating of 2,049 sq. ft. evaporative surface at 12 lbs. steam per sq. ft. per hour, the total evaporations is 24,588 lbs. of steam, and allowing 21 lb. per H.P., the total H.P. would be 1,171. (For development of 1,567·5 H.P. it would require a rate of 15·9 lb. steam per sq. ft. of evaporative surface).

FASTEST RUNS ON BRITISH RAILWAYS, 1927.

Railway.	Section.	Train.	From	To	Distance miles.	Time min.	Speed m.p.h.
G.W.R. ..	—	3-45 p.m.	Swindon	Paddington	77 ·3	75	61 ·8
L. & N.E.R.	N.E.	9-1 p.m.	Darlington	York	44 ·1	43	61 ·5
"	G.C.	4-30 a.m.	Leicester	Arkwright St., Nott'm	22 ·6	22	61 ·5
L.M. & S.R.	L. & N.W.	9-21 a.m.	Will'den J.	Birm'gham	107 ·5	109	59 ·2
L.M. & S.R.	Midland	9-4 a.m.	Luton	Kettering	41 ·8	43	58 ·3
L. & N.E.R.	G.N.	9-44 a.m.	Grantham	Kings Cr'ss	105 ·5	111	57 ·0
Southern R.	L. & S.W.	3-22 p.m.	Salisbury	Surbiton	71 ·7	77	55 ·9
G.N.R. (I) ..	—	6-45 a.m.	Dublin	Drogheda	31 ·8	35	54 ·5
L.M. & S.R.	Caledonian	6-13 a.m.	Perth	Aberdeen	89 ·8	99	54 ·4
Southern R.	S.E. & C.	8-27 a.m.	Redhill	Tonbridge Junc.	19 ·6	22	53 ·4
L.M. & S.R.	G. & S.W.	10-54 p.m.	Thornhill	Dumfries	14 ·2	16	53 ·3
G.S. Rys.	G.S.W.R.	6-42 p.m.	Maryboro'	Kingsb'dge	51	58	52 ·7
L. & N.E.R.	G.E.	10-19 p.m.	Shenfield	Prittlewell	20 ·7	24	51 ·8
"	N.B.	12-28 p.m.	Falkirk	Edinburgh (Waverley)	25 ·5	29	52 ·7
Southern R.	L.B. & S. C.	10-46 a.m.	Redhill	Hayw'ds H.	17 ·0	19	53 ·7
L.M. & S.R.	L. & Y.	4-47 p.m.	Hellifield	Chatburn	11 ·6	14	49 ·7
M. & G.N.R.	—	Several	Fakenham	South Lynn	22 ·2	30	44 ·4
L. & N.E.R	G.N. of S.	9-8 p.m.	Dufftown	Aberdeen	64	82	46 ·8
S. & D.J.R.	—	3-35 p.m.	Evercreech Junction	Blandford	26 ·4	33	48 ·0
L.M. & S.R.	N.C.C.	12-29 p.m.	Greenisland	Portstewart	58 ·2	77	45 ·3
B. & C.D.R.	—	12-0 noon	Belfast	Newcastle	37 ·5	50	45
L.M. & S.R.	Highland	11-14 a.m.	Pitlochry	Perth	28 ·5	39	43·8
G.S. Rys.	M.G.W.R.	2 trains	Mullingar	Dublin Broadstone	50 ·3	75	40 ·2

LONDON, MIDLAND & SCOTTISH RAILWAY.

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup. ft.	Wheelbase Coup. ins.	Wheelbase Total. ft.	Wheelbase Total. ins.	Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press	Weight adh.	Weight total	Tender gals.	Tender fuel	Tender wgt.
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
66	5450	L.N.W.	4-6-0	19 × 26	75	13	7	26	8½	133	1780	—	25	175	46·75	65·75	3000	5	37
819	5600	L.N.W.	,,	20½ × 26	75	13	7	26	8½	136	1376	304	25	175	46·75	66·2	3000	6	39·2
2222	5900	L.N.W.	,,	(4) 15¾ × 26	81	15	3	29	0	174	1574	379	30·5	175	59·0	77·75	3000	6	39·2
285	8700	L.N.W.	,,	19 × 26	62½	13	7	26	8½	144	1764	—	25	175	44·2	63	3000	5	37
—	10447	L.M.S.	,,	(4) 16½ × 26	75	13	7	25	7	176	1717	430	27	180	59·3	79	3000	6	40
—	10455	L.M.S.	,,	(4) 16½ × 26	75	13	7	26	7	180	1817	430	29·6	180	58·6	77·9	3000	6	40
55	14600	C.R.	,,	19 × 26	60	11	3	23	9½	105	1800	—	20·6	175	42·8	57·4	3000	4½	37·3
191	14619	C.R.	,,	19½ × 26	66	12	4	24	9	116	1707	—	21·9	185	45·8	62·75	3000	4½	37·8
903	14752	C.R.	,,	20¾ × 26	78	14	8	28	9	148	1666	515	26	175	55·75	74·25	5000	5	57
60	14650	C.R.	,,	20 × 26	73	14	6	27	6	146	1529	258	25·5	175	56·5	75	4200	6	46·5
956	14800	C.R.	,,	(3) 18½ × 26	73	15	0	28	8	170	2200	270	28	180	60	81	4500	5½	48
179	17905	C.R.	,,	19½ × 26	69	13	4	26	1½	128	1439	403	21	170	51	68 5	3570	5	38
512	14673	G.& S.W	,,	21 × 26	78	15	0	27	11	130	1430	445	24·5	160	51·6	69·1	4100	4	50
495	14656	G.& S.W.	,,	20 × 26	78	15	0	27	8	131	1721	—	24·5	175	51·1	67·1	4100	4	50
140	14675	H.R.	,,	19½ × 26	69	14	3	26	3	134	1916	—	26·5	175	44·8	59·9	3350	5	44·4
50	14691	H.R.	,,	19½ × 26	72	14	6	26	7½	132	1916	—	25·5	175	45·8	60·65	4000	6½	46·3
49	14762	H.R.	,,	21 × 26	72	14	0	25	9	139	1328	—	25·5	175	45·5	62·2	3500	7	42
—	6100	L.M.S.	4-6-0	(3) 18 × 26	81	15	4	27	6	189	1892	445	31·2	250	62·5	84·9	3500	5	42·2
34	17800	C.R.	2-6-0	19½ × 26	60	16	9	24	0	119	1071	267	20·6	160	46·1	54·25	3000	4½	37 25
51	17820	G.& S.W.	,,	19½ × 26	60	17	1	23	7	147	1344	211	26·25	180	54·35	62	3800	6	47·3
—	13000	L.M.S.	,,	21 × 26	66	16	6	25	6	160	1361	307	27·5	180	55·5	65·5	3500	5	42·2

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total.		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press	Weight adh.	Weight total	Tender gals.	Tender fuel	Tender wgt.
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	tons	tons	gals.	tons	tons
1000	1000	M.R.	4-4-0	(3) $\frac{19}{21}$ ×26	84	9	6	24	4½	147	1181	291	28·4	200	39·2	61·7	3500	7	45·9
—	1065	L.M.S.	,,	(3) $\frac{19}{21}$ ×26	81	9	6	24	4½	147	1181	291	28·4	200	39·2	61·7	3500	5½	42·7
999	999	M.R.	,,	20½×26	78½	9	6	24	4½	147	1181	291	28·4	180	39	60·25	3500	7	45·9
483	483	M.R.	,,	20½×26	84½	9	6	22	8½	123	1044	253	21·1	160	34·5	53·3	3250	4	39·8
513	5278	L.N.W.	,,	19 ×26	81	10	0	25	1½	161	1728	—	22·4	185	38	59·75	3000	5	37
2663	5320	L.N.W.	,,	20½×26	81	10	0	25	1½	165	1313	285	22·4	175	38·25	59·85	3000	6	39·25
132	10187	F.R.	,,	18 ×26	72	8	6	21	9½	107	1139	—	20·5	170	31 3	47·6	3300	5	37
72	14477	C.R.	..	20½×26	78	9	9	24	4	144	1185	200	20·7	180	39·75	61·25	4200	5	46·5
113	14461	C.R.	,,	20 ×26	78	9	9	24	4	144	1185	200	20·7	175	39·75	61·25	4200	5	46·5
325	14516	G.&S.W.	,,	19½×26	72	10	0	24	9	148	1444	330	27·6	180	39·9	61·85	3800	6	47·3
73	14522	H.R.	,,	20 ×26	75	8	9	22	11½	124	1013	180	22·5	175	34·2	54·95	3500	7	43·15
1400	10300	L.Y.R.	4-4-2	19 ×26	87	7	6	27	9	171	1540	—	23	180	35	58·75	2290	5	30·65
3835	3835	M.R.	0-6-0	20 ×26	63	16	6	16	6	123	1044	253	21·1	175	48·75	48·75	3500	4	41·2
130	12083	L.Y.R.	,,	18 ×26	61	16	4	16	4	108	943	—	18·75	180	42·15	42·15	1800	3	26·1
1	12557	L.Y.R.	,,	20½×26	61	16	4	16	4	107	790	195	18·75	180	46·5	46·5	1800	3	26·1
19	12500	F.R.	,,	18 ×26	55½	15	6	15	6	107	1139	—	20·5	170	44·85	44·85	3300	5	37·45
30	17646	C.R.	,,	19½×26	60	16	9	16	9	119	1071	267	20·6	160	51·1	51·1	3000	4½	37·9
294	17650	G.&S.W.	,,	18½×26	60	16	9	16	9	119	1333	—	20	170	49·25	49·25	3000	4½	37·25
71	17750	G.&S.W.	,,	19½×26	60	17	1	17	1	148	1637	—	26·25	180	57·75	57·75	3800	6	47·3
134	17693	H.R.	,,	18½×26	60	16	6	16	6	115	1060	—	20·3	175	43	43	3200	5	40

Old No.	New No.	Section	Type	Cylinders	Coup Wheels	Wheelbase				Heating Surface			Grate	Boiler Pres.	Weight		Tender		
				Diam. × Stroke		Coup.		Total.		F'box	Tubes	Supr.							
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wg. tons
1648	12968	L.&Y.	0-8-0	21½ × 26	54	16	4	16	4	192	1656	430	25 ·5	180	66 ·2	66 ·2	3600	5	41 ·45
1471	12761	L.&Y.	,,	(4)15½ × 26 22	54	16	4	16	4	155	1540	—	23	180	60 ·8	60 ·8	3600	5	41 ·45
325	12700	L.&Y.	,,	20 × 26	54	16	4	16	4	155	1540	—	23	180	53 ·75	53 ·75	3600	5	41 ·45
2178	9454	L.N.W.	,,	20½ × 24	53½	17	3	17	3	149	1538	358	23 ·6	175	62	62	3000	6	40 ·75
1866	9002	L.N.W.	,,	19½ × 24	53½	17	3	17	3	147	1896	—	23 ·6	175	56 ·25	56 ·25	3000	5	37
600	17990	C.R.	,,	21 × 26	54	22	4	22	4	138	1970	—	23	175	60 ·6	60 ·6	3570	4½	41
2290	2290	M.R.	0-10-0	(4)16¾ × 26	55½	20	11	20	11	158	1560	445	31 ·5	180	73 ·65	73 ·65	2050	4	31 ·55
380	7930	L.N.W.	0-8-4T	20½ × 24	53½	17	3	29	3	149	1538	358	23 ·6	185	66 ·5	88	2030	3½	Tank
—	11110	L.M.S.	4-6-4T	(4)16½ × 26	75	13	7	40	4	180	1817	430	29 ·6	180	56 ·5	99 ·95	2000	3½	,,
2100	2100	M.R.	,,	20 × 26	75	13	10	38	10½	123	1173	319	25	160	53 ·65	94 ·6	2200	3	,,
540	15400	G&S.W.	,,	22 × 26	72	13	2	39	0	156	1574	255	30	180	54	99 ·1	2400	3½	,,
115	11100	F.R.	,,	19½ × 26	68	13	3	40	9	153	1850	—	26	170	54 ·9	92 ·75	2200	4	,,
2665	6950	L.N.W.	4-6-2T	20 × 26	68½	14	0	33	9	140	947	231	23 ·9	175	44	77	1700	3	,,
944	15350	C.R.	,,	19½ × 26	69	13	3	33	1	121	1395	200	21 ·5	170	55 ·1	91 ·65	1800	3	,,
528	6780	L.N.W.	4-4-2T	19 × 26	75	10	0	32	7½	161	1706	—	22 ·4	175	39 ·5	74 ·75	1705	2½	,,
8	2180	N.S.	,,	20 × 26	72	9	6	31	1½	132	878	194	21 ·2	170	37 ·2	70 ·5	2000	3½	,,
114	2048	N.S.	0-6-4T	20 × 26	66	16	0	27	9	130	878	194	21 ·2	170	55 ·85	77 ·35	2250	3½	,,
356	10950	L.Y.R.	2-4-2T	20½ × 26	68	8	7	24	4	107	691	191	18 ·75	180	39 ·25	66 ·45	1540	3	,,
—	7100	L.M.S.	0-6-0T	18 × 26	55	16	6	16	6	97	977	—	16 ·0	160	50 ·2	50 ·2	1200	2½	,,

LONDON AND NORTH-EASTERN RAILWAY.

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press.	Weight		Tender		
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
1470	4470	G.N.	4-6-2	(3)20 ×26	80	14	6	35	9	215	2715	525	41 ·2	180	60	92 ·4	5000	8	56 ·3
2400	2400	N.E.	,,	(3)19 ×26	80	15	0	37	2	200	2164	501	41 ·5	200	60	101 ·5	4125	5½	46 ·6
1169	6169	G.C.	4-6-0	(4)16 ×26	81	15	6	28	10	163	1881	343	26	180	57 ·1	79 ·1	4000	6	48 ·3
423	5423	,,	,,	21½ ×26	81	15	6	28	10	163	2020	294	26	180	57 ·5	75 ·2	4000	6	48 ·3
416	5416	,,	,,	21 ×26	68	15	3	27	6	174	1641	308	26 ·2	180	53 ·9	72 ·9	4000	6	48 ·3
72	5072	,,	,,	(4)16 ×26	68	14	5	28	3	163	1881	343	26 ·2	180	58 ·5	79 ·5	4000	6	48 ·3
195	5195	,,	,,	21 ×26	81	14	6	26	9½	133	1818	—	26 ·2	180	55 ·2	71 ·0	4000	6	48 ·3
1105	6105	,,	,,	19 ×26	64	14	0	26	1½	133	1818	—	25 ·7	180	52 ·1	67 ·3	4000	6	48 ·3
1500	8500	G.E.	,,	20 ×28	78	14	0	28	6	144	1489	286	26 ·5	180	43 ·4	63 ·0	3700	4	38 ·3
2111	2111	N.E.	,,	20 ×26	80¼	15	2	27	6	120	1336	294	23 ·0	175	51 ·9	67 ·1	4125	5	41 ·1
782	782	,,	,,	20 ×26	73¼	14	0	26	0½	140	1229	361	23 ·0	175	53 ·9	71 ·1	4125	5	44 ·0
840	840	,,	,,	(3)18½ ×26	68	13	6	27	8	166	1400	392	27 ·0	180	58 ·7	77 ·7	4125	5½	46.1
1650	4650	G.N.	2-6-0	20 ×26	68	16	3	25	2	152	1477	305	24 ·0	180	53 ·4	63 ·7	3500	6½	43 ·1
1630	4630	,,	,,	20 ×26	68	16	3	24	10	135	943	230	24 ·5	180	51 ·7	61 ·7	3500	6½	43 ·1
1000	4000	,,	,,	(3)18½ ×26	68	16	3	25	2	182	1719	407	28 ·0	180	60 ·0	71 ·7	3500	6½	43 ·1
868	9868	N.B.	4-4-2	21 ×28	81	7	3	27	9½	184	1619	263	28 ·5	180	40 ·0	76 ·7	4240	7	45 ·4
1452	4452	G.N.	,,	20 ×24	80	6	10	26	4¼	141	1882	427	31 ·0	170	40 ·0	69 ·6	3500	6½	43 ·1
990	3990	,,	,,	19 ×24	80	6	10	26	4¼	135	981	254	24 ·5	170	32 ·2	60 ·0	3500	6½	43 ·1
271	3271	,,	,,	18½ ×26	80	6	10½	27	6	135	981	254	24 ·5	170	33 ·4	58 ·7	3670	5	40 ·9
251	3251	,,	,,	19 ×24	80	6	10	26	4¼	141	1882	427	31 ·0	170	40 ·0	69 ·6	3500	6½	43 ·1

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press.	Weight		Tender		
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
292	3292	G.N.	4-4-2	4 { 13 × 20 / 16 × 26	80	6	10	26	4	141	2337	—	31 ·0	200	40 ·0	69	3670	5	40 ·9
2212	2212	N.E.	,,	(3) 16½ × 26	82	7	7	29	6	185	1298	392	27	175	40 ·7	79 ·2	4125	5½	46 ·6
532	532	,,	,,	20 × 28	82	7	7	28	0	180	1298	392	27	175	40 ·2	76 ·2	4125	5	45 ·6
730	730	,,	,,	4 { 14¼ × 26 / 22 × 26	85¼	7	6	28	9	180	1345	271	29	200	39 ·4	73 ·2	3800	5	44 ·2
258	5258	G.C.	,,	(3) 19/21 × 26	81	7	3	27	9½	154	1349	242	26	180	37 ·0	73 ·3	4000	5	48 ·3
192	5192	,,	,,	20 × 26	81	7	3	27	9½	154	1349	242	26	180	37 ·0	71 ·9	4000	6	48 ·3
506	5506	,,	4-4-0	20 × 26	81	10	0	25	3	155	1388	209	26 ·5	180	39 ·8	61 ·1	4000	6	48 ·4
429		,,	,,	20 × 26	81	10	0	25	3	155	1388	209	26 ·5	180	39 ·6	61	4000	6	48 ·4
258	9258	N.B.	,,	20 × 26	72	9	6	23	7	139	1013	192	21	180	37 ·1	57 ·2	4235	7	46 ·6
1850	8850	G.E.	,,	19 × 26	84	9	0	23	6	118	1158	155	21 ·6	180	34 ·0	52 ·0	3450	5	39 ·2
2011	2011	N.E.	,,	19 × 26	82	9	6	23	9	139	975	204	20	160	35 ·5	54 ·1	4135	5	41 ·2
—	234	L.N.E.	4-4-0	(3) 17 × 26	80	10	0	24	11	171·50	871·50	354·3	26	180	42	66	4200	7½	52·7
1013	6013	G.C.	4-4-0	19 × 26	81	9	9	23	10¾	141	1238	154	21	180	35 ·2	55 ·7	4000	6	48 ·3
47	6847	G.N.S.	,,	18 × 26	73	8	9	21	9½	106	754	140	18·24	165	33 ·4	48 ·7	3000	5	37 ·7
1326	4326	G.N.	,,	17½ × 26	80	9	0	22	0	120	1130	—	19 ·0	175	31 ·0	47 ·5	3670	5	40 ·9
1270	8270	G.E.	0-6-0	20 × 28	59	18	10	18	10	144	1489	202	26 ·5	180	54 ·8	54 ·8	3500	5	38 ·3
88	9088	N.B.	,,	19½ × 26	60	16	11	16	11	149	1094	176	19 ·8	180	54 ·7	54 ·7	3500	7	40 ·9

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press	Weight		Tender		
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
1150	8150	G.E.	0-6-0	19 × 26	59	17	8	17	8	107	1516	—	21·3	180	44·5	44·5	3500	5	38·2
1014	1014	N.E.	,,	18½ × 26	55½	16	6	16	6	136	943	—	20	180	49·5	49·5	3000	3½	37·6
901	901	N.E.	0-8-0	(3) 18½ × 26	55½	18	6	18	6	166	1663	392	27	180	71·6	71·6	4125	5½	44·1
1247	1247	,,	,,	20 × 26	55½	17	2	17	2	140	1229	361	24	180	65·9	65·9	4125	5½	44·1
2116	2116	,,	,,	20 × 26	55¼	17	2	17	2	120	1436	—	21·0	175	61·1	61·1	4125	5	40·9
1052	6052	G.C.	,,	19 × 26	56	17	1	17	1	140	1665	—	23·6	180	63·0	63·0	4000	6	48·3
401	3401	G.N.	,,	20 × 26	56	17	8	17	8	137	1302	—	24·5	175	55·7	55·7	3670	5	40·9
117	3117	H.&B	,,	19 × 26	54	16	6	16	6	133	1728	—	22	175	61·5	61·5	3300	4	29·4
477	3477	G.N.	2-8-0	(3) 18½ × 26	56	18	6	27	2	163	1868	430	27·5	180	67·3	75·8	3500	6½	43·1
461	3461	,,	,,	(3) 18 × 26	56	18	6	26	4	163	1868	430	27·5	180	66·6	76·4	3500	6½	43·1
412	5412	G.C.	,,	21 × 26	56	17	1	25	5	174	1641	308	26·2	180	67·9	75·2	4000	6	48·3
1350	1350	N.E.	4-8-0	(3) 18 × 26	37¼	15	3	29	0	127	1168	—	23	175	67·6	85·4	2500	4¼	Tank E.
1170	6170	G.C.	0-8-4	(3) 18 × 26	56	17	1	30	8	154	1818	—	26·2	180	75·6	99·0	3000	5	,,
3	5003	,,	4-6-2	20 × 26	67	13	0	32	9	141	1238	145	21	180	54·0	85·9	2280	4½	,,
1002	8002	G.E.	0-6-2	18 × 24	58	16	3	23	0	113	1281	—	17·7	180	49·2	61·6	1600	3¾	,,
1721	4721	G.N.	,,	19 × 26	68	16	3	23	9	118	880	208	19	170	55·7	70·5	2000	4	,,
858	9858	N.B.	,,	18 × 26	54	15	6	22	6	95	1214	—	16·6	175	49·2	62·8	1630	4½	,,
438	9438	,,	4-4-2	19 × 26	69	8	3	28	11½	95	913	220	16·6	165	37·3	72·5	2080	4½	,,

Old No.	New No.	District	Type	Cylinders Diam. × Stroke	CoupWheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press.	Weight		Tender			No.
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons	
6000		G.W.	4-6-0	(4)16¼×28	78	16	3	29	5				34·3	250	67·5	89	4000	6	46·7	6000
4046		,,	4-6-0	(4)15 ×26	80½	14	9	27	3	154	1686	263	27·1	225	55·4	75·6	3500	6	40	4046
4073		,,	,,	(4)16 ×26	80½	14	9	27	3	164	1885	263	30·2	225	58·8	79·8	3500	6	40	4073
	2931	,,	,,	18½×30	80½	14	9	27	1	154	1686	263	27·1	225	54·8	72	3500	6	40	2931
100	2900	,,	,,	18 ×30	80½	14	9	27	2	154	1686	263	27·1	225	52·5	67·8	4000	5	43·1	2900
171	2971	,,	,,	18 ×30	80½	14	0	27	3	154	1686	263	27·1	225	54·2	70·2	4000	5	43·1	2971
33	2600	,,	2-6-0	18 ×26	55½	15	0	22	6	128	1350	192	20·5	200	49·6	56·7	3000	6	36·7	2600
97	2800	,,	2-8-0	18½×30	55½	16	10	25	7	154	1686	263	27·1	225	67·5	75·5	3500	6	40·0	2800
4331		,,	2-6-0	18½×30	68	14	9	23	6	128	1350	192	20·5	200	52·0	62	3500	6	40	4331
4300		,,	,,	18½×30	68	14	9	23	6	128	1350	192	20·5	200	52·0	62	3500	6	40	4300
102		,,	4-4-2	4)13⅜/20¼ ×25 3/16	80½	7	0⅝	27	10⅝	154	1686	263	27·1	225	34·7	68·4	3500	6	40	102
103		,,		4)14 3/16/23⅝ ×25 3/16	80½	7	0⅝	28	6½	154	1686	263	27·1	225	38	70·7	3500	6	40	103
3473	3800	,,	4-4-0	18 ×30	80½	8	6	24	0	128	1350	192	20·5	200	37·6	58·8	3500	6	40	3800
4120	4168	,,	,,	18 ×26	80½	8	6	22	6	122	1145	82	20·3	195	35·7	53·3	3500	6	40	4120
4700		,,	2-8-0	19 ×30	68	20	0	29	3	169	2062	289	30·2	225	73·4	82	3500	6	40	4700
	G.W.																			
79	1380	Barry	0-8-2	20 ×26	52	15	5	22	11	115	1285	—	22·7	160	59·6	73·0	2100	3½	Tank E	1380
11	3600	G.W.	2-4-2	17 ×24	62	8	6	24	0	122	1039	100	20·3	195	35·0	66·6	1900	—	,,	3600
3	=438	as 356 except Boiler Pressure=160																		
123	356	Taff Vale	0-6-2	18½×26	63	14	6	20	7	100	1219	—	18·3	175	57·6	69·0	1700	2½	,,	356
42	=439	as 438																		
4500		G.W.	2-6-2	17 ×24	55½	11	6	26	10	94	1020	78	16·6	200	43·5	57·9	1000	3	,,	4500
5600			0-6-2	18 ×26	55½	15	3	21	9	122	1145	82	20·3	195	55·6	68·6	1900	3½	,,	5600

SOUTHERN RAILWAY.

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press.	Weight		Tender		
				ins.	ins	ft.	ins.	ft	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
482	E 482	L.S.W.	4-6-0	21 × 28	72	13	9	26	7½	167	1716	308	30	180	60·4	81·2	5200	5	57 7
496	E 496	,,	,,	21 × 28	67	13	9	26	7½	162	1716	308	30	180	59·8	79·8	5000	5	57·6
335	E 335	,,	,,	21 × 28	72	14	4	27	2½	162	1716	308	31·5	175	59·5	82·1	4500	5	48·6
458	E 458	,,	,,	(4)15 × 26	79	14	4	27	8	158	1280	269	31·5	175	53·2	75·8	5800	5	60·4
737	E 737	,,	,,	22 × 28	79	14	6	27	6	162	1716	308	30	180	58·3	80·3	5000	5	57·8
	E 850	S.E.&C.	,,	(4)16 × 26	79	15	0	29	6	194	1795	376	33	220	61·19	83·10	5000	5	56·14
337	B 337	L.B.S.C.	2-6-0	21 × 26	66	15	6	23	9	139	1156	279	24·8	170	55·5	64·0	3940	4	41·5
822	A 822	S.E.&C.	,,	(3)16 × 28	66	15	6	24	4	135	1390	285	25	190	53	62·7	3500	5	39·3
810	A 810	,,	,,	19 × 28	66	15	6	24	4	135	1390	285	25	200	50·9	59·4	3500	5	39·3
37	B 37	L.B.S.C.	4-4-2	18½ × 26	79½	6	10	26	4	137	2333	—	31	200	37·2	68·2	3500	4	39·2
179	A 179	S.E.&C.	4-4-0	19 × 26	78	9	6	23	6⅛	127	1150	228	24	180	34·6	53·4	3450	4½	39·0
760	A 760	,,	,,	20½ × 26	80	10	0	24	3½	160	1252	254	22·5	160	37·7	57·4	3450	4	40·3
415	E 415	L.S.W.	,,	19 × 26	79	10	0	23	3	161	993	195	24	175	36·5	55·2	4000		44·8
42	B 42	L.B.S C.	,,	19 × 26	81	8	9	22	2	120	1506	—	23·7	180	35·4	51·5	3000	4	35·2
492	E 492	L.S.W.	4-8-0	22 × 28	61	18	0	32	0	139	1267	231	27	180	72·9	95·1	2000	3½	Tank
516	E 516	L.S.W.	4-6-2	21 × 28	67	15	0	36	6	139	1267	231	27	180	59	96·4	2000	3½	E.
790	A 790	S.E.&C.	2-6-4	19 × 28	72	15	0	35	10	135	1390	285	25	200	52·7	82·6	2000	2½	,,
327	B 327	L.B.S.C.	4-6-4	22 × 28	81	14	9	40	0	152	1535	383	26·7	170	56·7	98·5	2700	3½	,,
696	A 696	S.E.&C.	0-4-4	17½ × 24	66	7	6	21	10	100	971	—	16·2	155	31·3	51·4	1100	2½	,,

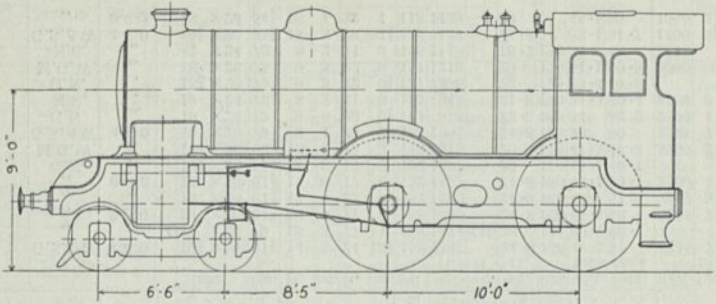
METROPOLITAN RAILWAY.

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup. ft.	Wheelbase Coup. ins.	Wheelbase Total ft	Wheelbase Total ins.	F'box	Tubes	Supr.	Grate	Boiler Press.	adh. tons	total tons	gals.	fuel tons	wgt. tons
103			4-4-4	19 × 26	69	7	9	33	6	132	1046	268	21·4	160	39	77	2000	4½	Tank
111			2-6-4	19 × 28	66	15	6	36	7	135	1390	285	25·0	200	54·7	87·6	2000	4	E

IRELAND (5 ft. 3 in. gauge).

Old No.	New No.	Section	Type	Cylinders Diam. × Stroke	Coup Wheels	Wheelbase Coup.		Wheelbase Total		Heating Surface F'box	Heating Surface Tubes	Heating Surface Supr.	Grate	Boiler Press.	Weight		Tender		
				ins.	ins.	ft.	ins.	ft.	ins.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	adh. tons	total tons	gals.	fuel tons	wgt. tons
365		G.S.&W	4-6-0	19¼ × 26	61¾	14	6	24	10½	153	1467		24·8	160	44·2	57	3345	7	36·1
		,,	,,	(4) 14 × 26	79	15	3	27	1	158	1614	440	28	175	50·7	68·7			
371		,,	2-6-0	19 × 26	61¾	16	0	21	0	138	1446		24·8	160	45·4	53	3345	7	32·5
355		,,	,,	19 × 26	61¾	17	0	22	0	132	1493		24·8	160		51	3500	5	34
355		,,	0-6-0	19 × 26	61¾	17	0	17	0	132	1403		24·8	160	49·1	49·1	3300	5	34
160		G.N.	,,	18½ × 26	55¼	16	8	16	8	122	1397		20	175	45·1	45·1			
143		M.G.W.	,,	18½ × 26	63	16	3	16	3	140	1213		20	175	47·5	47·5	3000	5	35·7
341		G.S.&W	4-4-0	19 × 26	79	9	1	24	2	135	1365		24·8	175	38	60	3345	7	36·1
174		G.N.	,,	19 × 26	79	9	6	23	0½	141	975		22·9	165	34	52·2	2500	4	30·5
28		N.C.	,,	19 × 24	72	8	2	21	3	123	1045		21·8	170	34·3	50·4	2500	5	32·8
113		G.N.	,,	18½ × 26	79	9	3	22	6½	137	1398		22	175	33·4	49·5			
129		M.G.W.	,,	18 × 26	75	9	3	22	6	151	1213		20	175	34·1	50·9	3000		36·1
65		N.C.	,,	18/28 × 24	72	8	2	21	3	108	1146		18·2	190	30	48	2090		26
1		G.S.&W	4-8-0	19¼ × 26	54¼	15	3	29	1¼	138	1426		24·8		63·4	81·7	1500	3½	Tank
211		,,	0-6-2	18 × 26	54½	16	1	22	1	118	1129	—	20		45·1	56	1050	2	E ,,

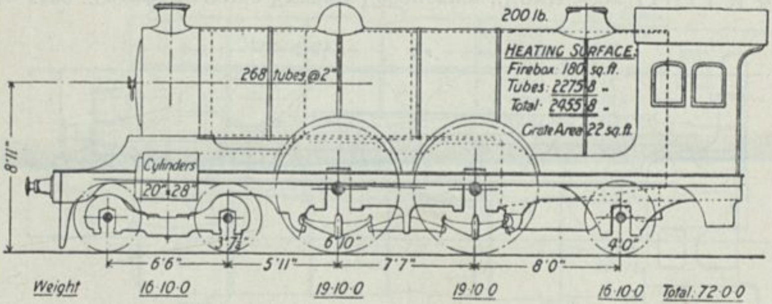
4-4-0 Type.



No 234. THREE-CYLINDER PASSENGER LOCOMOTIVE, "SHIRE" CLASS, L & N.E.R.

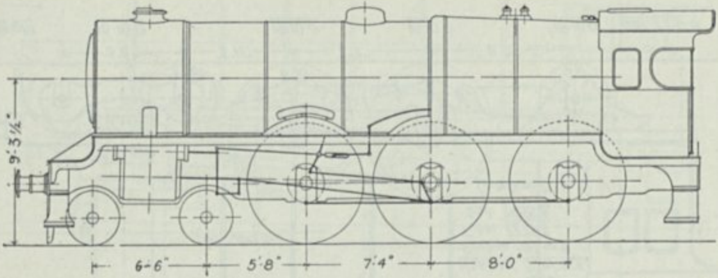
Cylinders (3): 17 in. dia. × 26 in. piston stroke. Piston valves (8 in. dia) driven by Walschaerts gear in conjunction with Gresley's patent system for the inside cylinder. Some of these engines to be fitted with Lentz patent poppet valves. Wheels: Coupled, 6 ft. 8 in. dia.; bogie, 3 ft. 1½ in. dia. Heating surface: Firebox, 171·50 sq. ft.; tubes, 871·50 sq. ft; flues, 354·53 sq. ft. Total evaporative H.S., 1,397·78 sq. ft. Superheating surface, 246·1 sq. ft. Grate area, 26 sq. ft. Working Pressure, 180 lbs./sq. in. Weight in working order, 66 tons. Adhesion weight, 42 tons.

4-4-2 Type.



Express Locomotive No. 532, N.E. Section, L. & N E.R.

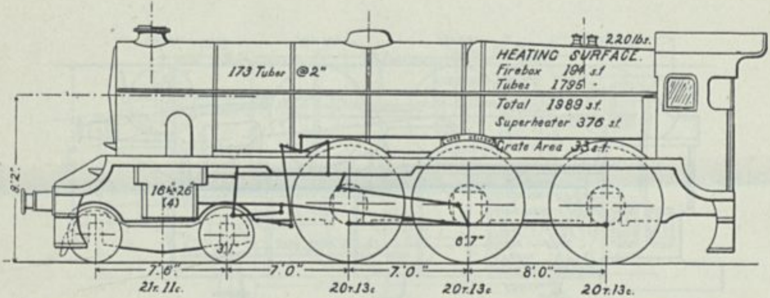
4-6-0 Type.



No. 6100. THREE-CYLINDER EXPRESS LOCOMOTIVE, "ROYAL SCOT" CLASS, L.M. & S. RY.

Cylinders (3), 18 in. dia. × 26 in. piston stroke. Piston valves driven by three independent sets of Walschaerts gear. Coupled wheels, 6 ft. 9 in. dia. Heating surface: Firebox, 189 sq ft.: tubes and flues, 1,892 sq. ft. Total evaporative H.S., 2,081 sq. ft. Superheating surface, 445 sq. ft. Grate area, 31·2 sq. ft. Working pressure, 250 lbs./sq. in. Weight in working order, 84 tons 18 cwt. Adhesion weight, 62 tons 10 cwt.

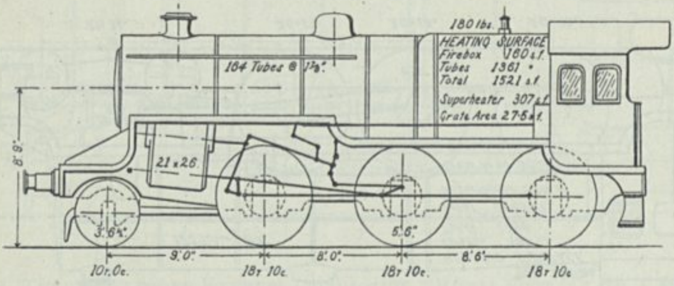
4-6-0 Type.



No. E850, "Lord Nelson," Four-Cylinder Express Locomotive, Southern Railway.

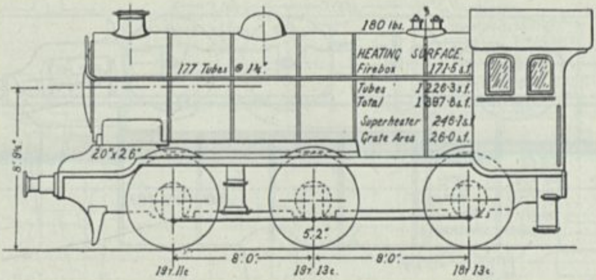
Cylinders (4), 16 in. dia. × 26 in. stroke. Coupled wheels, 6 ft. 7 in. dia.

2-6-0 Type.



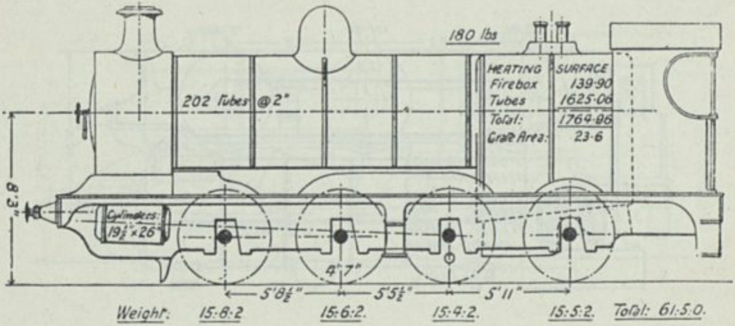
No. 13000, Mixed Traffic Locomotive, L.M.S.R.

0-6-0 Type.



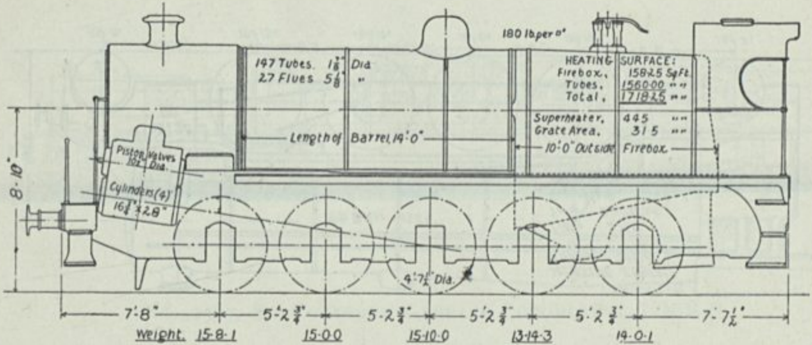
J39 Class Goods Locomotive, L.N.E.R.

0-8-0 Type.



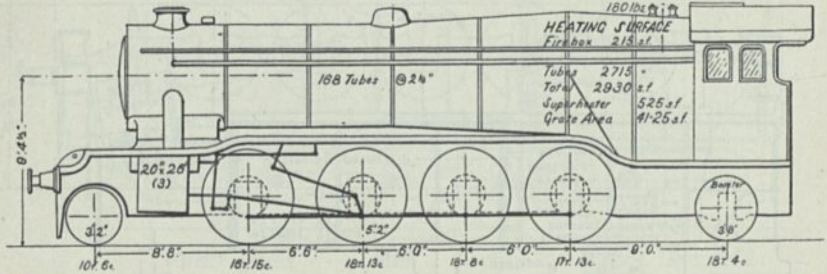
GOODS LOCOMOTIVE NO. 1052, GREAT CENTRAL SECTION, L.N.E.R.

0-10-0 Type.



FOUR-CYLINDER BANKING ENGINE, MIDLAND SECTION, L.M.S.R.

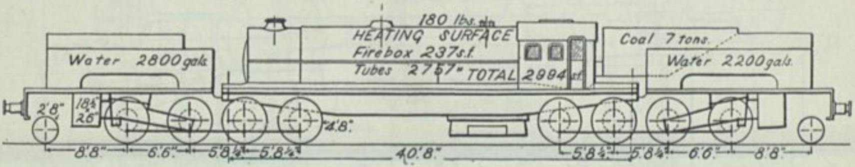
2-8-2 Type.



No. 2393, Three-Cylinder Mineral Locomotive, with Booster, L.N.E.R.

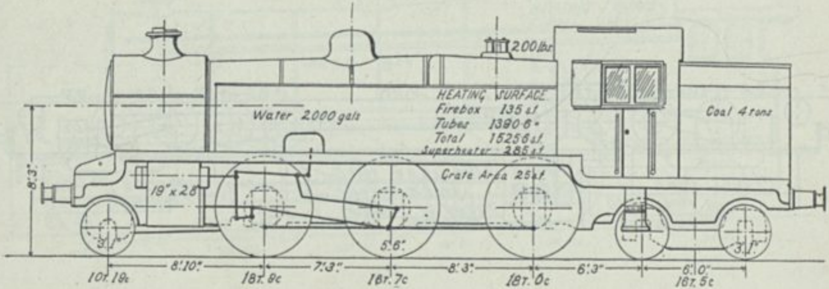
K

2-8-0—0-8-2 (Garratt) Type.



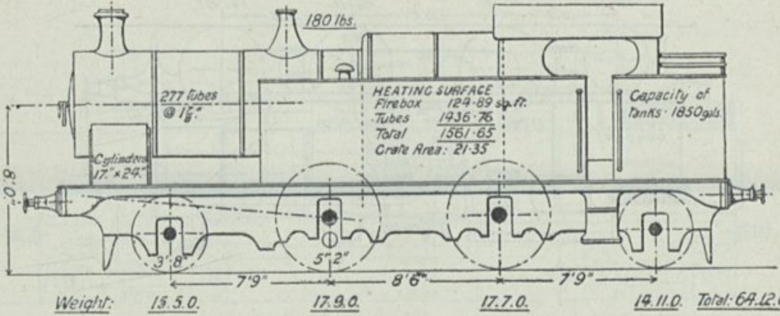
No. 2395, Six-Cylinder Garratt Locomotive, L.N.E.R.

2-6-4 Type.



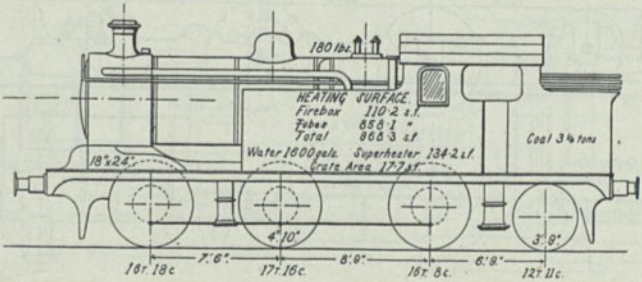
No. 111, Goods Tank Locomotive, Metropolitan Railway.

2-4-2 Type.



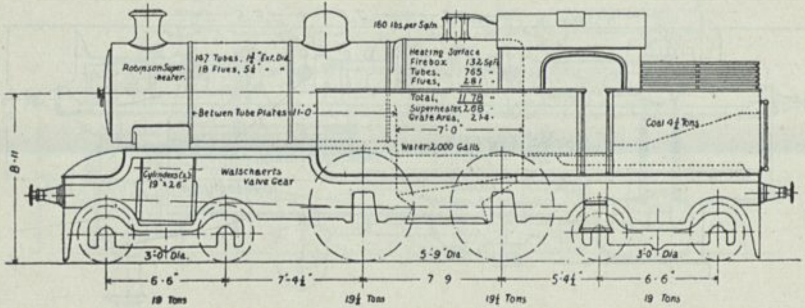
PASSENGER TANK LOCOMOTIVE, GREAT WESTERN RAILWAY.

0-6-2 Type.



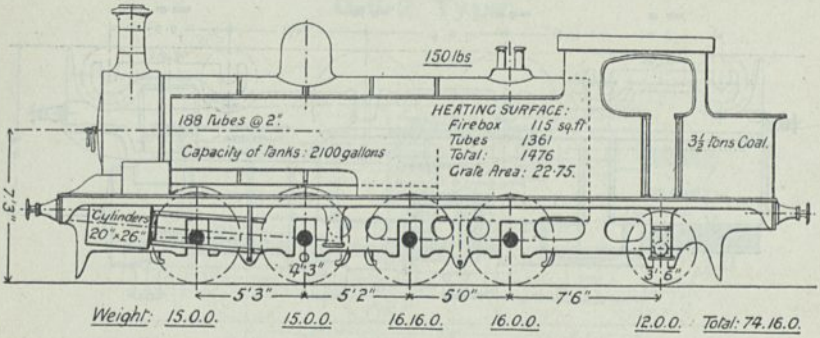
No. 8002, Passenger Tank Locomotive, L.N.E.R.

4-4-4 Type.



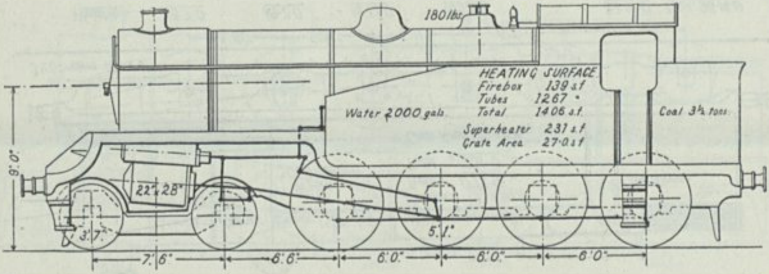
PASSENGER TANK LOCOMOTIVE, METROPOLITAN RAILWAY

0-8-2 Type.



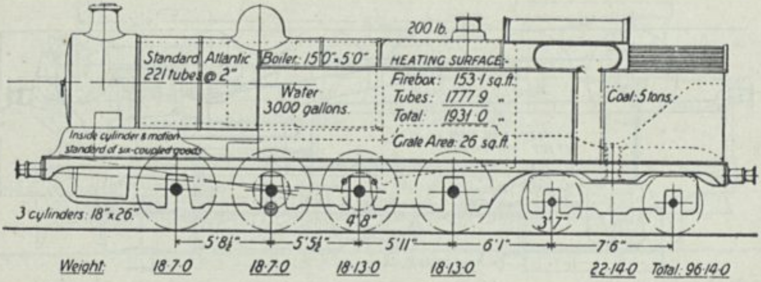
MINERAL TANK LOCOMOTIVE No. 79, BARRY SECTION, G.W.R.

4-8-0 Type.



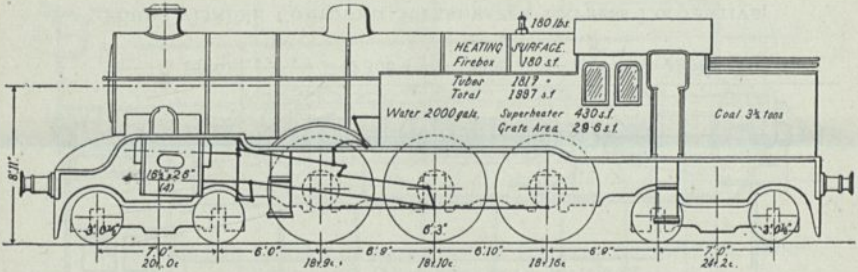
No. E492, Goods Tank Locomotive, Southern Railway.

0-8-4 Type.



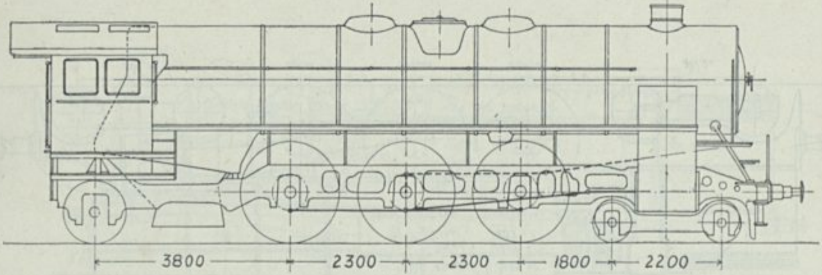
THREE-CYLINDER BANKING LOCOMOTIVE No. 1171, G.C. SECTION, L.N.E.R.

4-6-4 Type.



No. 11110. Four-Cylinder Passenger Tank Locomotive, L.M.S.R

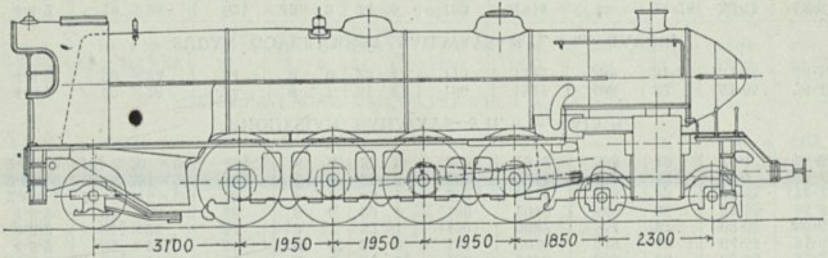
4-6-2 Type.



FOUR-CYLINDER COMPOUND SUPERHEATER EXPRESS LOCOMOTIVE,
GERMAN STATE RAILWAYS.

Cylinders: Dia., H.P., 460 mm.; L.P., 720 mm.; Piston stroke, 660 mm. Piston valves, Walschaerts valve gear. Wheels: Dia., coupled, 2.000 m.; Bogie, 0.850 m.; Trailing, 1.250 m. Heating surface: Evaporative, 238 m^2.; Superheating, 100 m.^{2}. Grate area, 4·5 m^2. Working pressure, 16 kgs./cm^2. Weight in working order, 108 tonnes. Adhesion weight, 60 tonnes.

4-8-2 Type.



Four-Cylinder Compound Superheater Express Locomotive, Paris, Lyons, and Mediterranean Railway.

Cylinders: H.P. dia., 510 mm; piston stroke, 650 mm.; L.P. dia., 720 mm.; piston stroke, 700 mm. Piston valves, Walschaerts valve gear. Wheels: Dia., coupled, 1·790 m.; bogie, 1·000 m.; trailing, 1·360 m. Heating surface: Evaporative, 255·70 m.^{2}; superheating, 113·90 m.^{2} Grate area, 5·000 m.^{2} Working pressure 16 kgs./cm.^{2} Weight in working order, 116·86 tonnes. Adhesion weight, 74 tonnes.

SOUTH AFRICAN RAILWAYS—3 FT. 6 IN. GAUGE.

Type.	Cylinders.	Coup. Wheels.	Wheelbase. Rigid.		Wheelbase. Total.		Boiler Pressure. lbs. per sq. in.	H. Surface. Evap.	H. Surface. Super.	Grate.	Weight. Adh.	Weight. Total.
		ins.	ft.	ins.	ft.	ins.						
4-6-2	22 × 26	60	10	9	29	5½	180	1706	292	36	53·1	82·35
4-8-2	24 × 26	51	9	0	32	1	185	2510	466	40·5	69·1	96·9
4-8-2	22½ × 26	51	9	0	31	9½	180	2470	669	40	66·55	92·2
4-8-2	22 × 28	57	10	0	33	8	185	2026	549	40	64·55	91·95
4-8-2	21½ × 28	54	9	7	32	1	180	2292	554	37	62·35	86·35
4-8-2	21 × 26	48	8	6	30	7	180	2048	549	36	59·85	85·5
2-6-6-2	20 & 31½ × 26	48	8	8	43	7	200	3211	616	53	105·65	128·25
2-6-6-0	18 & 28½ × 26	45½	8	4	33	5	200	2214	580	42·5	86·7	95·1
2-6-6-0	16½ & 26 × 24	42½	8	4	32	8	200	1913	398	40	79·1	86·65
RHODESIAN RAILWAYS—3 ft. 6 in. GAUGE.												
4-8-2	20 × 26	54	9	7	31	8	180	1527	488	32	51·85	76·45
4-8-2	20 × 24	54	9	0	23	4	175	1242	338	31·2	51·65	66·55
SUDAN GOVERNMENT RAILWAYS—3 ft. 6 in. GAUGE.												
4-4-2	18 × 26	62½	13	3	24	0	180	1518	—	24·75	30·75	53·3
4-6-2	18 × 24	54	10	0	25	9	180	1237	283	22·5	33·85	54·05
2-8-2	21 × 27	54	14	8	30	0½	160	1537	268	33·1	58·2	75·7

UGANDA RAILWAYS METRE GAUGE

Type	Cylinders.	Coup. Wheels.	Wheelbase.				Boiler Pressure. lbs. per sq. in.	H. Surface.		Grate.	Weight.	
			Rigid.		Total.			Evap.	Super.		Adh.	Total.
		ins.	ft.	ins.	ft.	ins.						
4-8-0	16 × 22	43	12	0	21	3	180	1173	—	17·5	34·15	42·3
0-6-6-0	15 & 24½ × 20	39	8	3	24	3	180	1442	—	33	59·05	59·05
SIERRA LEONE RAILWAYS—2 ft. 6 in. GAUGE.												
4-8-0	12 × 16	28	9	0	16	0	160	724	—	12	18·9	23·8
GOLD COAST RAILWAYS—3 ft. 6 in. GAUGE.												
4-8-0	18 × 21	40½	12	3	21	6	155	846	181	16·75	17·4	44·8
NIGERIA RAILWAYS—3 ft. 6 in. GAUGE.												
4-6-0	18 × 22	54	11	0	22	7	160	999	208	17·8	34·6	47·66
4-8-0	18 × 23	42¾	8	0	21	3½	160	880	168	17·5	38·4	50·15
4-8-0	17 × 21	40	12	0	21	3	160	952	—	15·8	31·0	41·35
4-8-0	20 × 24	45	8	6	22	9	160	1324	—	28·5	45·65	56·9
2-6-2	15 × 20	40	10	6	21	5	160	987	—	14·0	26·2	37·8

INDIAN RAILWAYS—5 ft. 6 in. GAUGE.

Rly. Co.	Type.	Cylinders	Coup. Wheels.	Wheelbase.		Boiler Pressure. lbs. per sq. in.	H. Surface.		Grate.	Weight.	
				Rigid.	Total.		Evap.	Super.		Adh.	Total.
		ins.		ft. ins.							
O. & R.	0-6-0	20 × 26	61½	15 6	15 6	160	1030	224	25·35	51·55	51·55
E.I.R.	0-6-0	18½ × 26	61½	15 6	15 6	180	1430	—	27	51·65	51·65
B.N.R.	4-6-0	21½ × 26	73½	13 10	26 6	160	1259	250	32	49·2	68·85
N.W.R.	4-6-0	20½ × 26	74	14 3	27 3	160	1571	407	32	50·7	70·35
G.I.P.	4-6-0	20½ × 26	74	14 3	27 3	180	1599	382	32	52·55	74·1
G.I.P.	2-8-0	22 × 26	56½	16 0	25 0	160	1726	383	32	66·75	75·05
B.N.R.	2-8-0	21½ × 26	56	16 0	24 2	160	1332	226	32	57·9	66·65
E.I.R.	2-8-0	22 × 26	56½	16 0	25 0	160	1692	390	32	65·0	73·7
G.I.P.	2-10-0	4 (20 × 26)	56½	15 6¾	31 3¾	160	2968	617	45	94·5	107·95

INDIAN RAILWAYS—METRE GAUGE.

Rly. Co.	Type.	Cylinders.	Coup. Wheels	Wheelbase.		Boiler Pressure. lbs. per sq. in.	H. Surface.		Grate.	Weight.	
				Rigid.	Total.		Evap.	Super.		Adh.	Total.
		ins.	ins.	ft. ins.	ft. ins.						
A.B.R.	4-6-0	16 ×22	48	12 0	21 1	160	708	112	15·3	27·65	36·35
B.R.	4-6-0	16 ×22	48	12 0	21 1	160	785	140	15·3	27·45	35·95
Bh. R.	4-6-0	16½ ×22	57	11 0	20 0½	160	746	130	15·0	25·4	33·9
S.I.R.	4-6-0	16 ×22	48	12 0	21 1	160	749	146	16·0	27·35	35·85
S.I.R.	4-6-0	16½ ×22	57	12 0	21 1½	160	718	108	16·0	28	36·3
S.I.R.	4-6-0	16½ ×22	57	12 0	21 1	160	783	108	15·0	28·05	36·45
M. & S.M.R.	4-6-0	16½ ×22	57	11 0	20 0½	160	746	130	15·3	25·4	33·9
S.I.R.	4-4-0	14 ×20	53	6 0	15 5	150	473	66	12·5	16·25	26·1
M. & S.M.R.	4-8-0	16½ ×22	43	8 0	20 6	160	851	160	16·8	33·3	41·75
B.R.	0-6-6-0	15½ & 24½ ×20	39	8 3	24 3	180	1442	—	33	59·5	59·5
INDIAN RAILWAYS—2 ft. 6 in. GAUGE.											
B.N.R.	4-6-2	16 ×18	42	8 0	23 7½	150	787	173	17·5	20·95	35·2
N.W.R.	2-8-2	16 ×18	34	9 7	22 10	160	995	234	20·5	27·75	39·4

FEDERATED MALAY STATE RAILWAYS—METRE GAUGE.

Type.	Cylinders	Coup. Wheels.	Wheelbase. Rigid.	Wheelbase. Total.	Boiler Press. lbs. per sq. in.	H. Surface. Evap.	H. Surface. Super.	Grate.	Weight. Adh.	Weight. Total.
		ins.	ft. ins.	ft ins.						
4-6-2	17 ×24	54	9 5	21 0	185	1000	217	18·5	31·5	50·3
4-6-2	17 ×24	54	9 6	27 0	170	1403	350	24·0	30·0	51·25

NEW ZEALAND GOVERNMENT RAILWAYS—3 ft. 6 in. GAUGE.

Type.	Cylinders	Coup. Wheels.	Wheelbase. Rigid.	Wheelbase. Total.	Boiler Press. lbs. per sq. in.	H. Surface. Evap.	H. Surface. Super.	Grate.	Weight. Adh.	Weight. Total.
4-6-2	17 ×26	54	10 0	27 1	180	1150	155	33·3	30·7	51·0

AUSTRALIAN RAILWAYS.

Rly.	Gauge. ft. ins.	Type.	Cylinders	Coup. Wheels.	Wheelbase. Rigid.	Wheelbase. Total.	Boiler Press. lbs. per sq. in.	H. Surface. Evap.	H. Surface. Super.	Grate.	Weight. Adh.	Weight. Total.
N.S.W.R.	4 8½	4-6-0	22½ ×26	69	14 0	26 3½	180	2205	547	30·5		
N.S.W.R.	4 8½	2-8-0	22 ×26	51	15 3	23 5	150	1757	445	28·75		
W.A.R.	3 6	4-6-2	17 ×23	54	11 0	27 2	175	1420	—	18·8	35·7	53·0
W.A.R.	4 8½	4-8-0	19 ×23	42½	12 6	22 1	175	1361	—	18·8	42·45	54·1
S.A.R.	5 3	4-6-0	18 ×24	54	6 11½	21 11½	175	1338	—	20·3	33·35	45·85

"HEILMANN" STEAM-ELECTRIC LOCOMOTIVE.

This locomotive was built in 1893 by J. J. Heilmann, Paris, in collaboration with M. Drouin, Chas. Brown (Winterthur Locomotive Works) and C. E. L. Brown (Brown, Boveri and Co.).

The boiler and steam engines were built at the P. L. M. Forges, Havre; the dynamos and motors by Messrs. Brown, Boveri & Co., and the frame, trucks, etc., by the Compagnie de Matériel de C. de F., Ivry.

The locomotive consisted of a carriage on two four-axle bogie trucks; each of the eight axles being actuated by an axle-wound motor. The boiler was placed on the back bogie (the chimney being therefore at the tail end of the locomotive).

The steam engine and the dynamo, together with the exciting plant, were carried on the front bogie.

The boiler was of the "Lentz" type, having 1561 sq. ft. heating surface and 24 ft. grate area. The tanks carried 10 tons of feed water and 6 tons of fuel.

The steam engine was horizontal compound designed for 600 H.P. at 360 r.p.m. to 1,000 H.P. at 600 r.p.m. The H.P. cylinder was 17·67" dia., and the L. P. 25·56"—the stroke in each case 11·8". (In the test the engine seems only to have developed 650 H.P.). The boiler pressure was 12 atmospheres.

The dynamo is coupled direct to the engine shaft; its normal output at 360 r.p.m. was 1025 ampères at 400 volts, or 410 kilowatts equal to 560 effective H.P.

The exciting dynamo ran at 350 r.p.m., and had an output of 260 ampères at 50 volts, or 13 kilowatts, of which only 5 were required for excitation and the remainder served for lighting the train; it was driven directly by a small vertical steam engine with two cylinders 5·89" dia. by 5·89" stroke.

The motors were continuous current, each 80 H.P. or 60 kilowatt. On a trial trip of 36·25 miles with grades 1 in 154 and 1 in 200 and with a train composed of the locomotive, 120 tons, five carriages and two vans, 63 tons, or a total of 183 tons, the average speed was 43·75 m.p.h., and the maximum 62 m.p.h.

As a sequence to the foregoing experimental machine, two locomotives of greater power were built in 1897 of the same type, *i.e.*, mounted on two eight-wheel bogies. The electrical machinery was placed in the fore end and the boiler (which was of the locomotive type) in the rear end. The power of the engines was doubled, and was provided by vertical engines of the Willans type. The official trial run, Paris-Mantes, a distance of 82 miles was made with a load of twelve corridor wagons of about 150 tons and a dynamometric van at a speed of 30 kilometres per hour (as restricted by the Railway Company), and it was intended on subsequent tests to attain 120 kilometres per hour.

"REID-RAMSAY" STEAM TURBO-ELECTRIC LOCOMOTIVE, 1904.

This locomotive, built by the North British Locomotive Co., Ltd., consists generally of a vehicle on two compound bogies (each 4-4-0 type), and equipped with a locomotive-type boiler, turbine engine and condenser, and with electric generator and motors.

The boiler is fitted with a superheater. The turbine is of the impulse type and runs at 3,000 r.p.m. The dynamo is a continuous current, variable voltage type supplying current at 200 to 600 volts to four series-wound motors, the armatures of which are built on the four main axles. The exhaust steam from the turbine passes into an ejector condenser and is, with the circulating condensing water, delivered eventually to the hotwell, and thence pumped back to the boiler. The supply of water in the tank is for condensation purposes.

The cycle of the condensing water is as follows, *viz.*, from the tanks through the first pump then through the condenser, where it becomes heated, then to the hotwell; from the hotwell it passes through the second pump to the cooler battery of tubes at the front end of the locomotive; there its temperature is reduced and the water is returned to the supply tanks.

The condenser system deprives the locomotive boiler of its usual draught apparatus (the blast pipe), and a forced draught system is installed. The fan is placed within the cooler so that it will deliver hot air to the furnace and at the same time assist the current of air through the cooler tubes.

"RAMSAY" CONDENSING TURBO-ELECTRIC LOCOMOTIVE, 1921.

This locomotive was designed by D. M. Ramsay of the Ramsay Condensing Locomotive Co., and was built by Messrs. Sir Wm. G. Armstrong, Whitworth & Co.

It consists of two vehicles, the boiler vehicle having a 2-6-0 wheel arrangement, and the vehicle for the turbo generator and condenser is of the 0-6-2 type.

The locomotive type boiler has a total heating surface of 1453 sq. ft., a grate area 28·4 sq. ft., and the working pressure is 200 lbs. per sq. in. The impulse pressure Compounded Multi-stage turbine is connected to a three-phase generator (Oerlikon) developing 890 kilowatts at 3,600 r.p.m., and furnishes current to four three-phase slip-ring motors of 275 H.P. each. One pair of these motors is on each vehicle, and is geared to countershafts with cranks for driving the wheels through coupling rods. A separate continuous current dynamo is provided for excitation of the generator and is driven by an auxiliary turbine.

The condenser consists of a series of tubes mounted in a cage that revolves them slowly through water. 2,200 gallons of water are provided. The cooling is assisted by a large air fan. The condensate is delivered to the hotwell and thence forced into the boiler by pumps.

Forced draught apparatus is provided.

In working order the boiler vehicle weighs 67 tons 5 cwts., and the condenser vehicle 63 tons 10 cwts. ; a total of 130 tons 15 cwts. ; of this weight, 108 tons 10 cwts. is available for adhesion. The overall length is 69 ft. 7 ins., and the total wheelbase 59 ft. 4 ins. Experimental tests of this locomotive have been made on the London & North Western Ry.

THE GEARED STEAM TURBINE.

The Geared Steam Turbine has, as is generally known, been for many years in successful operation for a great variety of power installations, including ship propulsion, electric power stations and other industrial purposes. The practical success of such plant, both from the mechanical and commercial standpoint in respect of steam economy, high power capacity and reliability, has, very naturally, ensured that serious consideration would be given to an application of the main features of the Geared Steam Turbine to the locomotive steam engine.

Such an application clearly involves the provision of a *condenser and auxiliaries*, in addition to the substitution of the *turbine and driving gear* in place of the reciprocating steam engine, and of some system of *forced draught*, for the boiler, in place of the induced draught produced by the exhaust steam.

THE ZOELLY GEARED STEAM TURBINE CONDENSING LOCOMOTIVE, 1921.

This locomotive was designed and constructed by the Swiss Locomotive & Machine Works, Winterthur, in conjunction with Messrs. Escher Wyss & Co., of Zurich. It takes the form of an experimental adaptation of an existing 2-6-0 type locomotive with tender. In the application the main driving machinery, comprising turbine and gearing, is located at the front end of the locomotive and between the main frames.

The power developed by the turbine is transmitted through double reduction gearing having a ratio of 30 to 1, to a jockey shaft, and thence by means of connecting rods to the six-coupled driving wheels. The exhaust steam from the turbine is led to a surface condenser situated underneath the boiler, where it is condensed and returned to the boiler as feed water, the circulating water for condensing purposes being cooled in a specially constructed air-cooled evaporative type water cooler. The cooler consists of a casing over the tender tank containing in its upper part a number of distributing tubes. Circulation is maintained by a small turbine-driven centrifugal pump which drains the water from the tender tank, passes it through the condenser and then passes it back to the re-cooler on the tender. The pipes in the latter have small perforations and a fine spray of water is ejected into a current of air, resulting from the speed of the locomotive. The loss of water as a result is said to be about one half of the quantity usually required by a locomotive. This cooler, as will be seen, in conjunction with the coal bunker, forms an independent vehicle, replacing the original locomotive-tender. Complete forced draught equipment is fitted to the boiler, taking the place of the original blast arrangement.

It has been reported that under actual service conditions the general performance of this machine has fulfilled expectations, inasmuch as it has demonstrated an overall fuel economy of 25 per cent. over that of a reciprocating locomotive of equal power.

THE REID MACLEOD GEARED STEAM-TURBINE. CONDENSING LOCOMOTIVE 1920.

This locomotive has been designed and constructed by the North British Locomotive Company, Glasgow.

As shown at the British Empire Exhibition (1924), it takes the form of a double-bogie vehicle. The upper structure is mounted on a continuous main frame. The bogies are eight wheeled and of the compound type, *i.e.*, each comprising four driving wheels and four bogie wheels. The rear bogie is fitted with a high-pressure turbine and the front bogie with a low-pressure turbine. Double reduction gear is employed. The gear is enclosed in an oil-tight casing and lubrication is arranged through a closed system with an independent pump and cooler. There are no reciprocating parts and no coupling rods. The condenser is of the air-cooled evaporative type, fitted with air induction fans and water-vapour spraying jets. The boiler is "loco. type" with superheater and forced draught.

LJUNGSTRÖM TURBINE CONDENSING LOCOMOTIVE.

Early in 1921 a turbine condenser locomotive was completed by the Aktiebolaget Ljungströms Angturbin of Stockholm, Sweden, and after exhaustive tests on a special plant at the makers' works, was placed on the rails of the Swedish State Railways at Stockholm in August, 1922.

The Ljungström locomotive consists of a boiler-carrying vehicle connected together in such a manner as to prevent relative lateral movement of the two vehicles at the point of connection. The leading vehicle has five pairs of carrying wheels, two being in the form of a four-wheeled bogie, whilst the remainder are located in the main frames which carry the boiler and coal bunker, this latter being arranged over the boiler and firebox. The boiler is of the ordinary locomotive type, with a working pressure of 285 lb. per sq. in. and small tube superheater.

The trailing vehicle is the power unit having three pairs of coupled wheels and a two-wheeled truck. Power is derived from a single direction turbine of the axial flow reaction type, acting through double helical reduction gearing and driving a jack shaft, located in the main gear box, to which the coupled wheels are connected by side rods in the usual manner. The gear box is flexibly attached to the engine frames, and the turbine is flexibly connected to the first pinion shafts of the main gearing and rigidly attached to the condenser main tank. The turbine has a maximum speed of 9,200 revolutions per minute and is capable of developing 1,800 H.P. Reversal is effected by means of an idle pinion and shaft controlled by oil operation, and the power of the locomotive is the same for both forward and backward running. The condenser is of the air-cooled type with auxiliary direct water condensation, and comprises a considerable number of copper condenser tubes attached to a large drum half filled with water and containing a circulating pump and sprayer. Exhaust steam is discharged from the turbine and auxiliaries into the upper half of the drum and rises through uptakes into a long header, and from thence proceeds through the special copper condenser elements to side headers, from which the condensed water is finally taken to the drum, the water in the drum forming the supply for the boiler. Condensation is effected by means of powerful fans which drive cold air through the spaces between the condenser elements, these fans being under separate control, independent of the movement of the locomotive. Two turbine-driven centrifugal pumps feed the boiler through feed-water heaters which serve to condense steam from various auxiliaries.

As the result of the successful working of the Swedish engine, and three others embodying various improvements, in the latter part of 1923 Messrs. Beyer, Peacock & Co. Ltd., arranged to take over a license for the manufacture of the Ljungström Turbine Condenser Locomotive, and prepared designs of a locomotive suitable for English conditions and embodying the principal features of the Swedish engines with many improvements devised as a result of the trials in service. It was not until the middle of 1926 that the new engine was completed, and a trial run on the L. & N.E.R. from Gorton to Woodhead was made on Sunday, July 4th, when a speed of 45 m.p.h. was attained. Soon after the engine was sent to Derby for trials in service on the L.M.S.R. At the end of 1926 it was thoroughly overhauled at Gorton Foundry and improvements made in the control, and since that time has been running express passenger trains between Derby and Manchester, Birmingham and London.

The Beyer, Peacock engine has a main driving turbine capable of developing about 2,000 horsepower, and arranged for a speed of about 10,500 revolutions per minute, corresponding to an engine speed of about 75 m.p.h. The boiler carries a working pressure of 300 lb. per sq. in., the inside firebox being of steel plates with a minimum thickness of $\frac{7}{16}$ in.

The grate area is 30 sq. ft. and the total heating surface, including superheater, is about 2,260 sq. ft. The six coupled wheels are 5 ft. 3 in. dia.

LOCOMOTIVE WITH INTERNAL-COMBUSTION ENGINE.

In the application of the Internal Combustion system to the locomotive, special arrangements have to be made in respect of " starting " and " power graduation." "Starting" in small power engines may be effected by hand ; in higher power, pneumatic or electric methods may be employed. For railway work starting must be accomplished with trains having a gross weight of from 150 to thousands of tons.

INTERNAL COMBUSTION LOCOMOTIVES.

A large experimental engine was built on the Continent in 1913. It was designed by Messrs. H. Klose and Sulzer, and built at Winterthur by Messrs. Sulzer. The frames, running gear and body were furnished by Messrs. A. Bersig of Berlin. The wheel arrangement is of the 4-4-4 type, *i.e.*, a four-wheeled bogie, two pairs of motor wheels and a four-wheeled bogie. The Diesel engines, of which there are two, situated vertically between the motor wheels, have each a pair of cylinders inclined at 90 deg. to each other (V type), and drive a lay shaft from discs, from which connecting rods communicate the drive to the motor wheels at 304 r.p.m.—the train speed is 62 m.p.h. The weight of the engine is 95 tons

The engine is started and runs up to a speed of about 6 m.p.h. by admitting compressed air to the cylinders. At that speed oil is admitted to the cylinders and the engine works as an internal combustion engine.

The compressed air equipment consists of a set of four hand-worked centrifugal pumps for initial charging of the system, two double-acting piston pumps driven from the engine connecting rods, and an auxiliary compressor set driven by a two-cylinder Diesel engine of effective 250 H.P., with air cooler and a battery of air reservoirs. There is also a multi-stage air pump (driven from the main engine connecting rods) which acts as a reserve for the auxiliary set, in the event of failure.

Pumps are fitted for lubrication, fuel supply, circulating water, as also are water and fuel tanks.

The sequence of operations is—the *auxiliary* engine has first to be *started* by admitting *air* to it, then changed over to *oil fuel* and charges the air reservoirs. The compressed air is then admitted to the main engine cylinders and when these have attained (as stated above) a speed of 6 miles per hour, the starting air valves are thrown out of action and the engine is changed over to oil fuel and works normally as an internal combustion engine.

The tests of this engine were interrupted by the war, and the only results hitherto published in this country were to the effect that speeds from 12 to 20 miles per hour had been attained.

NOTE.—In the trials of this engine it has been reported that grave difficulties were experienced in starting under conditions that involved a powerful effort, such as exists on an up grade, and also in regard to the cooling of the cylinders by expansion while working as a compressed air engine serving to increase the ignition trouble.

1,200 B.H.P. GEARED DIESEL LOCOMOTIVE, 5 FT. GAUGE.

Prof. Lomonossoff (on behalf of the Russian Government) has had constructed by the A.G. Co. of Dusseldorf, a locomotive of the 4-10-2 type fitted with a six-cylinder, four cycle engine with compressed air injection. It develops 1,200 B.H.P. at 450 r.p.m. The cylinders are 17 $\frac{11}{16}$ ins. dia. and 16 $\frac{9}{16}$ ins. stroke. A clutch, gearing and coupling-rods connect the engine to the five driving axles. Between the engine and the gear box the main clutch is interposed. In the gear box are three clutches controlling three gears having speed ratios of 6·6, 4, and 2 to 1 respectively. All clutches are of the magnetic type. Reversing is effected on the engine. An auxiliary Diesel motor drives the cooling fan, etc. A battery of accumulators is provided for lighting. On its road tests it is reported to have hauled a train of 1,330 tons up a grade of 1 in 100 of 11 miles long at a speed of 8 miles per hour.

1,200 B.H.P. DIESEL ELECTRIC LOCOMOTIVE, 5 FT. GAUGE.

A similar locomotive has been constructed by the Esslingen Engine Works, Stuttgart, and Brown Boveri of Baden, of the 2-10-2 type fitted with a six-cylinder, four-cycle engine with compressed air injection. The cylinders are 17 $\frac{11}{16}$ ins. dia. and 19 $\frac{3}{16}$ ins. stroke. It develops 1,200 B.H.P. at 450 r.p.m. The drive to the generator, which is of the 12 pole type, giving 800 Kw. at 600 to 1,100 volts, is made through an elastic coupling. Each of the driving axles is fitted with an enclosed tramway motor series type, self-ventilated, with four poles and of 142 Kw. capacity. The coupled wheels are 4 ft. dia. The weight in working order is 118 tons. A special cooling plant for summer time working is provided and this is carried on a separate tender fitted with an auxiliary 100 B.H.P. Diesel engine for driving the fans. The locomotive is reported to have taken 1,950 tons up a grade of 1 in 200, 4·7 miles long, at a speed of about 9½ miles per hour.

1,000 B.H.P. DIESEL ELECTRIC LOCOMOTIVE, 4 FT. 8½ INS. GAUGE.

The Baldwin Locomotive Works of Philadelphia, has built a locomotive of the 0-6-6-0 type fitted with a twelve-cylinder (two cycle) "Knudsen" double crankshaft engine which drives a Westinghouse D.C. generator. Two axles on each truck are equipped with 750-volt traction motors. The mid axles are idle. The engines are of the inverted V type, arranged in two rows with the driving shaft for the generator centrally between them, the engine crankshafts run at 450 r.p.m. and are geared to the main shaft to give it 1,200 r.p.m. In each adjoining pair of engines in the rows the cylinders are cast in one piece and in this way one combustion space serves for two cylinders. Scavenging air is furnished by a turbo-blower gear-driven at 3,600 r.p.m. by the engine. The control is by the "Ward Leonard" system. The cylinders are 9¾ ins. dia. by 13½ ins. stroke. The wheels are 40 ins. dia. The overall dimensions of the locomotive are—Length over couplers, 52 ft. 1¾ ins.; width, 10 ft. 5 ins.; height, 14 ft. 7 ins. The total wheelbase is 38 ft. 4 ins. and the total weight 122·8 tons.

300 AND 600 H.P. DIESEL ELECTRIC LOCOMOTIVES.

The "Ingersoll-Rand" Co., in combination with "The American Locomotive Company" and "The General Electric Co." (U.S.A.) have built locomotives of the 0-4-4-0 type fitted with one or two 300 H.P. at 600 r.p.m. six-cylinder engines of the four cycle vertical type. Direct injection is employed. The cylinders are 10 ins. dia. and 12 ins. stroke. The generator is 200 Kw. 600 volt, 600 r.p.m. For the 600 H.P. locomotive two generators are fitted. A motor is fitted on each axle. On the 300 H.P. locomotive the motors are 95 H.P. 600 volts geared 14/82 and in the 600 H.P. locomotive 200 H.P. 600 volts geared 15/70. Compressed air is used for starting the engine. The oil fuel consumption is stated to be 0·43 lbs. per B.H.P. hour. The weight of the 300 H.P. locomotive is given as 60 tons and of the 600 H.P. as 100 tons.

ARRANGEMENT OF LOCOMOTIVE SHOPS.

As with other manufactures, so with that of locomotives the locality chosen and the arrangement of the different buildings comprised in the works will necessarily affect the economical production of the output, and therefore the value of careful consideration of the details of any scheme cannot be over-estimated when new shops are in contemplation or additions to existing works are about to be undertaken.

With new establishments, suitable provision for development and extension is of more than ordinary consequence and although an increased outlay of capital may be called for, the timely thought for the future may result in very considerable reduction in annual expenditure later.

In deciding the locality best suited for such a factory, its size, the proximity of raw material and the labour market of the neighbourhood naturally hold controlling influences. Generally the site would appear to be the best chosen in the vicinity of a fair-sized manufacturing town, as near to the coal and iron head-quarters as possible. It should be either adjacent to a main line of railway or in such a position as to be easily connected by a short branch, the lower price of land probably favouring the latter. The ground should be level and have a subsoil of gravel and clay, whilst a good water supply is imperative.

The labour question will always be a difficult one, but there is no reason why, assuming the opportunity exists, every effort should not be made to make the shops as accessible as possible to that portion of the community from which the workers will be drawn, and all modern conveniences installed for the comfort of the operatives will doubtless be appreciated. A long weary walk to work over a badly kept road is not conducive to energy or discipline. The possibility of employment for wives and families also should not be lost sight of, a contented staff being one of the greatest influences toward success.

After the selection of the site for the new shops comes the laying out of area to secure the best results. The arrangement of the shops should as far as possible provide for the arrival of the raw material at one end and the despatch of the finished locomotive from the other, with a minimum of transport and handling; in other words, the construction of the machine should be co-incident with a passage through the shops.

The type of shop, whether of one or more floors with the means of lighting, heating and ventilating, must be decided upon. The class of work which is to be dealt with in the various shops will to a large extent dictate the number of floors permissible. Where large machinery is to be employed a ground floor alone is convenient, but a shop producing small articles may have a gallery or be composed of more than one storey. The latter arrangement saves ground, and may be found convenient provided a good system of hoists and staircases is installed. The shops should be capacious and of good height, conditions which will facilitate good distribution of natural and artificial light, heating and ventilation.

Provision should be made for the shops, both relatively and individually, to occupy such positions and be so constructed that any extensions required can be carried out with as little disorganisation and at as small a cost as possible. With this in view it is often wise to substitute corrugated iron for masonry for the ends of shops.

On the type of roof employed largely depends the satisfactory lighting of the shop. Abundant light, with the absence of any glare or heavy shadows, is essential. The central monitor roof with side skylights is largely used, and besides distributing the light well allows plenty of head room where overhead cranes are used. The "saw tooth" is another satisfactory type of roof, but in adopting it care must be exercised, especially in a paint shop, that the light is projected in the same direction as the work stands, otherwise it will be found that one side of the work —say a locomotive—is in a very poor light. Whilst on the subject of light the method of artificial illumination may be briefly considered. In the majority of modern shops electric arc lamps are used. These should be hung high up so as to diffuse their light, and some convenient arrangement should be fixed for lowering them when requiring attention. It is questionable, however, whether well-placed intensified incandescent gas jets are not more satisfactory, especially when the cost per candle power is taken into consideration. In any case gas may be laid on to the shops and a liberal supply of jets be provided in those where machinery for small work is performed, as gas jets are preferable to incandescent electric lamps for such work. Portable electric hand lamps prove useful in many cases, and suitable connections should be provided for them.

The heating of shops in cold weather is important. A cold shop hinders more than urges men to work hard, and consequently to provide no heating arrangements is false economy. A temperature of about 55 degrees F. is desirable, and this can be attained either by a supply of hot air, hot water pipes or steam pipes. The last method is often the most convenient, and can be made to work satisfactorily. Ventilation should be carried out by a plentiful supply of openings in the roof and side lights, and in some cases, such as a brass foundry, by fans. Sanitary arrangements must receive attention, and be dealt with according to circumstances.

The position occupied by one shop relatively to another is the next and most important point. For convenience the shops and yards may be grouped together.

Group 1.—Timber yard, pattern and joiners' shop, brass, iron and steel foundries and yards

Group 2.—Fitting and machine shop, forge, smithy, wheel shop.

Group. 3—Boiler shop, erecting shops, paint shop.

Group 4.—Electrical shop, millwrights' shop, tinsmiths' shop and other small shops.

Taking the groups in order and in detail, there should be a yard set apart for the storage of timber, with sheds for drying purposes, close to the pattern shop, a portion of which may be occupied by joiners. Floor space will be required for some machinery, and the shop should be provided with a gallery for the storage of patterns. Next should come the brass foundry, then the iron and steel foundry, having all its furnaces along one side and provided with numerous lifting hoists and a good floor run for the carriage of ladles of molten metal. If cupolas are used in the manufacture of steel, they should be partitioned off from the foundry so that the impurities not required in the metal may be discharged in the outside atmosphere. The foundry must be well provided with overhead electric cranes, the combined capacity of which should be capable of dealing with the largest quantity of metal likely to be required for any big casting. They also ought to be able to deal with the moulding boxes, which should be stored in a yard at the end of the foundry. The gas producers in connection with the steel melting furnaces should be in close proximity to the point of consumption. A portion of the shop should be set apart for the cleaning of castings, and the ovens for dealing with cores and malleable castings should be conveniently situated, preferably somewhere near the gas producers. Around the foundry there should be a yard for the storage of pig iron, steel and iron scrap, coke, sand, etc., and an enclosed yard with loading facilities for the storage of castings.

As to Group 2, the bulk of castings will be required in the fitting and machine shop, so this shop should be near to the casting storage yard. The size and design of the shop will depend on the number of machines to be installed, and this in turn will be governed by the quantity and type of work to be dealt with. It is customary now to group the machines together, *viz.*, drills, lathes, milling machines, etc. The idea of a circular shop with all the machines around and the fitting benches in the centre is worthy of passing consideration, but in adopting this plan what are often known as "walking" cranes would have to be used instead of overhead cranes. In the machine shop there should be a grind shop, tool room, tool stores, template stores, and a smith's fire, partitioned off from the remainder of the shop. Work from the forge and smithy will be required in the fitting and machine shop, so these two shops should be near at hand. Due regard should be paid to the arrangement of steam hammers, hydraulic press, bending, punching, and shearing machines, etc., in the forge, and both in this shop and the smithy there should be plenty of floor space. Near these shops should be left a yard for storing steel and iron of various sections.

It is a good plan to deal with axles and wheels and side frame plates in a shop apart from the fitting and machine shop, and such a shop should be near to the forge. It will probably be known as the wheel shop, and should contain all machinery necessary for dealing with this work.

Group 3.—The boiler shop should be self-contained, *i.e.*, having its own drills, punches, shears, bending rolls, etc., and every facility for quick and convenient riveting. Overhead cranes should be provided. The erecting shops should be in close proximity to the boiler, fitting and machine and wheel shops. No erecting shop can be complete without overhead cranes and sufficient machinery to deal with light repair jobs, and traversers by means of which locomotives can be expeditiously taken in and out of the shops, are practically a necessity.

The paint shop, with a special room for paint mixing, should be situated and constructed with a view of securing the best means of lighting, heating and maintaining in a state of cleanliness.

Group 4 calls for no special mention here, but when being planned should receive careful thought in all details. All sources of power, steam and electricity for the main drive, hydraulic pumps and accumulators, air compressors, etc., for various operations should occupy a central position in a suitable power house in the works area, and isolated boilers, etc., should be avoided as much as possible. The general stores should be in a central position and easily accessible by road and rail.

The necessity for a good water supply in such works may be mentioned, with high pressure mains for supplying fire hydrants, etc., whilst a narrow gauge railway connecting every shop and yard, a telephone system, and a proper number of entrances, are adjuncts to good turn-out which no engineer can afford to neglect.

LUBRICATION.

The lubrication of a locomotive is an important matter that requires careful attention from the men in charge of it.

In order that bearing surfaces should run cool and easily a thin film of lubricating medium is required between those surfaces to prevent them coming into actual contact. If the lubricant is not there, friction will follow which will generate heat, causing the soft metal parts to melt and the harder parts to expand, and if not attended to in time is liable to cause delays and damage. The large ends of the connecting rods in inside cylinder engines are the most dangerous parts to get hot. When a large end gets very hot and the metal expands there is the liability of the front cylinder cover being knocked out, or the connecting rod breaking and knocking a hole in the firebox, needless to say with extremely serious results.

The kinds and qualities of oil used by the different companies vary. For the axleboxes, motion, etc., rape oil alone or mixed with a little mineral oil is commonly used. Tallow is not used so much now as formerly; it is a good lubricant for axleboxes when running warm, but if they are behaving satisfactorily it is best to keep it out of them, as it will thicken the oil, causing it to pass too slowly through the trimming—more so of course in cold weather.

For use in sight-feed lubricators for the cylinders and slide valves, a thick mineral oil (sometimes nicknamed "Black Jack" by enginemen) is commonly used; it will stand the heat and is not so corrosive as tallow, which at one time was employed so much for these parts.

Trimmings to fit in the syphon pipes are usually made with wire plaited and with a loop at the end for strands of worsted to be held in. For the rotating parts, such as coupling rods, etc., short trimmings, known as "plug" trimmings, are required, the worsted barely reaching to the top of the pipe, so as to leave a small space to catch the oil when it is thrown about by the movement of the engine. A piece of cane or cork should be screwed in the hole in the oil cup to prevent the oil being thrown out, and, being porous, will admit air to replace the oil as it is used. In some cases a spring button fits the oil hole, then a small hole is drilled through the button to admit air.

For the axleboxes, slide-bar cups and other stationary oil vessels, "tail" trimmings are used; the worsted in these is required long enough to reach to the bottom of the oil recess; the oil will work its way through the trimming to the bearing by capillary attraction.

The number of strands of worsted required for the trimmings must be determined by the thickness of the oil used; if a trimming is found to syphon too large a quantity of oil more strands should be added, and the number lessened if not using enough. A note should be taken of the number of strands required, for future guidance. Some trimmings ready made, also some pieces of cane or cork, should always be kept by enginemen.

A driver, when getting his engine ready for the day's work, should see that all lubricator and oil-cup covers are not loose; if they are left loose they are liable to work out when running and be lost.

If any part is found not to take much oil it should be inspected at once, the trimmings cleaned or renewed or the oilcup cleaned out as required. Tail trimmings should be adjusted and gland "swabs" or "mops" seen to be properly in their places.

Mops for the glands are made of worsted or lamp cotton, plaited and tied into a ring to fit on the gland nuts. The ends of the cotton or worsted after being tied should not be left hanging round the rods; mops with straggling "tails" conduct half the oil to the ground, consequently wasting it and causing the driver to wonder why the rods do not run a bright colour.

The parts with plug trimmings should be oiled before leaving the shed, as the engine cannot always be placed in the right position when standing on a train. The horn-blocks require a little oil, especially on a line with many curves, and the engine will ride easier with horn-blocks greased. The slide bar and gland cups should be the last to be filled up, so as to save going round to them while the engine is moving. The pins in the link motion require a little rape oil in the holes made for the purpose. Neglect to oil these small but important parts is likely to cause them to get hot and seize.

It is difficult to fix a rule as to how many drops of oil per mile any particular part should use, owing to the fact that different kinds and qualities of oils are used by the different companies, also that engines work under greatly dissimilar conditions. An engineman should make himself well acquainted with the character of the material he is supplied with, so as to know just how to deal with it.

When an engine is running its first trips when new or after coming out of the repair shops, it is the best plan to be rather generous with the lubrication until everything is in good order, for once a bearing gets hot it is often a source of trouble and anxiety for some time after.

Some enginemen are in the habit of putting cylinder oil in the axleboxes; this is not advisable in cold weather. In warm weather a little of it helps to check the rape oil from being used too quickly, but if a large quantity of mineral oil is put into the axleboxes it will not syphon through the trimmings until the axlebox begins to run warm. If a driver finds that someone else has been working his engine and has served the axleboxes with the thick oil, the best way is to clean the trimmings and dose the thick oil with paraffin, which will help it to get through the trimmings and also soften the pads, which may have become almost solid with the thick oil.

When axleboxes are lubricated by the forced feed system —thereby dispensing with trimmings—it is desirable to use a heavy-bodied cylinder oil, particularly in hot climates. Forced feed lubrication for locomotive axleboxes is now making great headway in this country as well as other parts of the world.

In conclusion, it can be said that a well-lubricated engine should be lighter on coal than one that is marked light on oil consumption.

LOCOMOTIVE INJECTOR FAULTS AND FAILURES.

Of all the different designs of injectors now in use, each particular type has its own peculiar characteristics, neglect to reckon with which may occasion serious trouble. With combination face-plate injectors, for example, it is most important that the injector should be properly fitted to the face-plate and a good joint be made between the live steam pipe from the dome and the internal delivery pipe; if there is leakage, trouble will ensue in getting the injector to start.

Another source of trouble is the leaking of union nut joints, which allows air to be drawn into the suction-pipe. One of the most common faults with some injectors is due to the steam valves and top clacks blowing through owing to defective seatings; the water in the feed pipe becomes heated and the injector will not lift it on account of a reduced vacuum in the combining cone, the result being a great waste at the overflow.

Over-twist of the feed-cock rods and handle is another reason for failure, as it prevents the feed-plug from opening properly, and the injector will often keep flying off on account of not getting sufficient water.

Another cause of unsatisfactory working is the impurity of the water supply, which leads to scale being deposited on the cones, with a consequent wastage at the overflow. Great care should be exercised in cleaning injector cones that the scale only is removed, as should they become enlarged in the process they will get out of proportion and cease to act properly.

Serious failure can result from the top-clack refusing to return to its seat; this is generally due to the dirty condition of the water in the tanks, and care should be taken to remedy this, as particles of rust, pieces of wood and waste, etc., if allowed to collect may work through the sieve and pass to the clack and jam it.

On those lines using the water pick-up another drawback is introduced by the tendency for fallen leaves and other matter to lodge in the water troughs; they are picked up by the scoop and deposited in the tender tank with the water, where they gradually accumulate about the outlet pipe and choke up the sieve; the injector then fails owing to a deficient water supply.

ERECTING A LOCOMOTIVE.

In order to erect locomotives in an economical manner, a leading hand should have, whenever possible, three pits under his charge. By this arrangement any time of waiting for delivery of work belonging to one engine from the machine-fitting shops, etc., can be utilised by the men in forwarding the others.

The details of erection naturally differ in various classes of locomotives. In the present article, as a typical case, the erection of an ordinary inside cylinder single-framed 0-6-0 goods engine is briefly described.

The first step is the setting up of the frames. These are sent to the erecting shop in as complete a state as is practicable, having been slotted round the edges, straightened, and having all holes drilled where possible and sharp corners taken off. They are first laid on trestles and the various centre lines marked out. They are then placed upright in forked supports, stayed together by means of standard temporary stays cut to dead length, and set square and level with each other.

In order to ascertain when they are square, centre pops are made at various points on the top edges of the frame plates, the pops being put on to each frame at exactly similar points. The frames can then be set square by trammelling diagonally from a point near the front of each plate to one near the back of the other. They are levelled, both longitudinally and transversely, by means of a straight edge and spirit level. A cord is also placed along each side at a given distance back and front, and the space between the cord and frame plate is then callipered at various places in order to make sure that the plates are straight.

All footplate brackets, cross stays, etc., are next fixed. These are first bolted up with a few bolts, then set to their exact position and riveted up, the holes being opened out where necessary. The motion plate and other important cross stays are usually fastened with cold rivets, which are turned a driving fit to the holes. The horn blocks are secured with turned bolts.

The cylinders are next lowered into position between the frames, the weight being taken on a pair of jacks placed one under each end of the cylinder casting.

Strips of template iron, having a small central hole, are bolted across the front of each cylinder and set so that the small hole is exactly on the centre line. A line is then passed through each hole and secured at the other end to a straight edge, which is laid across the driving horns with the top edge on the centre line of the driving axle according to the drawing. These lines are set parallel to the frames and to each other, and the position of the cylinders adjusted by means of the jacks until their centre lines exactly correspond with the actual lines, after which the bolt holes which in the cylinders are drilled in the first instance below the required size, are rosebitted out, and the bolts, which are turned to a driving fit, driven in and the nuts firmly screwed up.

After securing the cylinders the slide bars are put up and set. The bottom bars are set to the lines used in setting the cylinders. A gauge is used, which is shaped to fit the bars on its bottom edge, and has a pointer on its top which is exactly central at the required distance from the bottom, each bar being so set that the gauge, when resting at any point along its length, will just touch the centre line with the pointer. When all the bottom bars are set, a straight edge, thinly smeared with red paint, is rubbed over them to see that they are all fairly in the same plane.

The top bars are now set from the bottom ones by means of a dummy slide block, which must work freely, but without "slogger," between the two.

At this stage all the measurements are usually checked over by the foreman, in order that he may satisfy himself that all the essential parts of the engine are square and true.

The boiler may next be lowered on to the frames and secured. Before being received in the erecting shop it has been mounted and tested under both hydraulic and steam pressure. The expansion brackets should have been so set when mounting the boiler that no adjustment is necessary, and having been once placed in the frames it remains there. The front tube plate is bolted to the cylinder casting, the joint being usually made with red lead putty, and the expansion bracket guides attached to the frame at the firebox end.

When in position the boiler is lagged and cleaded, and the smokebox, cab, splashers, etc., put up, this latter work being done by a gang of boiler makers usually attached to the erecting shop.

In the meantime the axleboxes may be fitted up in the horn blocks. The boxes are left a little large in the planing machine and are scraped down to fit the blocks, the latter being coated with "red marking," so that a true bearing may be obtained. They are fitted fairly tight, but should be capable of being comfortably moved up and down by means of a bar three or four feet long. They are next bedded down to their respective journals, the surface cleaned out and oiled and the keeps put on.

The engine is now ready for wheeling. To do this it is lifted clear by means of an overhead crane, the wheels rolled underneath, and then the engine is lowered on to them; a man being stationed at each axlebox to guide it into the horn blocks. Small pieces of packing are placed on the tops of the axleboxes, on which the tops of the horns rest until the springs are put up and secured.

The engine is now ready for the motion, which is put up, and the valves set. The setting of the valves is the most important piece of work in connection with the erection of a locomotive, and is only performed by specially skilled men.

On completion of the motion the springs are put up and fastened, the buffer beam attached, and the engine lifted on to a "running road," if such is available. The coupling rods are put on, and when all the minor details, such as brake gear, feed pipes, cylinder cock gear etc., have been completed the engine is ready for trial.

When the boiler has been filled with water, the fire lighted, and the engine coupled to the tender (which is coaled and watered), before starting on the trial trip the whole is weighed. The weighing machine is so arranged that each wheel rests on a separate table and may be weighed by itself. The springs are adjusted until a correct proportion of the weight is obtained on each wheel.

The tender is put together in a similar manner to the engine, the frames being set, marked off, riveted up and wheeled, and the tank (which is made in a separate shop) lowered into them and secured and the various fittings attached.

A LOCOMOTIVE DEPARTMENT LABORATORY.

The laboratory of a railway locomotive department is an interesting place to most persons connected with the construction and running of locomotives, because in it are performed the manifold chemical and physical investigations which are necessary to enable the locomotive engineer and the various officers of his staff, constructional and operative, to form an opinion regarding the various materials which they may have to use in any branch of their work, and to decide scientifically the varied questions which are constantly arising in the conduct of a great mechanical undertaking.

The laboratory usually consists of a large room for general chemical work, to which are attached smaller rooms for special purposes, such as work which necessitates the evaporation of corrosive acids and other unpleasantly fuming substances; a room for water analysis and other work which should be carried out in a pure atmosphere; a dark-room for photometric work and the photography which is almost indispensable, now that microscopic methods for the examination of steel and metallic alloys are being practised to a considerable extent; a room to contain the balances and other delicate physical instruments which are liable to damage if they be not kept as far as possible from the fumes and steam attendant upon the actual chemical operations; and lastly, there is usually a quiet room apart from the others, in which the chemist may think out the course of procedure to be adopted in an investigation, or compose his reports in freedom from the distraction of the work going on in the laboratory proper.

The chemist is concerned with the history of the locomotive from its inception, and his chief work will usually consist of steel analysis and metallurgical work generally; where the railway company has its own steel works, the material and products must be carefully and constantly examined, and even where the steel is bought from merchants and is required to comply with a specification as regards chemical constituents and mechanical properties, it is usually thought necessary to have the constant check of chemical analysis in addition to stringent mechanical test, in order to ensure uniform and satisfactory quality.

The pig-iron, coke, and various other materials for the iron foundry are all subjected to analysis, the results of which permit the selection of the best material for each purpose, and enable the locomotive engineer to scientifically blend two or more varieties of metal so as to obtain a good cast-iron, when the use of either variety alone would result in an unsatisfactory casting, owing to the excessive proportion of some deleterious constituent, such as sulphur, silicon or phosphorus.

The analysis of copper plate for fireboxes, copper and bronze bars for firebox stays, and copper tubes for the locomotive boiler is another important branch of the chemist's work: small quantities of impurities in these materials have an important effect, both for good and evil, upon the life and efficiency of the boiler into whose construction they may enter; for instance, in firebox plate, a certain small quantity of the metal arsenic is said to be distinctly advantageous, while more than this proportion is, without doubt, most objectionable.

The materials for the bearing brasses and bronzes are also closely examined to determine their purity in order that no irregularity of composition may be experienced in the finished castings; alloys for metallic packing and the so-called frictionless metals also pass through the chemist's hands to prove that they possess the requisite qualities for the purposes to which they have to be applied, and to insure that their value, as judged from their chemical composition, is proportionate to their price, which is by no means invariably the case with proprietary articles.

The locomotive, having been built, passes from the erecting shop into the painters' hands, and the chemist maintains his connection with it even in the paint shop by closely testing the quality of the various paints and gold leaf used in decorating, and the varnish used to protect its outer surfaces. In most railway companies the materials for painting are supplied to stringent specifications and it is most important that the supplies should conform to them if the locomotives are to present a uniform appearance as regards colour, and resist the ravages of weather, smoke and wear.

After the locomotive has commenced running, the chemist will by no means have severed his connection with it. His business is now to closely watch the composition and quality of the various materials necessary for its maintenance and well-being; for instance, the water with which its boiler is to be fed, the coal with which that water is to be converted into steam to actuate its motion, and the oil with which its cylinders and motion are to be lubricated, these and the many other things required for the running of a locomotive are all subject to the chemist's scrutiny.

If the water contains more than a certain proportion of chalky matter, which would deposit upon the tubes and firebox plates so as greatly to reduce their efficiency as conductors of heat from the furnace to the water, then the chemist will advise the substitution of another source of the boiler feed water which shall not possess this objectionable feature; or he may be called upon to suggest a method of chemical treatment to remove the cause of trouble from the water before entry into the boiler. Again, if he finds the water to contain even small quantities of an apparently harmless substance—nitrate of soda—it will be his duty to advise that the use of the water be discontinued for locomotive purposes, because its presence in conjunction with the small quantity of common salt which exists in almost every natural water, is likely to cause serious corrosion in a double metal boiler at the points of contact between copper and steel when the water becomes concentrated after continued steaming.

The coal will be examined by combustion in a suitable calorimeter to estimate its comparative heat-giving qualities, and the composition and quality of its ash will be determined. If the coal contains much ash which is fusible or liable to decompose into fusible substances (for instance, iron pyrites) it is likely to give rise to the troublesome formation so well known to locomotive and naval engineers under the name of "swallow's-nest," on the tube-ends in the firebox; this formation may choke the tubes—particularly if the coal be friable or dusty—and prevent the boiler from steaming satisfactorily and responding to the heavy demands which long distance runs with heavy loads make upon the modern locomotive.

The examination of the oil for the lubrication of the locomotive is a most important branch of the chemist's duty; the number of proprietary oils offered to the locomotive engineer for each particular purpose is very great; the chemist enables him to choose between them when it would be impossible to carry out satisfactory practical trials on the locomotive, and by acquainting him with the nature and proportions of their constituents, places him in a position to judge whether he gets value for money. In many instances the locomotive engineer prefers to make his own mixtures of oil for each purpose, so as to get a satisfactory and uniform article at the lowest price, and in this case the chemist will check the purity of deliveries and the standardizing of the mixtures.

The chemist has many other duties, the recital of which would require more space than is available for this article, but it will suffice to say that in these days of reform in expenditure, it is to the locomotive departments, the great spending arms of the railway organizations, that the directors chiefly look for prospective savings, and at such a time when no item of expenditure is too insignificant for rigorous inspection, it is from the chemist, if he be the right sort of man, that the scientific locomotive engineer will get most useful assistance in his efforts to effect economies.

VACUUM BRAKE HINTS.

The simplicity of the apparatus employed in the automatic vacuum brake tends to make those to whom the repair and maintenance is entrusted, somewhat careless in the handling of many of the details when overhauling or renewing.

Generally, faults in the mechanism are to be looked for in those parts made of elastic material. A frequent cause of leaky couplings is due to the carelessness of the traffic staff in disconnecting the pipes of adjacent vehicles. The couplings are forcibly pulled asunder whilst a good vacuum is being maintained by the locomotive in the train pipe, with the consequence that the india-rubber joint rings are torn from the grooved recesses made to contain their inner edges and the next time a connection is required there is considerable difficulty. The continuous vacuum in the train pipe should be destroyed prior to uncoupling, and when a joint ring gets pulled out of place the examiner should reinstate it at once before it has time to become set and hardened in a wrong shape.

In replacing coupling hose the connections at the ends should be left in correct alignment so that they will readily couple with adjacent hose without requiring to be twisted to allow the horns of the ends to engage. Frequent twisting destroys the hose at the ends where attached to the necks of the train pipe. A strip is provided down the hose pipe on many railways as a guide to ensure straight connection.

The renewal of the rolling rings in the cylinders requires attention, as when carelessly done there is liability to replace them with an initial twist which naturally prevents the free rolling action necessary when the piston moves up and down in the cylinder and which causes a "jamb" sooner or later. After putting a new rolling ring into position on the drum of the piston it should be pulled away from the metal in two or three places and allowed to naturally reseat itself on the periphery of the piston; this procedure will ensure a smooth bearing of the ring, free from twist or distortion.

The accurate rolling of the ring is better ensured on pistons left with pronounced tool marks than with those finished smooth, and for the same reason lubricants such as graphite, etc., should not be used in the brake cylinders, as the rough surfaces will then have the effect of causing the ring to roll or revolve uniformly all round.

With piston rod neck rings, too, some care should be exercised in adjusting them: they should be moved up and down the piston rod by hand, to ascertain if the rod will pass fairly through with a minimum of friction. In this case a little "black lead" painted on will be of service, as the resistance to motion is rubbing friction.

When the rubber diaphragms of ball valves require renewal, the valves should be worked to and fro before securing the flanges to ascertain if the diaphragm properly occupies its appointed seating.

Care in fixing diaphragms, rolling rings, etc., will materially lengthen their period of service as well as ensure smooth working and freedom from failures.

PAINTING AND FINISHING LOCOMOTIVES.

All metal work not intended to be left bright should be painted as soon as possible after it is put into place on the engine or before if convenient, for if the surfaces become rusted over first the paint will peel off or be destroyed from its action underneath; if deeply rusted the stopping up of the "pitting" will be more difficult if a flat face is required. A coat of lead colour is therefore applied whilst the engine is in the final stages of construction in the erecting shop, and it usually runs its trial trip in this colour before going into the paint shop for finishing. All dirt and grease should be wiped or scoured off with turpentine and glass paper, before the colour is applied to the metal.

On arrival in the paint shop this coat of priming is left on if the metal holds it firmly, which can be tested by scraping it away in places with a flat scraper to ascertain how the plate is underneath. If clean and metallic, with no rust, the coat may safely be left; if, however, the surfaces have not been properly cleaned preparatory to the colour being laid on, the latter must all come off, otherwise the rust will act below the paint, allow it to peel off, or kill the colour.

The lead colour paint first laid on is a mixture of white lead and common varnish thinned with boiled linseed oil, turpentine and terebene driers. These ingredients give a good covering and adhesive colour, which will form a substantial foundation and protect the metal. The whole surface will be coated with stopping or filling spread on as evenly as possible with flat trowels. This filling is composed of dry white lead and dry ochre, in the proportion of four of the lead to one of ochre, mixed with gold size to a consistency of thin putty.

When the coating of filling is laid on it is allowed to dry until quite hard; it is then ready for the next operation—rubbing down. This latter is done with pieces of pumice stone or other similar preparation made flat on the sides and worked with water. Several pieces of the stone, a large sponge and a bucket of water are required, as well as trestles upon which the operator stands to work.

Assuming that a large flat surface is to be worked upon —say the side of a tender or tank—the painter places his support so that he can start at one end with the sponge soaked with water. The plate is wiped over, then the pumice stone rubbed on with a circular motion over the plate, not pressing it hard on the stone, as it will tend to follow the inequalities of the stopping. If rubbed with gentle pressure until the lumps are off more pressure may then be applied. After rubbing a few minutes it will be found that the stone will get dull, as the pores in it get filled with the stopping it takes off; it is then placed in the water to wash this off and restore the cut. The surface is frequently washed with the sponge and water during the operation. When the stopping is removed level and the surface is flat, with the hollows filled up, another part is worked upon until all is finished.

The first coat of lead colour is next applied, and when dry sometimes a second one, but often the second coat is of the intended colour, not necessarily of as good a quality as the final coat, which is laid on after the others have thoroughly dried. At this stage the lettering is put on, figures painted and the lines and stripes applied. The latter are run with fine long-hair pencils and suitably mixed colour, along lines carefully set out with chalk.

The cost of painting a locomotive and tender is very much increased by the elaborate lining of some railways and a new and cheaper method of doing this is now being introduced. Ribbons of prepared "transfer" of the desired colour and width are applied on the painted surfaces, preferably in straight lines or stripes.

When all has well dried the engine receives a first coat of varnish, which, when hard, is "flattened" down by rubbing with very finely powdered pumice stone and water, on a piece of horsehair, this removing all the ridges left by the "tools" in varnishing. A second coat is next applied and in some cases, after being flattened down, a third finishes the varnishing. Best engine copal varnish is used in all cases, as it sets hard and is very durable.

The amount of time and material used in finishing an engine will vary very much, as a great deal depends upon the time the engine can be spared from the work, as well as the amount of money that is to be spent on the finish. The time is usually reduced by letting the engine dry and harden for a short time, say one day instead of one week or longer. The materials will also vary, depending upon the colour of the finishing coats, etc.

The smokebox is coloured with "Eboline" or a Japan black, as ordinary colour would not stand the heat at all.

The brakework below, springs, etc., will also receive two coats of the same material for a finish. The inside of the cab is painted some light tint as being more satisfactory in appearance. The motion and inside of the frames are also finished a light colour, so that the light from a hand lamp is better reflected when the driver is oiling up at night.

The wheels are often painted and lined before being put under the engine, as they are then more accessible; if they are done under the engine the latter has to be "pinched" along the rails to enable all portions of the wheels to be reached.

The engine or engine and tender should now stand for a week in the paint shop, which is kept at a uniform heat to allow the varnish to thoroughly dry and harden; if good materials have been used and care bestowed on their application, the engine will keep its fresh appearance for some considerable time, especially where the cleaning in the shed is carefully done. When, however, the drying has been "rushed" and the cleaning afterwards scamped, engines soon lose their smart appearance; grease and dirt accumulate on the varnished surfaces, and the whole machine assumes a melancholy look.

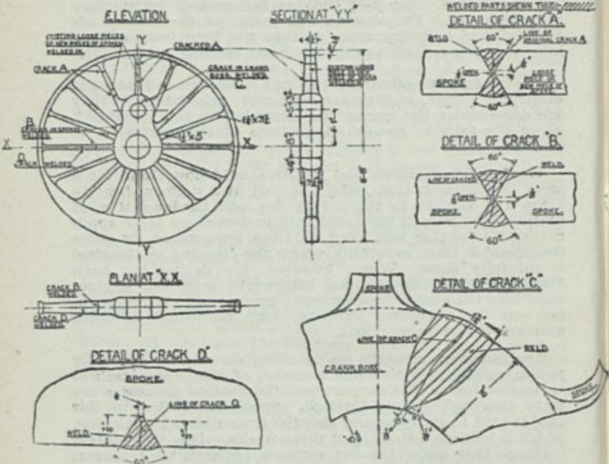
The foregoing remarks on painting, etc., apply generally to our railways, but on the occasion of the preparation of an engine for exhibition purposes the various processes are more thoroughly gone through. Special attention in this case is paid to stopping and also the time allowed for drying, which is increased to at least three weeks. It is these latter features that make the flat surfaces appear like a mirror. In usual practice several details are painted black; but for attractive work, springs, tyres, buffers, brake pipes, screw couplings, etc., are left polished.

It is essential that numbers (where painted on) and also the initial letters of the company should be very prominent on the tender or tank sides, so as to be readily seen by night, the practice of the Great Northern, Furness and North British lines being especially good in this direction.

ELECTRIC WELDING WITH "QUASI-ARC" PLANTS AND ELECTRODES.

Electric welding, both for constructional and repair work, possesses many advantages, though it is perhaps in the latter connection that its chief interest lies for locomotive engineers. In its earlier stages electric welding was sometimes deemed unreliable, but to-day, provided that discretion be exercised in the selection of the process, and due care taken to work upon correct principles, much time may be saved by it and costly "scrapping" frequently avoided.

The drawing herewith reproduced shows a repair actually effected upon a badly broken locomotive driving wheel, the



method and apparatus used being that invented and patented by the Quasi-Arc Company, Ltd. "Quasi-Arc" Electrodes have been very widely adopted by locomotive builders and in railway repair shops, etc., so that some notes upon it may be of value.

Essentially, the "Quasi-Arc" Electrode consists of a steel wire covered by a robust mineral flux, through which runs a length of fine aluminium wire. These electrodes are supplied in standard lengths of 18 in., and in about half a dozen gauges. Various electrodes are supplied for welding mild, carbon, vanadium, chromium and manganese steels and a special type for boiler repairs or overhead work. An electrode for cast iron has been developed to give a diffused weld junction free from the layer of hard white iron sometimes found in cast-iron welds, and which, when present, is apt to make machining troublesome.

The electrical energy can be supplied in continuous or single phase alternating current, at potentials not greater than 110 volts; by using special regulators in the welding circuit, a potential as low as 45 volts D.C. or 70 volts A.C. may be employed. In each case the regulator should give a current range of from 25 to 200 amps. with adequate intermediate stops. The current consumption will, of course, vary with the nature of the work, but when using a reactance coil and current regulator, it may be taken as about 8, 12 and 15 kw. for one, two or three welders respectively. The most economical method, however, if a single welder D.C. plant only is required, is to use the special "Quasi-Arc" drooping characteristic dynamo which gives 60 volts on open circuit and 30 volts at 200 amps. maximum current. This machine must always be used in conjunction with the Company's reactance, and also their portable current regulator. In general, continuous current is to be preferred, the connection to the work being made through the negative terminal, while the electrode forms the positive pole.

Welding is commenced by momentarily touching the work with the electrode, thus striking an arc, and then withdrawing slowly in the direction of the weld, keeping it at an angle of about 45° to maintain a uniform flow of metal into the work. The flux covering, which melts at a lower temperature than the steel, becomes a secondary conductor, and also forms a screen which prevents access of atmospheric oxygen to the molten metal. The aluminium wire, owing to its strong affinity for oxygen, further prevents oxidation; as the molten slag flows over the molten metal, it picks up any foreign matter and oxide that may be present. The combination of qualities above indicated ensure the presence of clean pure metal in the weld, an absolutely essential point if reliable results are to be achieved.

The preparation of the work will, of course, vary according to the size, position, material, etc., but it may be said in general that no special operations are necessary (preliminary heating, for example, as demanded by some autogenous welding processes, is entirely avoided when using "Quasi-Arc" Electrodes); nor is highly skilled labour called for.

With the help of electric welding it is possible to effect repairs to details of locomotives which previously had to be entirely replaced with new parts. In the case of cylinders which have suffered damage in service, portions of worn or condemned castings can be utilised to "re-make" a defective part or cylinder barrel, thereby saving considerable expenditure. Cases wherein a cylinder casting had developed defects have been treated by cutting out the faulty section and welding in a new portion which had been cast from a templet and carefully prepared to fill the space, the welding being carried out with "Quasi-Arc" Electrodes.

In boiler work, most useful and effective repairs have been made; new half-sides are being welded to fire-boxes whilst stays are welded to the side sheets. In an interesting example a complete back-plate was welded in, no rivets being used. Crown stays are also being screwed into the sling stays. A simple and ready means of securing to the firebox, the studs which are required to support the brick arch, is to weld them to the plate.

Another detail in boiler construction is the welding to the boiler shell of the steel cups used for receiving the heads of flexible stays used for supporting the crown of the inner firebox. A considerable number of boilers have had their flexible stay cups welded in this manner.

Full information as to methods, operation, sizes and composition of electrodes, etc., will be furnished by The Quasi-Arc Company, Limited, whose engineers have made a special study of the requirements for locomotive work.

SHED NOTES.

WASHING OUT OF LOCO BOILERS.

This operation should be carried out at stated intervals, its frequency being determined by the quality of water used. With water of average scale or sludge-forming tendency, the following periods may be taken as representative practice.

The most important expresses, 600 miles—800 miles.

Other expresses, 800—1,000 miles. With superior water, 1,200 miles.

Suburban tanks, goods and shunting engines, after 6 days' running.

Where water of excellent quality is available, e.g., in some parts of Scotland, washing out only becomes necessary at intervals of 2-4 weeks.

In a working day of 8 hours a boiler washer and mate can properly wash out the average number of 3 engines, assuming that their work is divided between passenger and goods engines.

In sheds where engines are washed out cold, the wash-out water should be delivered at a pressure of at least 50 lb. per sq. in (maximum should not exceed 60 lb. per sq. in.), otherwise the water has not sufficient force to help the rods effectively to remove the scale lodging between the tubes, stays, etc. Definite time allowances, ranging from 3 hours for small tank engines to 5 hours for a 4-6-0 or 4-4-2 express, should be laid down for cooling, after the steam has been blown off and water let out. This will prevent leakage troubles which would occur from a too rapid rate of cooling. Mud plugs should not be withdrawn until the pressure gauge registers zero.

Excessive contraction is prevented by washing out with hot water. Further, by this method, engine availability is increased. A modern 4-4-0 engine will be out of traffic approximately 10 hours for a cold wash-out, whereas 4 hours at most will suffice with the hot water apparatus. The disparity increases with the dimensions of the engine concerned; a ten or twelve-wheeled engine will lose about 13 hours from traffic for cold wash-out but only 5 for hot. On the other hand, the washer is not able to manipulate his rods effectively when large quantities of steam are rising, and further, certain forms of scale are more effectively removed cold than hot; for these reasons, in sheds where hot washing out is customary, a monthly cold wash-out should be insisted upon for each engine.

Mud plugs should always be carefully cleaned and greased before replacement, care also being taken to ensure their entry without cross-threading. All mud-hole door joints should be carefully examined before being passed for further use.

The water used in washing out a boiler is in part determined by the delivery pressure, and may in extreme cases amount to twice the quantity of water normally contained in the boiler at half-glass. The average amount used is from 1·50 times the latter quantity.

TUBE SWEEPING AND ARCH CLEANING.

These operations should always be carried out whenever the engine is stopped for washing out. In addition, engines on the principal expresses duties, and all those burning soft, friable coal should have the tubes swept and arches cleaned down daily. Engines fitted with self-cleaners, which should always be operated in a thorough manner at least once per trip, should need little, if any attention in the shed as regards tube cleaning, unless individual tubes become completely made up, in which case boring out is essential.

Time allowances for tube cleaning:

By compressed air, 1 hour per set.
By hand, 3 hours per set.

COAL REQUIRED AND TIME TAKEN TO RAISE STEAM.

These quantities depend on various factors, such as grate area, water content of boiler, material of firebox, quality of fuel, etc. Representative figures, assuming the water to be cold in the first instance, are:

Water capacity of boiler. (gallons)	Grate area. (sq. ft.)	Quantity of coal used. (cwt.)	Time taken (hours) to raise steam to 50 lb. sq. in.
1200-1400	26-30	10	4¾-5
800-1000	20-26	6	3½
600- 800	15-20	4¼	3
500- 600	12-15	3	2¾

SPONGE CLOTHS.

Where sponge cloths are used for engine cleaning, the supplies issued are approximately as follows:—

	per engine	
Large Passenger Engines....	36 cloths	
Small Passenger Engines....	24 ,,	
Passenger Tank Engines	16-24 ,,	according to size
Goods Engines	18-30 ,,	,, ,,
Shunting Engines..........	12-14 ,,	,, ,,

The above allowances are for washed cloths; it is not now customary to issue new cloths for this purpose on the home railways. Large passenger engines are usually allowed about 5 pints of oil and ½ lb. of tallow per clean.

ENGINE OIL ALLOWANCES.

Typical oil issues, in pints per 100 miles, are given below:—

Type of Engine	Engine Oil	Cylinder Oil
10-Wheeled Passenger Engine	6	2
8 ,, ,, ,,	5	1½
66 ,, goods ,,	4½	1½
10 ,, Passenger Tank ,,	4	1¼
8 ,, ,, ,,	4	1
6 ,, Shunting ,, ,,	3	1

These quantities may be taken as maximum, i.e., for hauling full loads on an arduous road.

PERIODIC EXAMINATIONS.

A certain amount of latitude must be allowed in fixing periods between examinations to enable the latter to be carried out on shed days and so prevent unnecessary additional withdrawal of the engine from traffic. Suitable periods are as follows:—

Weekly.—Firebox, stays, firebars and arches.
Monthly.—Injectors, water gauges, main steam pipes, wheels and tyres, mechanical lubricators, tender tanks, drip valves, fusible plugs, water pick-up apparatus, brakes, sanding gear, safety valves.
Two Months.—Piston valves.
Three Months.—Pistons, drawbars, big ends, axlebox pads.
Six months.—Crank pins and axles, small ends.

SHED STAFF.

One fitter and mate will maintain 6-8 engines in running order. The number of boiler makers required will of course depend on the quality of water used; on an average, one boiler maker can maintain 20-30 boilers, whilst one tuber and assistant will be required per 15-20 boilers.

TYPICAL BREAKDOWN GANG.

1 fitter, 1 tool attendant, 2 men for jacks, 2 men for packing, 1 steam crane driver and 1 guard. Total, 8 men.

ENGINE AVAILABILITY.

In normal British working 18-23 per cent. of the total engine stock is under repair at one time, and therefore not available for traffic.

COAL STACKING.

One man will stack 20 tons per day, inclusive of walling. Piecework prices range from 7d. to 9d. per ton, according to the locality. Bituminous coal used for stacking may usually.

be taken to run out at 45 lb. per cu. ft. of stack, and Welsh coal at 55 lb. per cu. ft. A section of an average coal-stack 1 ft. square at the base and 9 ft. high will equal approximately $\frac{1}{8}$ ton.

FEED WATER AND PRIMING.

An average locomotive boiler contains about 1,250 gallons of water and evaporates about 7,500 gallons per day. The average impurities found in locomotive feed water in England are about 2 lb. per 1,000 gallons. Of these, chlorine and sulphates remain in suspension in the water, and do not deposit on the tubes, barrel and firebox plates in the form of scale. As the quantity of water evaporated increases, the concentration of these two impurities becomes greater and greater until finally that point of concentration is reached when foaming or priming commences.

When chemical analysis reveals the presence of chlorine and nitrates together in large quantities, the water will be of a corrosive nature and should, if possible, be avoided.

LUBRICATING OIL.

A cask (wooden) of lubricating oil usually contains about 42 gallons or 380 lb. of oil.

One gallon of lubricating, cylinder or burning oil,	9lb. approx.
,, ,, ,, paraffin	8 lb. ,,
,, ,, ,, cleaning oil	$8\frac{1}{2}$ lb. ,,
,, ,, ,, water	10 lb. ,,

BRICK ARCHES.

The average life of a brick arch is:—

Shunting engines, 12 weeks.
Average passenger and goods engines, 10 weeks.
Express engines, 6 weeks.

MANUAL COALING.

In a working day of 8 hours, one man will unload 20 tons of coal from truck to stage and load it thence to tenders as required.

BLAST PIPE ORIFICES.

The actual diameter of a blast pipe orifice is determined by several factors, e.g., ratio of tube length to diameter, nature of fuel burnt, normal running cut-off, smokebox volume, etc., and is also closely related to chimney and petticoat pipe dimensions, diameter of and distance from tubeplate, and position relative to the boiler centre line.

For these reasons, the following figures, whilst representative of average practice as regards two-cylinder simplet engines in this country, must only be regarded as approximate.

Diameter of cylinders, inches	Diameter of blast pipe orifice, inches
21	5¼
20	5-5⅛
19	4⅞
18	4¾-4⅞
17	4½*
16	4¾*

* In the case of tank engines working heavy suburban services at late cut-offs, the orifices will probably require opening to about 5 in. diameter.

VACUUM AUTOMATIC BRAKE.

British railways using this brake generally work at a pressure of 20 in. or 10 lbs. The Great Western Railway, and more recently the L.N.E.R. (G.C.) are exceptions to this rule, and these two railways now work at 25 in. or 12½ lbs.

TABLE OF COAL AND WATER CONSUMPTIONS OF LOCOMOTIVES PER 100 MILES.

Large Passenger Engines, 35 cwt. of coal and 3,500 gallons of water.

Small Passenger Engines, 25 cwt. of coal and 3,000 gallons of water.

Small Passenger Tank Engines, 37 cwt. of coal and 4,000 gallons of water.

Express Goods Engines, 55 cwt. of coal and 3,700 gallons of water.

Mineral Goods Engines, 60 cwt. of coal and 3,700 gallons of water.

Colliery Collecting Engines, 80 cwt. of coal and 7,000 gallons of water.

The above figures will be found to be fair averages of British practice with engines of approved design and using suitable coal.

COAL.

AVERAGE COMPOSITION OF STEAM COAL. SEMI-ANTHRACITE CLASS.

Carbon	=	80%
Hydrogen	=	5%
Oxygen	=	8%
Ash	=	4·5%
Nitrogen	=	1·5%
Sulphur	=	1%

To completely burn 1 lb. of coal in a locomotive firebox 12 lbs. of air, or about 156 cubic ft., are required.

Air contains 77% of nitrogen and 23% of oxygen.

ANTHRACITE COAL.

Hard, high percentage of carbon, burns with very little flame, does not swell or soften in burning.

BITUMINOUS COAL.

Soft, lower in percentage of carbon than anthracite coal, burns with a long yellow flame, swells in burning, is liable to cause a dense yellowish smoke unless skilfully handled.

RUNNING ADHESION.

The running adhesion for a locomotive in fine weather is usually taken as being 450 lbs. per ton of load carried on the coupled wheels for large driving wheels, and as 360 lbs. for small driving wheels.

Add 50% to the above for well-sanded rails and deduct 50% for wet and greasy rails.

LOCOMOTIVE BOILER PERFORMANCE.

An express locomotive with a boiler having a grate area of 25 square ft. will, when the engine is running at 50 to 60 M.P.H., consume about :—

35 lbs. of coal per minute.
5,500 cubic ft. of air per minute.
and 38 gallons of water per minute.

The firebox temperature will be about			1,800°F.
" " vacuum	"	"	2 in. (water).
The smoke box temperature		"	550°F.
" " vacuum	"	"	5 in. (water).
The chimney vacuum	"	"	13 in. (water).

SAND USED BY LOCOMOTIVES.

The approximate quantity of sand used by a locomotive is five tons per annum. Locomotive sand should be as "sharp" as possible and should be carefully dried and well riddled before use.

DELIVERY OF INJECTORS.

The following table shows the maximum quantity of water, in gallons, which an ordinary locomotive injector should deliver per hour.

Boiler Press. in lbs. per sq. in.	Size of Injector.			
	No. 7.	No. 8.	No. 9.	No. 10.
140	1080	1450	1800	2100
160	1120	1500	1850	2155
180	1170	1560	1900	2210
200	1220	1600	1950	2270
220	1270	1650	2000	2330

A No. 8 Gresham & Craven injector of the combination type and situated on the firebox front will deliver a maximum of 1,500 gallons and a minimum of 975 gallons per hour, working with a boiler pressure of 160 lbs. per square inch and unheated feed water.

LIFE OF BRASS SLIDE VALVES.

The life of locomotive slide valves per 10,000 miles may be taken as approximately as under, though, of course, the quality and nature of the metal used in the valves and steam chests, along with the nature of the road run over and the work performed by the engine, will naturally cause very considerable variations in the life of the valves. New valves are usually at least 1 in. thick on the flanges.

Passenger engines, $\frac{3}{16}$ in.
Passenger tank engines, $\frac{5}{32}$ in. (on easy road).
Passenger tank engines, $\frac{3}{8}$ in. (on heavy road).
Goods engines, $\frac{5}{32}$ in.
Shunting engines, $\frac{1}{8}$ in.

SECURING LOCOMOTIVE TYRES TO WHEEL CENTRES.

The usual practice in Great Britain is as follows:—The wheel centre is turned to a given diameter and the tyre for it is bored out a fraction of an inch smaller on its inside diameter than the outside diameter of the wheel centre. The tyre is next heated in a suitable furnace or by means of a ring of gas jets until it obtains a temperature of about 550°F. The tyre is now placed flange upwards in a shallow rimmed dish, usually made of cast-iron. The heating of the tyre having caused it to expand the wheel centre is lowered into it by suitably arranged purchase tackle, care being taken that the wheel centre goes down quite evenly. The tyre is now contracted on to the centre by means of a fine jet of water played evenly round it. It is usual to further secure the tyre by means of $\frac{7}{8}$ in. studs spaced between each pair of spokes, these studs being screwed through the edge of the wheel centre and entering the tyre for a depth of from $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. Some companies, instead of finally securing with studs, use a thin steel ring on the inside of the tyre, this ring being recessed into both the wheel centre and flange and riveted through from the lip of the tyre with $\frac{5}{8}$ in. rivets Practically all railway companies have a tyre shrinkage table of their own, but the appended table may be taken as a fair average allowance, the fractions of an inch being the amount less than the diameter of the wheel centre to which the tyre is bored out.

For 3-0 wheel centre	=	·035
„ 4-0 „ „	=	·045
„ 5-0 „ „	=	·055
„ 6-0 „ „	=	·065
„ 7-0 „ „	=	·075

New tyres are usually about 3 in. thick on the tread and are scrapped when they are a little more than half this thickness.

The standard allowances for shrinkage, by the American Master Mechanics' Association are as under, *viz:*—

38-in. Centre	=	·0597	72-in. Centre	=	·0955
44-in. ,,	=	·0495	74-in. ,,	=	·0988
50-in. ,,	=	·0594	78-in. ,,	=	·1053
56-in. ,,	=	·0692	82-in. ,,	=	·1119
62-in. ,,	=	·0791	86-in. ,,	=	·1184
66-in. ,,	=	·0856	90-in. ,,	=	·1250
70-in. ,,	=	·0922			

PATENT OFFICE FEES.

The Patent Office fees for a person taking out his own patent are as follows:—

Form 1. Application for patent or provisional specification, £1.

Form 3. Complete specification, £3.

Form 10. Sealing fee, £1. Payable within 15 months of the official date of application for Patent or Provisional Specification.

Form 13. No further payments are required until four years from the date of application, when a payment of £5 must be made, followed by subsequent annual payments rising by £1 year up to £14 at the expiration of the 13th year. The total minimum fees are, therefore, £100 for each patent.

The registered stamped forms and unstamped duplicate copies, etc., may be obtained from the Patent Office direct, or at a few days' notice from any Money Order Office in the United Kingdom. Drawings must be made on sheets 13 in. long and 8 in. or 16 in. wide.

ELECTRIC BATTERY LOCOMOTIVES.

For shunting and sorting wagons in a goods yard, especially where the duties are carried out at irregular intervals, it is found economical to use electric battery locomotives. Frequently too it happens that to use steam locomotives would be dangerous on account of fire risks.

An example which may be referred to is a locomotive belonging to the L.M.S.R. at work in the West India Dock Coal Depot, London.

High speeds are, of course, unnecessary in working a yard of the type in question, and the maximum speed attained with full load is only about seven miles per hour, speeds up to twelve miles per hour being attained with light loads. The rated capacity of the locomotive is six loaded wagons weighing 15 tons each, and twelve light wagons of approximately 6 tons each. The weight of the locomotive complete with battery is 17½ tons, and the wheel base, which is, of course, rigid, is 8-ft. 6-in. There are two motors—one per axle—of 22 h.p. each. The battery consisting of 108 cells, situated in the two end compartments, was provided by "D.P." Battery Company. Control is by the ordinary series-parallel method, providing two economical running speeds, but no restrictions are put on the drivers with regard to the use of the other notches. Braking is of the rheostatic type operated by the main controller, this method being very useful for shunting operations. A hand brake with hand operation is also fitted to each axle.

The mechanical portions of the locomotive are largely constructed of standard wagon parts, *e.g.*, the wheels, axles, draw-gear, etc. The body and cab are of wood, suitably braced with ironwork. The covers over the battery compartments are arranged to drain off all rain water, while both sections are so ventilated that gases given off during charging, or working the battery, are carried off.

Charging is performed by a motor generator, the voltage of supply from the Poplar Borough Council of 460 volts being too high to offer any advantages for the use of a reversible booster. The generator is differentially compounded, so that after current is switched on, further attention is unnecessary except in the case of a "gassing" charge.

The results, after fifteen years' working, have been most satisfactory. The same battery is still in use, and of which only the positive plates have been renewed.

Similar locomotives and others of larger haulage capacity are now in use in Depôts where danger from fire is to be avoided. The haulage capacity varies from 100 to 300 tons.

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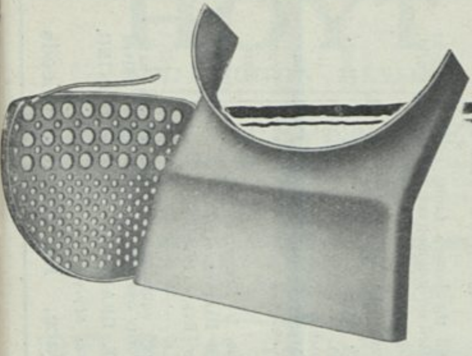

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