THE LOCOMOTIVE OF TO-DAY

THE LOCOMOTIVE OF TO-DAY

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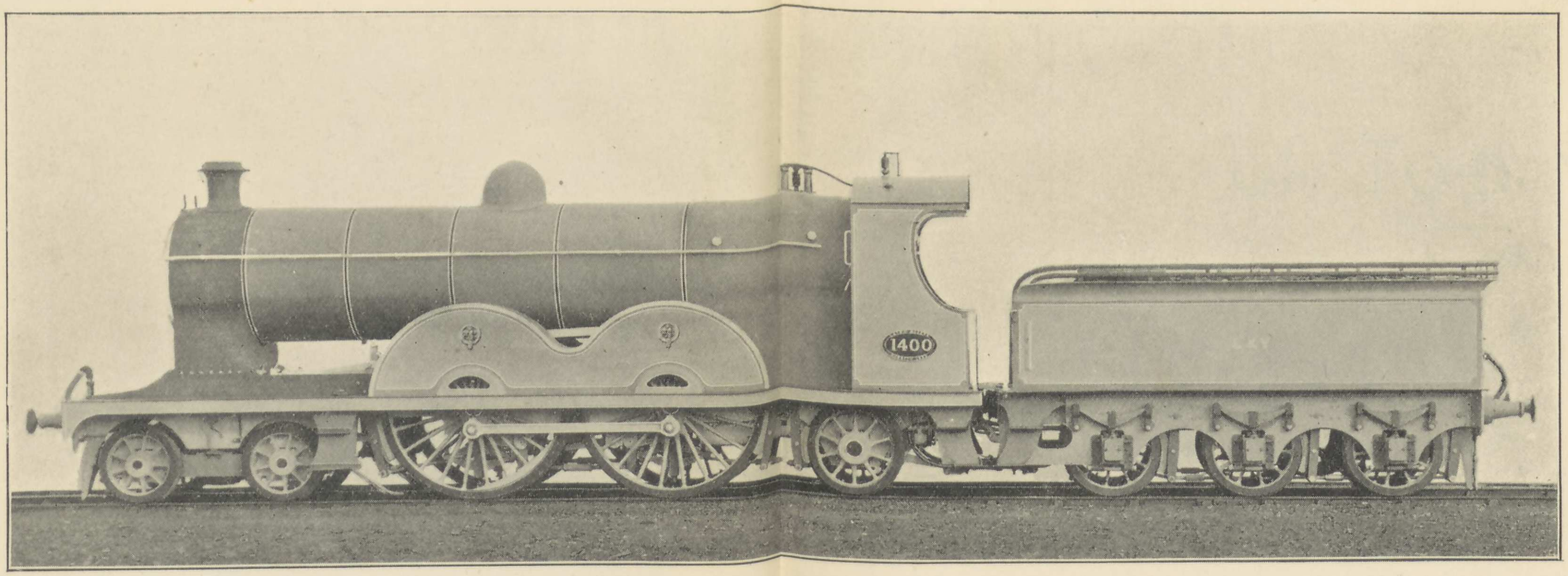

PLATE I.—TEN WHEELS FOUR-COUPLED BOGIE EXPRESS ENGINE, LANCASHIRE & YORKSHIRE RAILWAY.

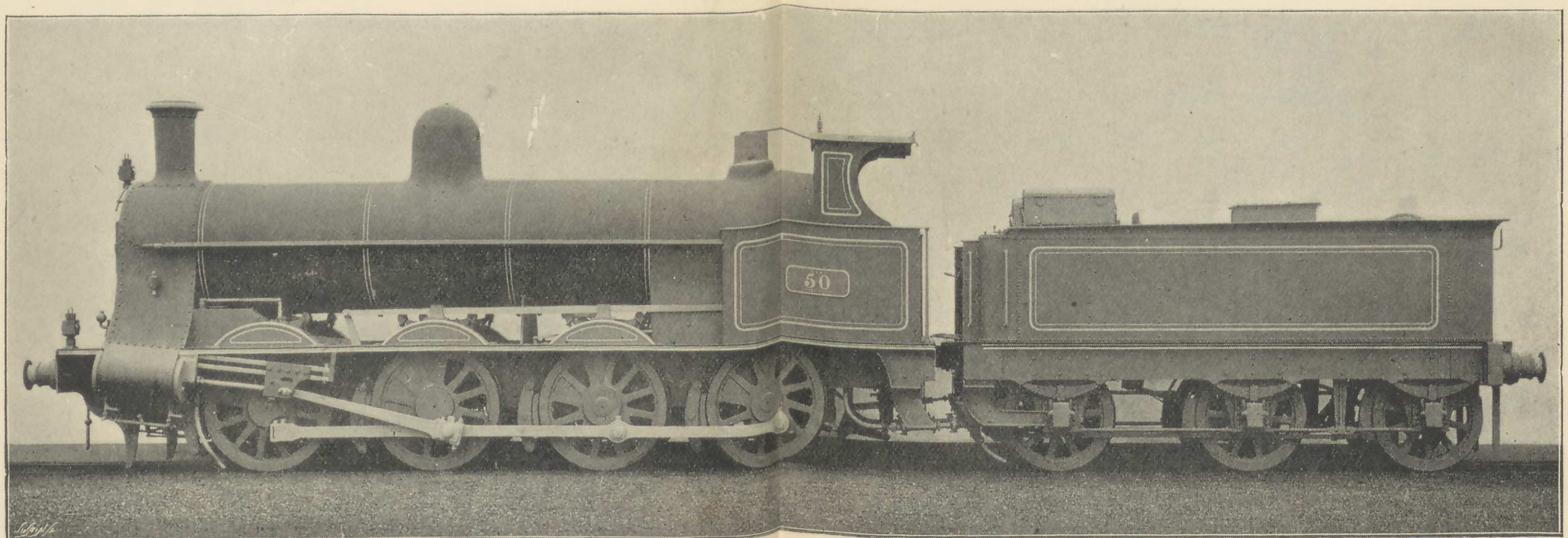

PLATE II.—EIGHT WHEELS COUPLED COMPOUND MINERAL ENGINE, LONDON & NORTH WESTERN RAILWAY.

THE LOCOMOTIVE OF TO-DAY.

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"THE LOCOMOTIVE MAGAZINE."

THIRD EDITION.

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INTRODUCTORY.

The modern locomotive, as we see it to-day, incorporates the combined efforts of many master minds, and although the general character of the earlier engines has not been radically departed from, the details have been greatly improved and the dimensions considerably increased. This addition in size is not so apparent when comparing English engines as foreign ones, for the reason that the loading gauge adopted for the English railways is more limited than that chosen by our friends over the seas; consequently our locomotives not only have, but probably always will have, to be more closely built.

A comparison of weights will give a more graphic impression: where the engine of 1830 only weighed from 8 to 10 tons, that of to-day often turns the scale at between 45 and 50 tons, yet the height from rail to chimney is approximately the same, and the extreme width will only vary a few inches. The locomotive of 1900 is more solid and compact than its predecessor of 70 years ago.

Our remarks are confined chiefly to the details of British locomotives, but at times reference is made to Continental and American practice, as comparison often adds interest. Each section is devoted to some member of the locomotive organism, and as the engine must primarily be dependent for power on its steam generator, we take first the boiler, following with the engine, cylinders, motion, etc., and finally deal with the carriage, running gear and tender.

The contents of this book have been carefully revised since their original appearance in *The Locomotive Magazine*, and illustrations of some typical examples of modern practice added, together with their chief dimensions.

PREFACE TO THE THIRD EDITION.

The success of the previous editions of this book has prompted us to go to press with a third and revised edition. Whilst the contents include nearly the whole of the matter of the previous issues, they have been enhanced by the addition of further illustrations and descriptive notes. For the facilities for reproducing the working drawings of the four wheels coupled express engine of the Great Northern Railway we are indebted to the kindness of Mr. H. A. IVATT, the locomotive engineer of that system.

That our efforts in compiling this work may prove of assistance to those whose daily calling brings them in close contact with the "Locomotive of To-day," is our sincerest wish.

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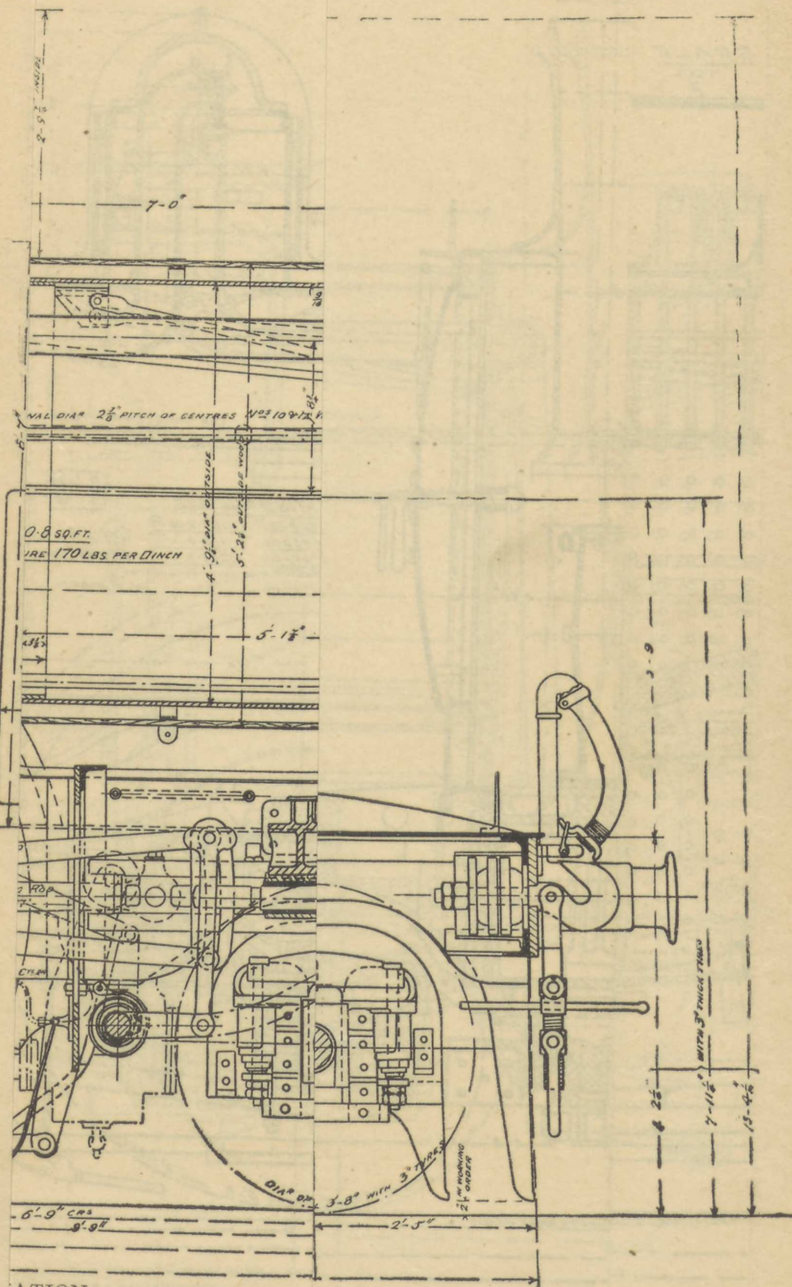

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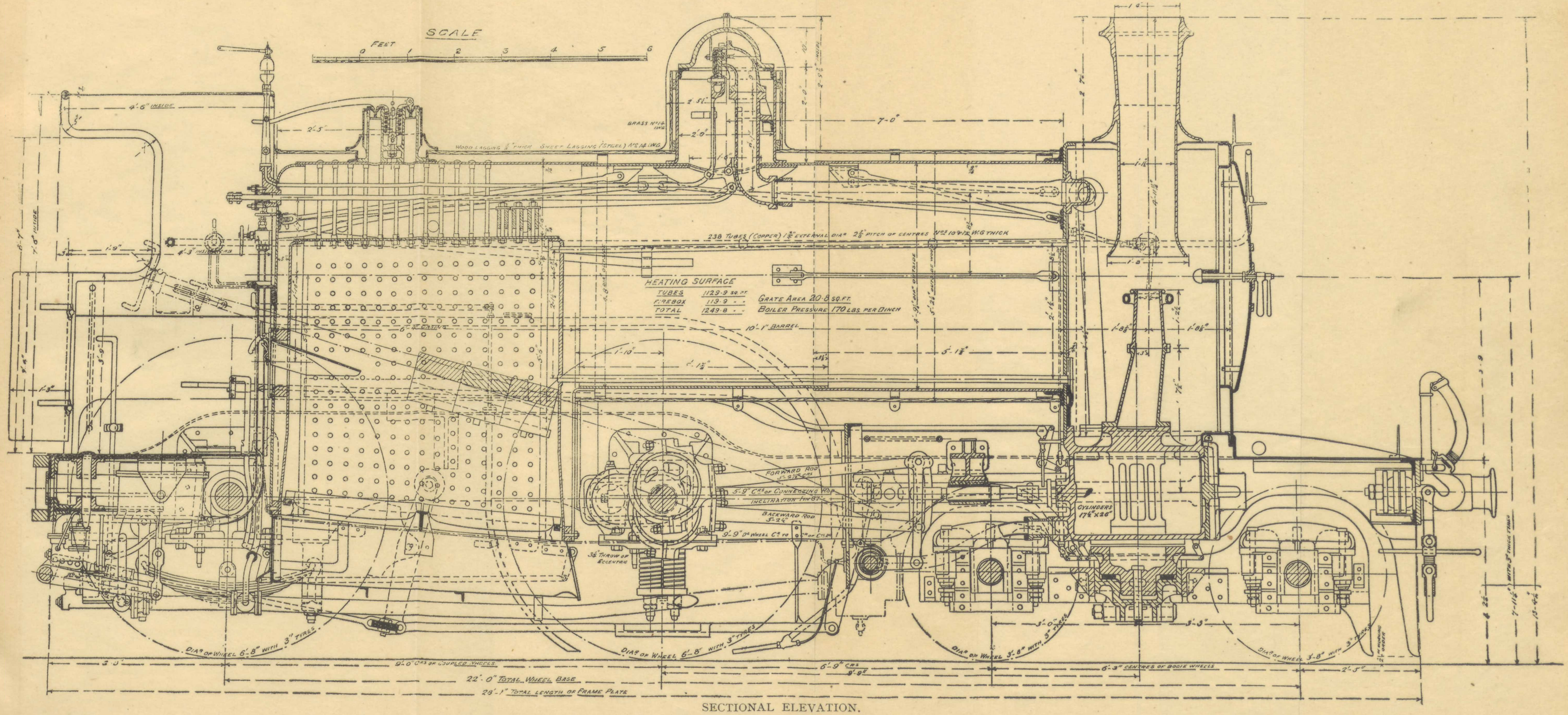
Designed by Mr. H. A. Ivatt, *Locomotive Engineer, Doncaster.*



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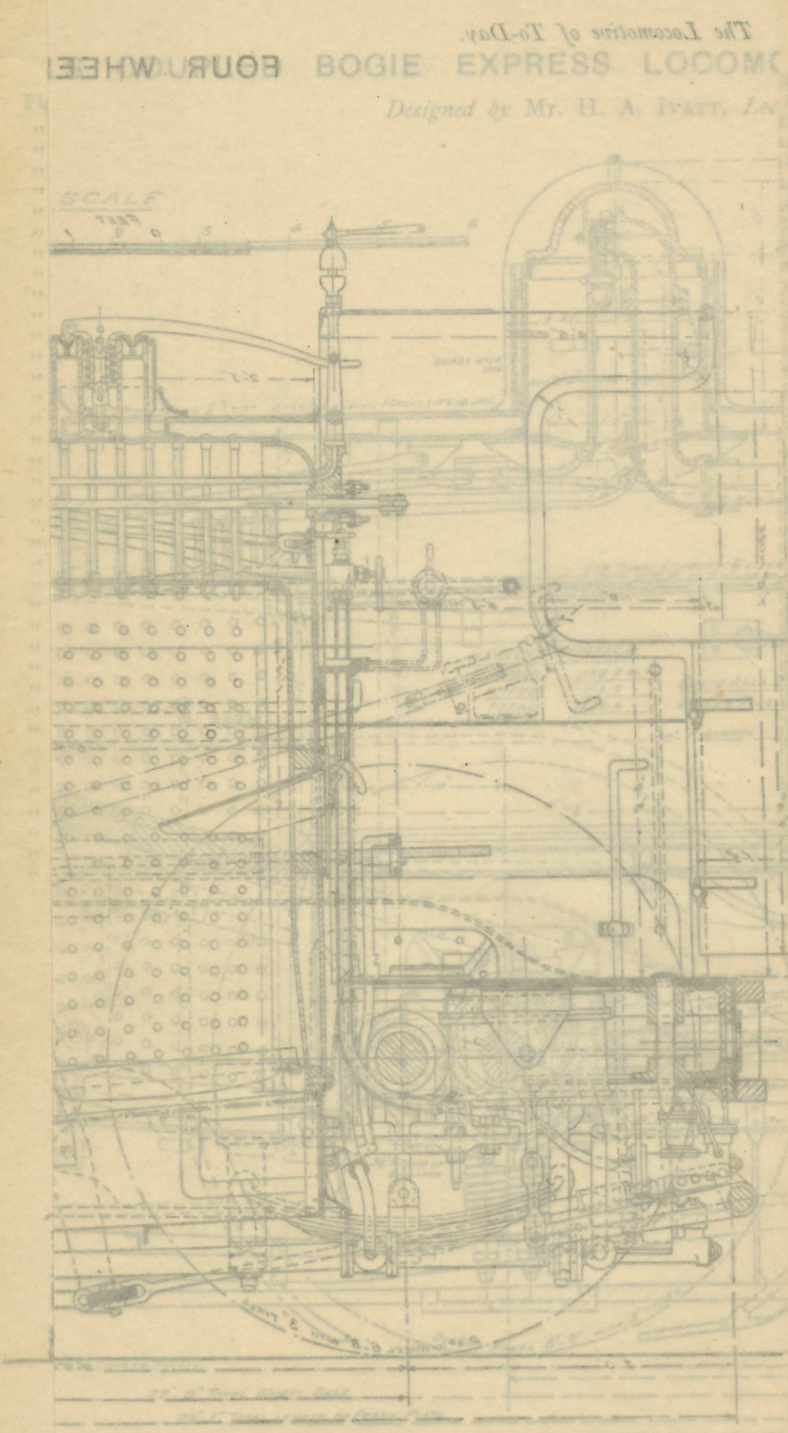
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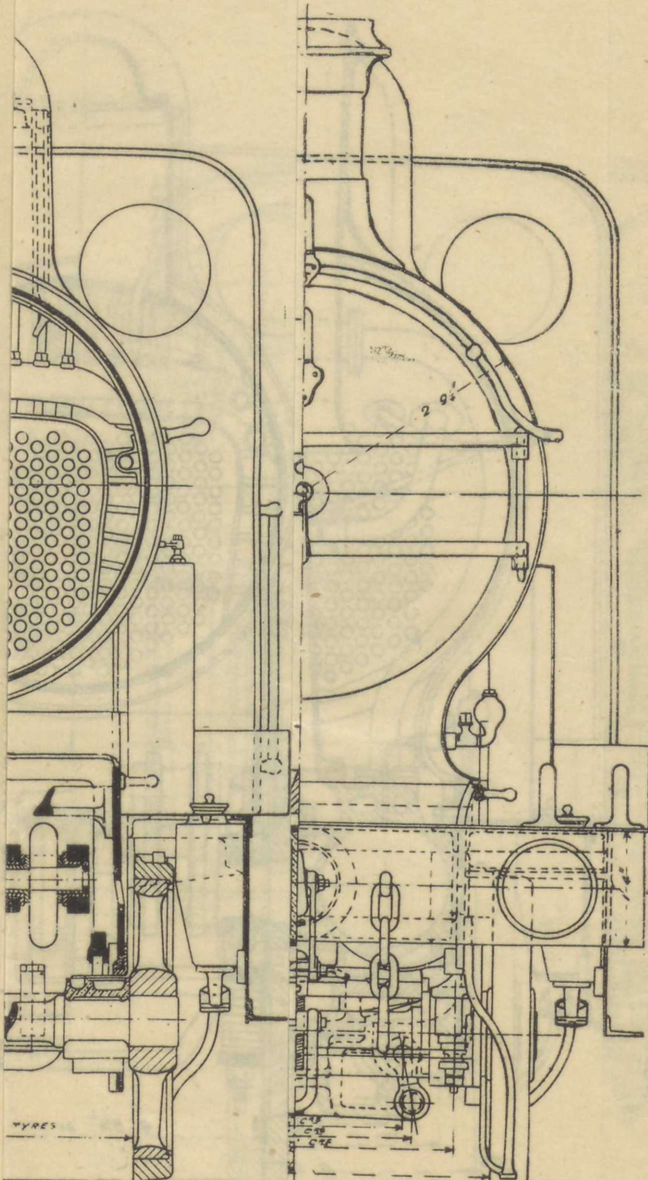

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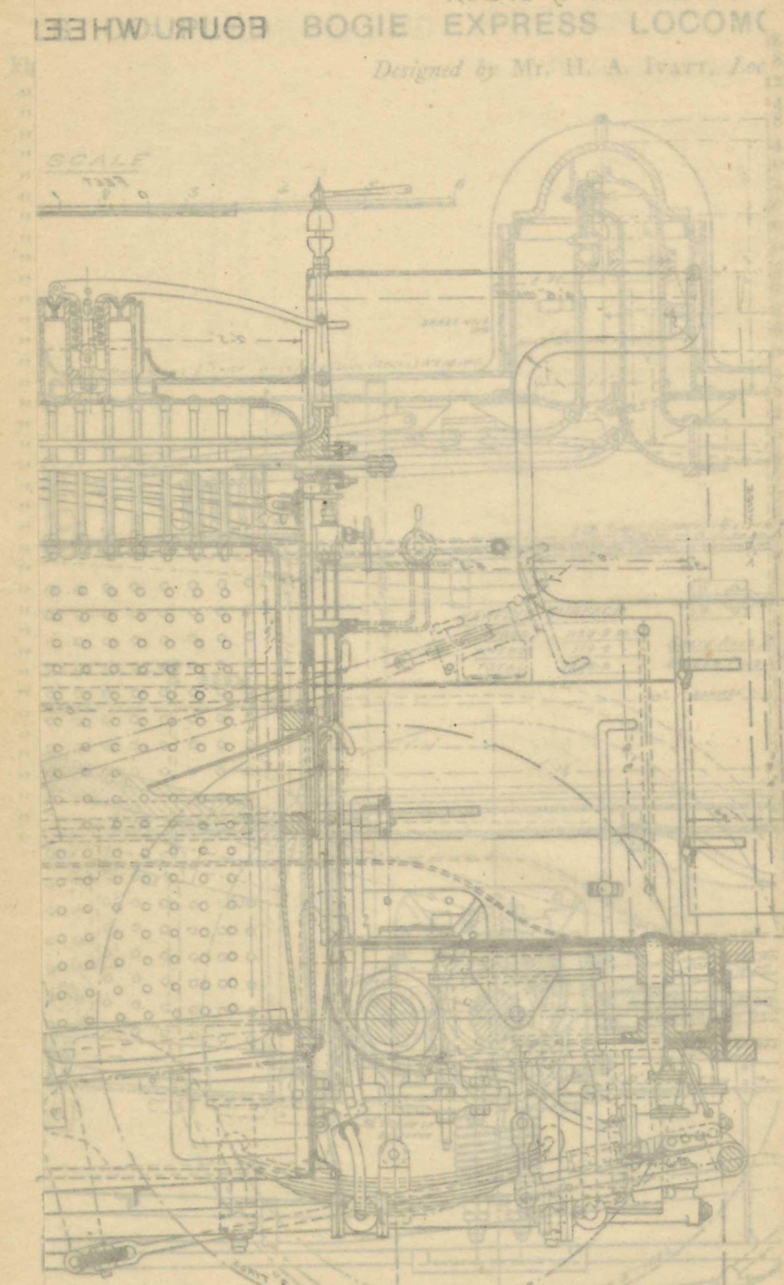
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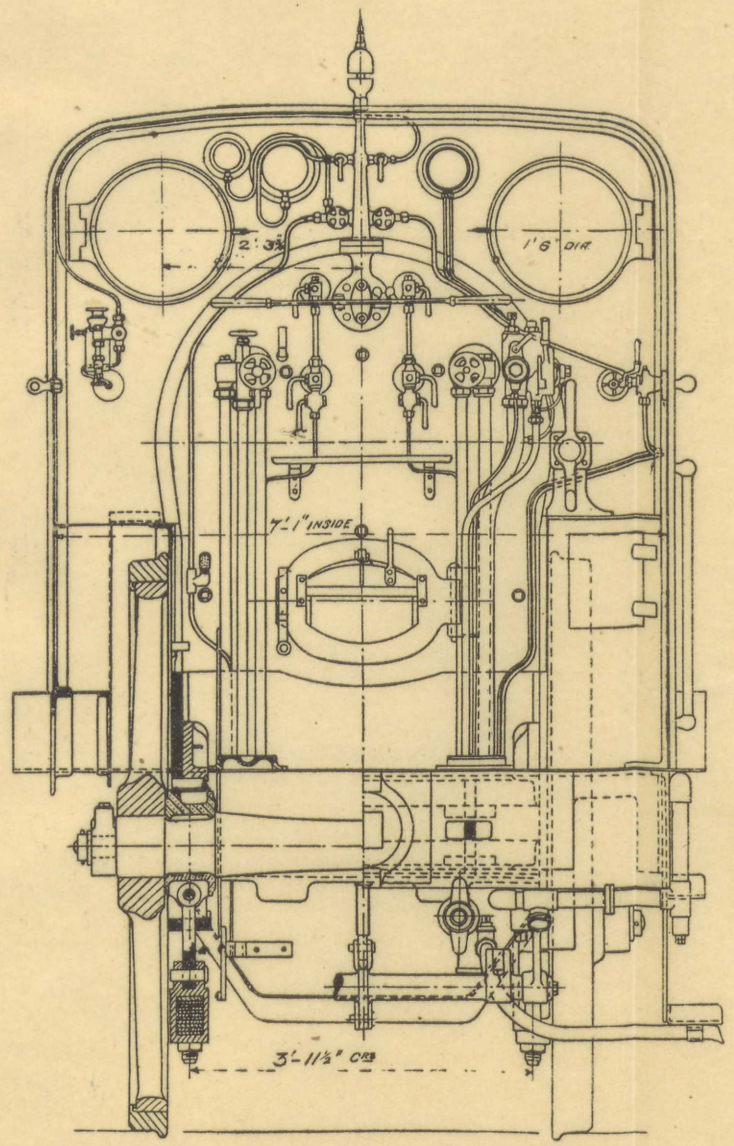

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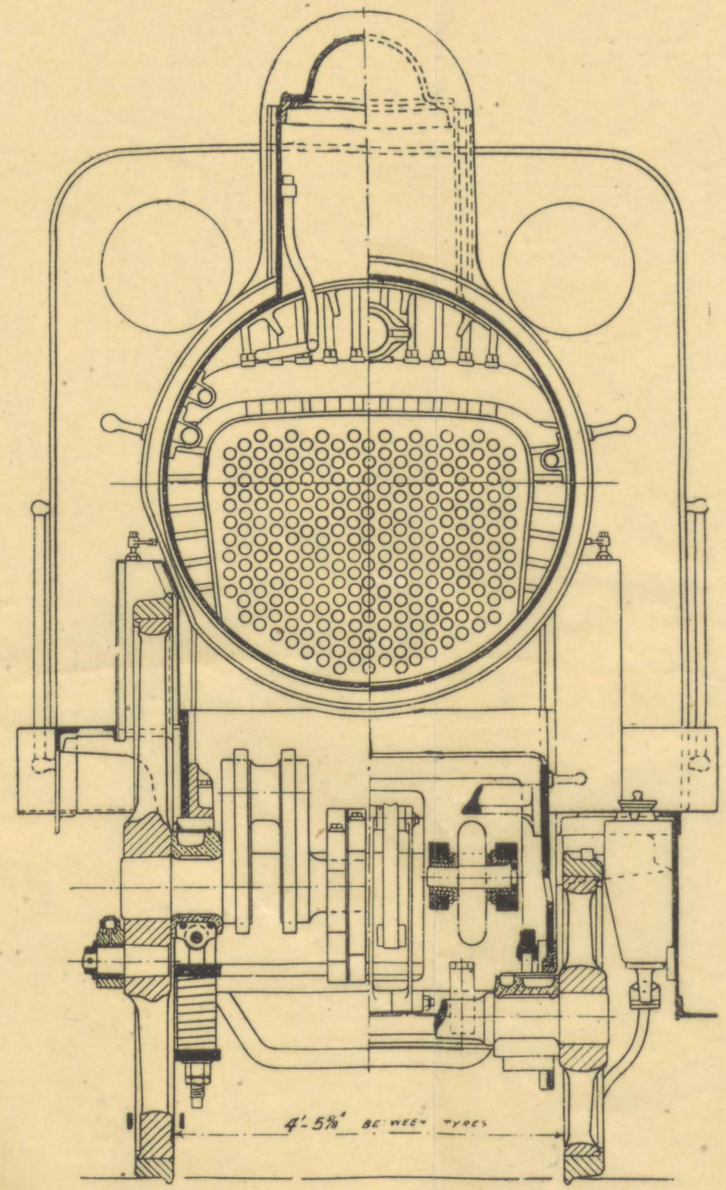

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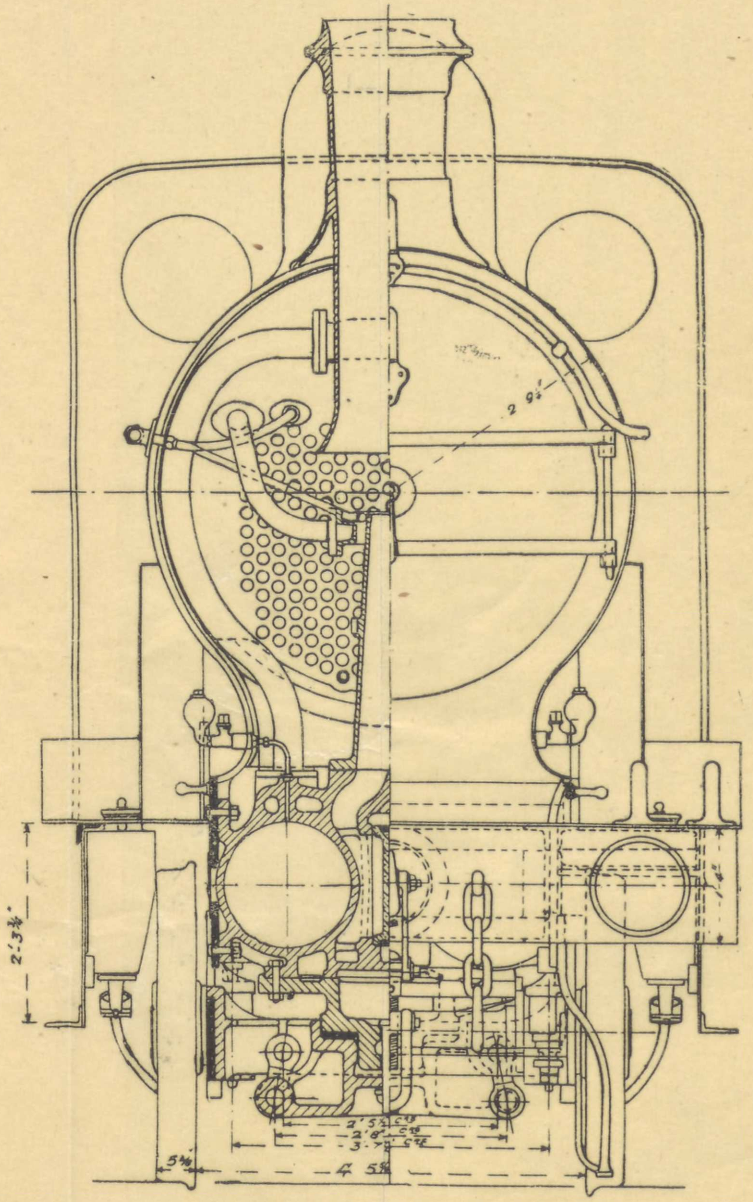

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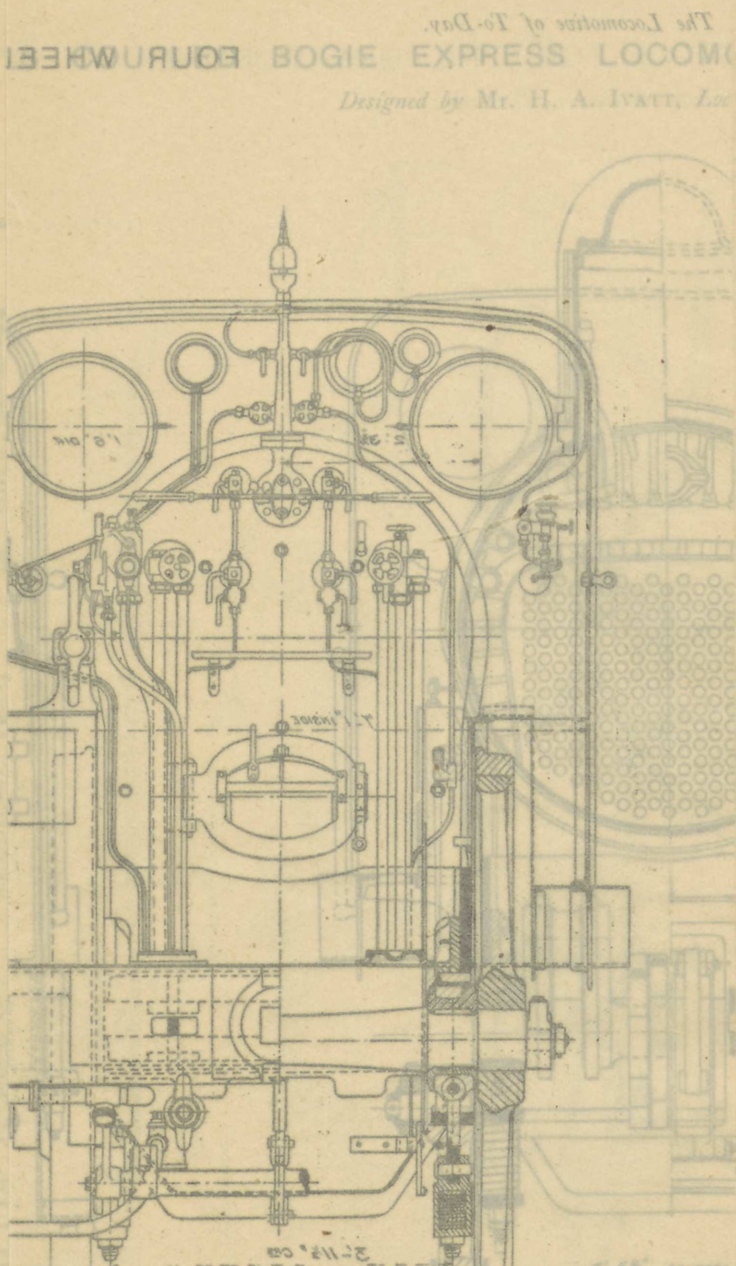
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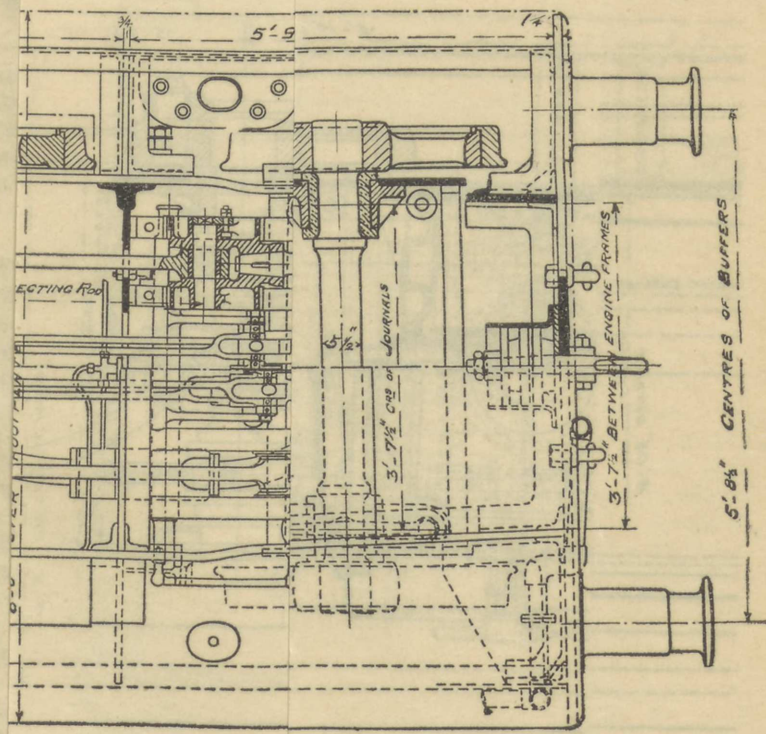

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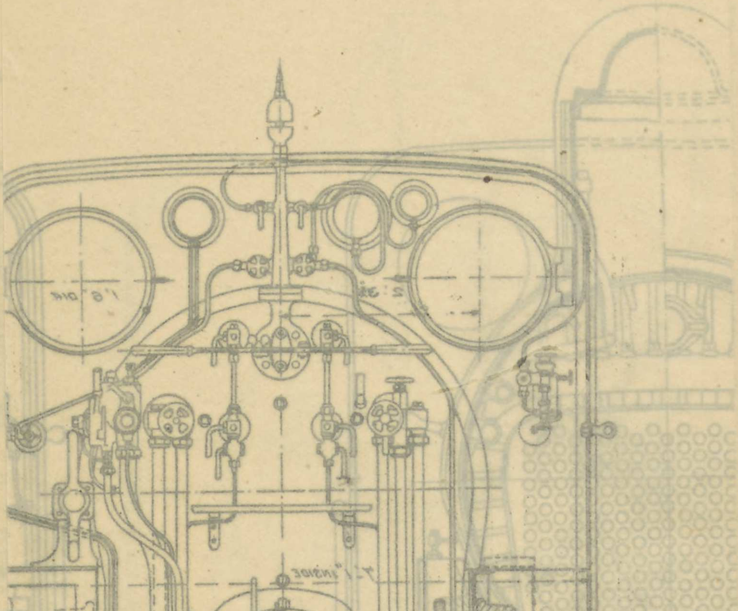

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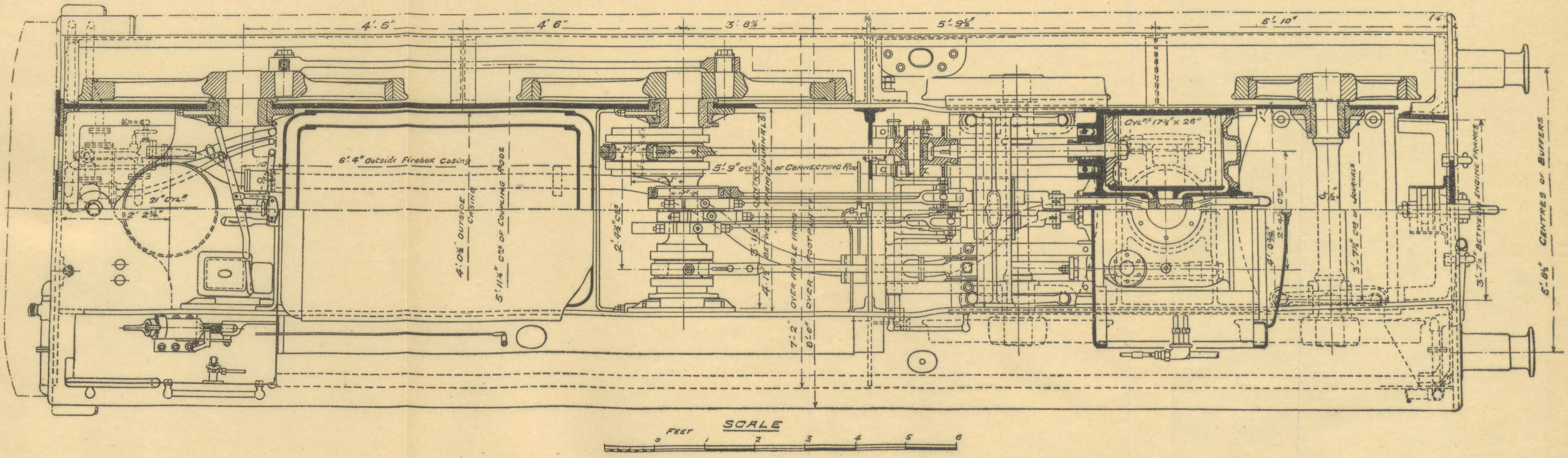
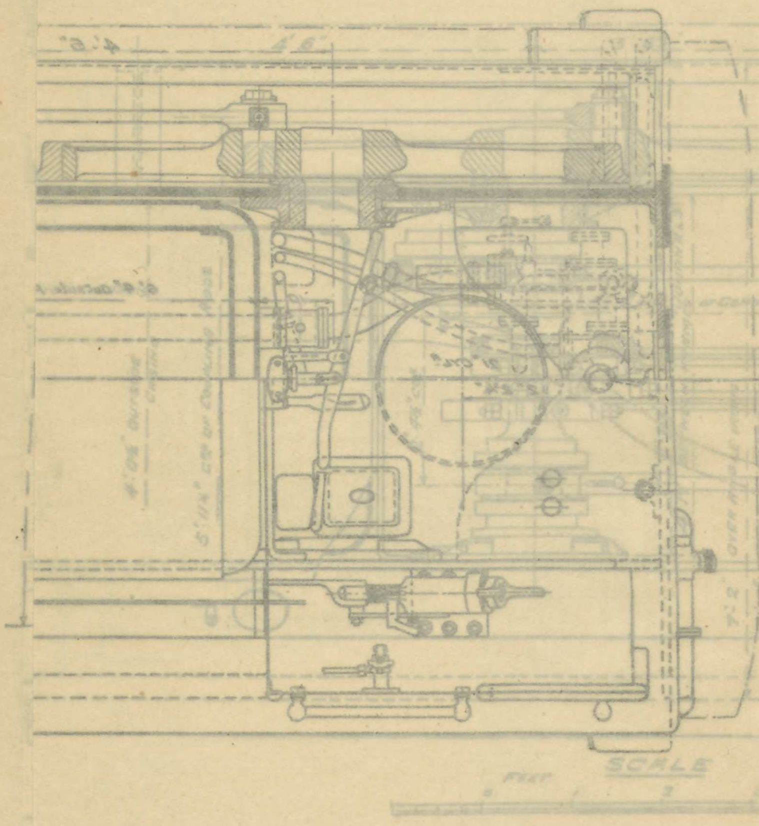
HALF SECTIONAL PLAN.



HALF PLAN.

BOGIE EXPRESS LOCOM

Designed by Mr. H. A. Ivatt, *Loco*



THE LOCOMOTIVE OF TO-DAY.

SECTION I.—THE BOILER.

ALTHOUGH not the most economical steam generator, the modern locomotive boiler possesses numerous advantages. It is a quick steam producer for its size and weight, can be readily forced when occasion demands, and in shape is admirably adapted for its particular purpose. It is, however, expensive, and many attempts have been made to substitute a less costly construction, but although some of these have been partially successful, the fact remains that the improved boiler of the "Rocket," of Rainhill fame, is the accepted model for the locomotive boiler of to-day.

It may be described as an internally fired horizontal multitubular boiler, consisting essentially of four main portions:—The inner firebox, the outer firebox or shell, the barrel containing the tubes, and the smokebox. Referring now to our illustration, Fig. 1, at one end of the boiler, in the inner firebox the fire is placed and the heated gases from it are conducted through a number of tubes or flues arranged in the barrel, and around which the water to be raised into steam circulates, to the smokebox at the other end, and thence to the chimney. With the number of tubes employed, usually from 200 to 250, it will be seen that the heating surface in contact with the water is very large, but even then to make sufficient steam to keep the engine supplied it is necessary to urge the fire artificially to increase the rate of combustion. To do this the exhaust steam escaping from the engine cylinders is utilised. It is emitted from a so-called "blast pipe" below the base of the chimney, and almost any desired intensity of draught can be obtained by contracting this outlet for the exhaust steam. Every stroke of the piston sends a discharge of steam through this "blast pipe" up the chimney, withdrawing a percentage of the contents of the smokebox with it, and leaving a partial vacuum in that chamber, and it is to destroy this that atmospheric air rushes through the fire from beneath producing the rapid combustion desired. Passing now to the construction of the boiler, the inner firebox first demands attention. In the early Bury locomotives this was

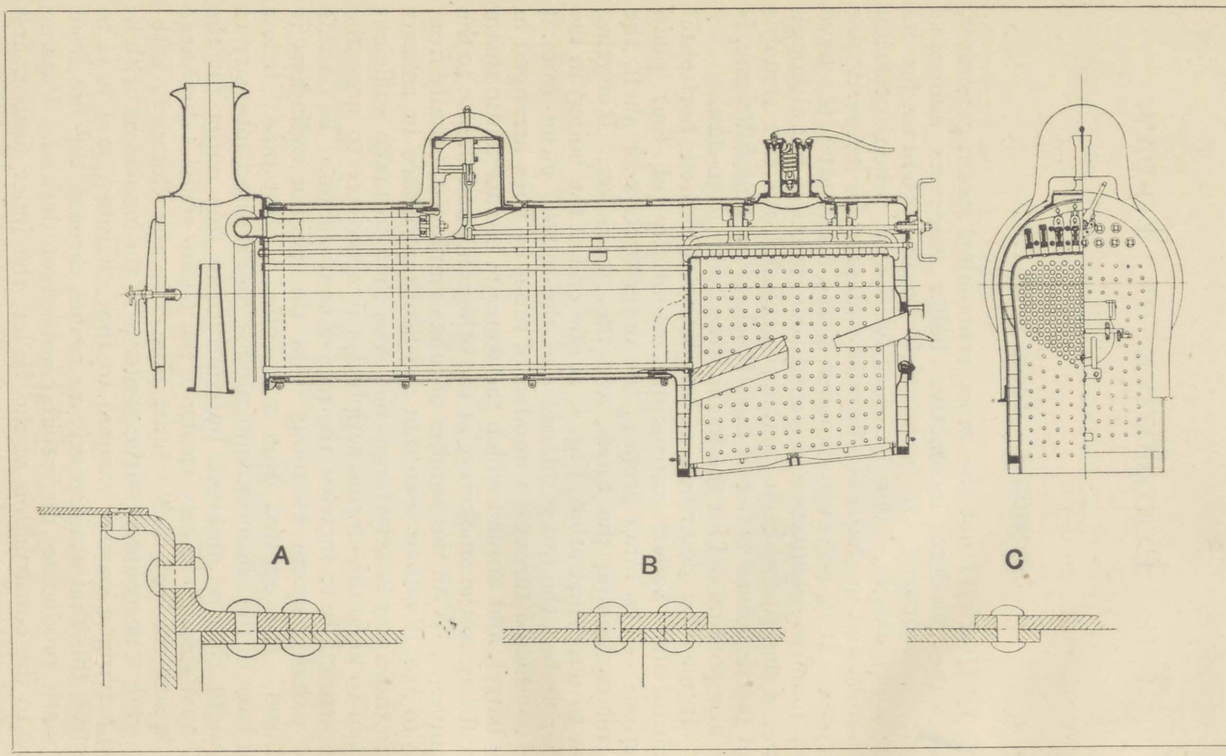


FIG. 1.—MODERN LOCOMOTIVE BOILER.

cylindrical in form, but in all recent engines it has been made rectangular, roughly a box, with the sides and top or crown in one sheet rolled to the requisite shape, the front or tube plate and back plate are flanged over on three edges to fit inside this sheet and are rivetted to it. This internal firebox is usually entirely surrounded with water, except at the bottom where the firegrate is placed. The majority of inner fireboxes are of copper, but a great number of steel ones are now in use. When of copper the metal may be $\frac{1}{2}$-in. to $\frac{9}{16}$-in. thick throughout, except that portion of the tube plate which is drilled to receive the tubes, where, to secure a good joint, the plate is thickened up to about 1-in. When steel is used, the plate would probably be $\frac{1}{4}$-in. thick with $\frac{1}{2}$-in. at the tube plate.

The outer firebox or shell is commonly built up of three plates—the wrapper which is rolled to form the sides and top, the throat or saddle plate which forms the front, and the back plate which has the firehole through it and acts as an end to the boiler. These latter are flanged to form the corners, either by hand on suitable blocks, or, as is now more customary, pressed to shape in a hydraulic press. The outer shell is rivetted to the inner firebox through the foundation ring, forming the bottom of the water space, and also round the firehole. The wrapper plate has a manhole on the top, which may be used as a seating for the safety valves; it is of steel, or best Yorkshire iron from $\frac{1}{2}$-in. to $\frac{9}{16}$-in. thick. The rivets are of best iron or mild steel.

The barrel is the portion which contains the tubes, and is usually made up of two or three plates which are rivetted together with either "butt" or "lap" joints; when "butt" jointed, the barrel is parallel throughout, but if "lap" jointed, it is often telescopic with the smallest ring at the front end. Longitudinal joints are usually double plated "butt" joints. The front tube plate forms the end of the boiler, and in the majority of cases is attached to the barrel by an angle ring. It is frequently customary to rivet the smokebox to the tube plate.

When a steam dome is used it is placed on one of the barrel rings. It is the dry steam collector, and within it the regulator is usually placed; pipes also lead steam from it to several of the valves on the boiler front.

The barrel plates are about $\frac{9}{16}$-in. thick, the front tube plate $\frac{5}{8}$-in. or $\frac{3}{4}$-in. thick. The dome is either built up of the same material as the barrel, or is cast in brass, iron, or steel, certain designers placing the safety valves upon it.

All flat surfaces in the boilers are strengthened by means of stays to resist the pressures commonly employed, which vary from 120 to 200 pounds per sq. in., and all rivetting now, is as far as possible done by hydraulic power. Seams and joints are caulked by having a blunt tool smartly hammered along the edges of the plates; mechanical caulking tools are largely employed for this operation.

The exposed portions of the boiler are lagged or covered with a non-conducting material to prevent, as far as possible, loss of heat by radiation. Felt, preparations of asbestos, silicate cotton, but more often wood, sometimes covered with a fire-resisting compound, are used for this purpose; the whole is then covered with cleading plates of steel, held in position by means of bands. It is also a practice on some railways for these cleading plates to be made a good fit to enclose a layer of air, which is alone relied on for non-conduction.

In Fig. 1 sectional drawings are given of three forms of joint usually employed in connecting the various parts of locomotive boilers together. A shows the angle iron joint between the barrel, front tube plate, and smokebox. B a specimen of single plate butt jointing where the plates to be connected have their ends brought together in the same plane and a cover strip rivetted on one side only. This joint is the one often employed for securing the rings of the barrel together. Longitudinal joints are also made in this manner, but with a cover plate on each side and double rivetting. C shows a lap joint where one plate overlaps the other; the outer firebox shell is usually fixed to the barrel by means of a lap joint.

Best iron or mild steel rivets are used with both steel and iron boilers for the seams round the inner copper firebox, and the joints round the foundation ring and firehole. Snap heads or their equivalents are employed where possible, but a close fit at places may necessitate a few "countersinks."

As already mentioned it is necessary that all the flat surfaces in a locomotive boiler should be well stayed or supported to resist the high pressure generated within. The inner and outer fireboxes having flat sides, back and front, more or less parallel to each other, with pressure between which tends to force them apart, are tied together, as it were, by means of screwed stays or stay bolts. The holes to receive these are either punched or drilled through the wrapper plate before it is bent to shape, and are drilled through the inner box after it is built up and rivetted together, this latter being then secured in its appointed place by rivetting round the foundation ring and firehole. With the fireboxes in position the stay holes are tapped by means of a long tap having fine threads of 11 or 12 to the inch, and the screwed stays are then driven in, either by means of a "stud wrench," holding the extreme end of the round stay, or with an ordinary tap wrench taking a square head, made on the stay for this operation and afterwards cut off. When screwed in the stay should stand with about $\frac{1}{4}$ of an inch projecting through both plates, inner and outer; this projection is hammered down to form a head and to ensure a good steam tight joint. The above methods refer chiefly to copper stays, as shown at A, Fig. 2, or to wrought iron when used; with the steel ones, now adopted on several English railways, it is customary to drill a hole of say $\frac{3}{8}$-in. diameter into both ends of the stay about 1-in. or $1\frac{1}{4}$-in. deep, as shown at B, so that the ends can be expanded in the plates by hammering a hard steel drift into these holes. With steel stays the screwed threads are turned off the middle portion and the diameter reduced to secure greater flexibility; copper stays are usually screwed their entire length, but undercut along the middle portion to ease the thread. Recently stay bolts of phosphor bronze, with longitudinal saw cuts at right angles down the central part to secure flexibility, have been introduced with success.

The stays may be $\frac{7}{8}$-in. or 1-in. diameter, and if pitched 4-in. apart, each will support 16 sq. in. of plate at each end. Some makers drill a small hole through the longitudinal centre of the stay, so that should one break the steam and water will escape through it and give warning; without this hole the stay breakages can only be detected by tapping with a hand hammer on the ends and carefully noting the sound. Examiners accustomed to this work get so skilful that they rarely pass a defective stay. When it becomes necessary to take out the inner firebox all the stays must be removed, either by drilling, punching, or tearing out with pneumatic or hydraulic tools; in any case the screwed holes, especially in the copper plates, are liable to damage and require re-tapping, it is thus seldom possible to use stays again of the original diameter, and they are usually replaced by new ones of larger size. In renewing broken stays with the boiler in position, it is not possible to get at the outside ends of those immediately behind the frames or tanks to rivet them over, and the stays must therefore be screwed in a very good fit to get a steam tight joint. In screwing in, this tightness imparts an initial torsional strain to the stay, which may prove detrimental to its life. Copper stays possess many advantages over their wrought iron and steel rivals, as not only are they admirably suited to the various twisting strains that the expansion and contraction of the two fireboxes subject them to, but the superior heat-conducting properties of copper are greatly in its favour when used for this purpose.

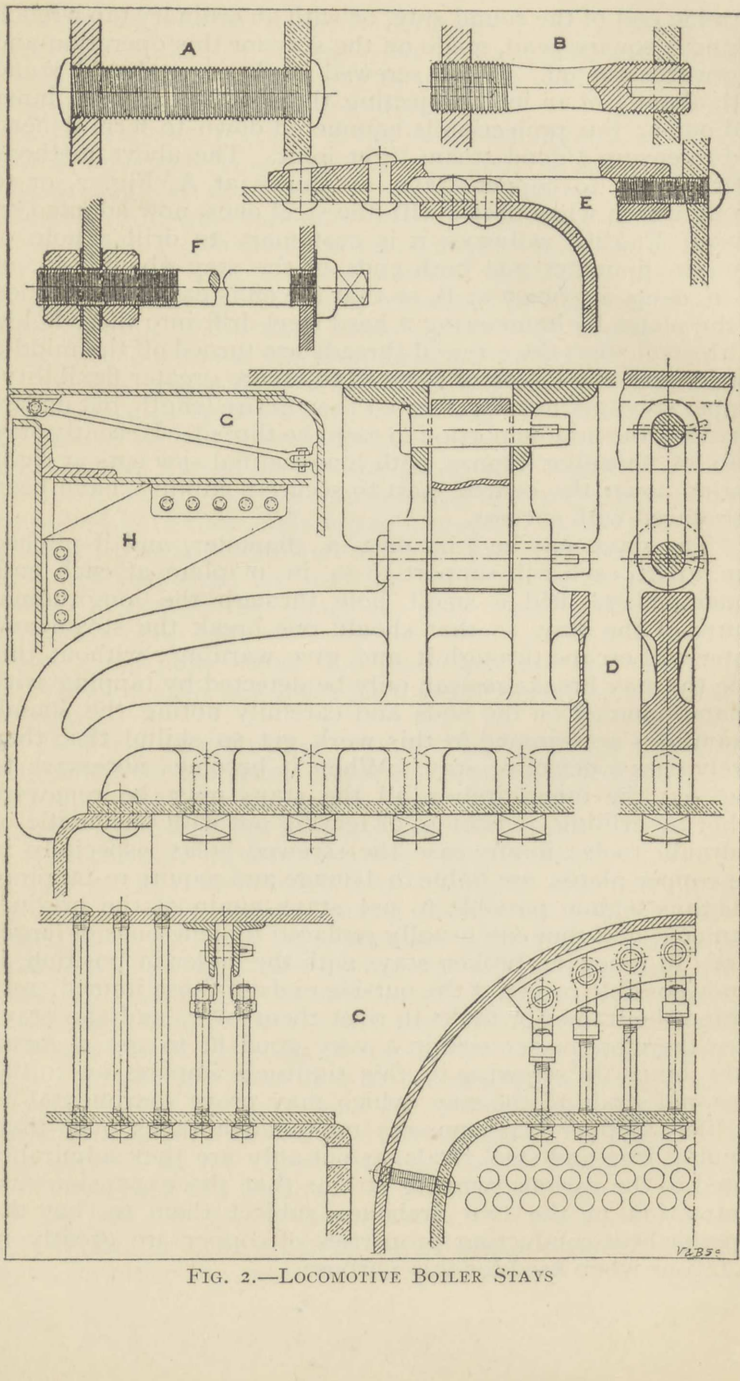


FIG. 2.—LOCOMOTIVE BOILER STAYS

The crown of the firebox is supported either with direct stays to the outer shell or with girder stays. When direct stays are employed they are passed through the crown to the outer plate, the end inside the firebox having a square to fit a spanner, whilst the other is hammered over to form a head after the stay is screwed home, the holes, of course, being previously tapped to receive them. When the fire is first lighted, the gases passing through the tubes heat the tube plate more than any other part of the box, and it naturally follows that this expands more than any other portion ; to allow for this expansion the first two rows of stays are made of special form, which will permit of an upward movement of the box, but will resist collapsing when subjected to pressure; this construction is shown in sectional views at C in the plate. When girder stays or roof bars are used, the crown plate is fixed to them by means of bolts, so that it is independent of the outer box, though some of the roof bars are usually connected to the outer shell by sling stays as a precaution. These girders may be built up of stout plates, fixed together at the ends and about $1\frac{1}{4}$-in. apart, having stay bolts passing up through the crown plate and between them, the heads being inside the box, and the nuts on the top of the girder ; but more generally now, they are cast in steel with lugs provided along their length for the reception of short set bolts, which are screwed into them up through the crown plate. D shows in part elevation and in section, one of these girders the ends of which are made to fit and take a bearing on the top corners of the box sides or ends, according to whether they are arranged transversely or longitudinally. Another form of crown staying has been introduced with half girders, the rear half of the crown plate being fitted with transverse stays, each of which extends to about the centre of the box where it is supported by a sling stay ; the front half of the crown is also supported in a similar manner by longitudinal girders, with their front ends resting on the tube plate and the back ends hung from the firebox wrapper plate by a sling stay. This method has been adopted to avoid too great rigidity and allow for the expansion of the plates.

Direct crown stays are to be preferred when the water used is very dirty, as they permit greater freedom for it to circulate and for steam bubbles to rise, and thus to an extent, minimise the formation of scale; they also allow the scale and dirt that does accumulate on top of the box to be more easily removed. They do not, however, let the firebox have the same amount of freedom for expansion as the girder stays.

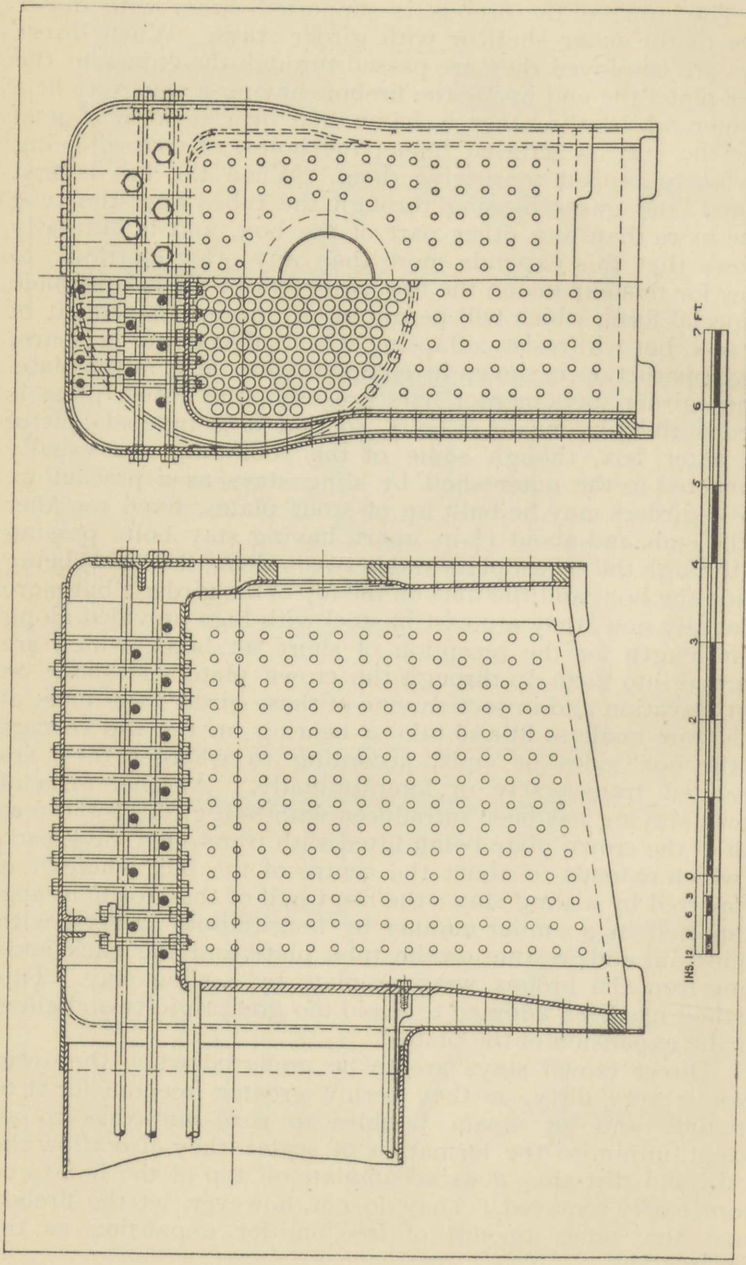


FIG. 3.—BELPAIRE FIREBOX.

The corners of the internal firebox should be made of large radius, so as to dispense with the necessity for a too close staying there, thus permitting more flexibility than could otherwise be obtained.

The portion of the firebox tube plate, immediately below the tubes, is connected to the barrel by palm stays, E., which are flattened at one end to take rivets for attachment to the barrel, and are provided with a boss at the other, drilled and tapped to receive set bolts. These latter may be of copper, screwed in and hammered over, the same as the other stays; or they may be of iron, and have cupheads and squares, the latter being used to screw the stays home, and afterwards cut off with a hand chisel. In some recent boilers these palm stays have been dispensed with by flanging the throat plate of the firebox to a small radius and having a row of stay bolts close up to it.

As to the ends of the boiler the upper parts of the front tube plate and back plate are the only portions usually stayed. These may be connected together by longitudinal stays of round bar iron or steel of about $1\frac{1}{4}$-in. diameter passing through the full length of the boiler from back to front. They are screwed into holes in the back plate, tapped large enough for the front screwed portion of the stay to clear, and this latter is secured to the front plate by nuts on each side of it. All the joints are made with washers of sheet copper. F shows this form of longitudinal stay, which being heavy, is supported at the centre to prevent sagging by bearers provided across the barrel for this purpose.

Another method of longitudinal staying is by stay bolts that do not run the entire length of the boiler, but have feet which are rivetted to the barrel plates, or forked ends connected to angle irons attached to the barrel at various points in its length, with either screwed ends for nuts, as described for the long stays, or forked ends which embrace T irons rivetted on to the back and front plates respectively, as at G. A third method is to provide "gusset" or plate stays, which are formed of pieces of plate connected to pieces of angle iron rivetted to the barrel, and end plates similar to H in the Fig.

The remaining flat surface of the boiler is that portion of the tube plate that receives the tubes below the above-described longitudinal stays. Here in some examples a few of the tubes are made thicker, screwed in, and fitted with check nuts, whilst in others longitudinal stays are distributed among the tubes. It is not usually considered necessary to support these plates, however, as the tubes themselves act as stays, and the area of plate exposed to pressure is inconsiderable.

As the bosses on girder stays hamper the rising of the steam bubbles, as well as take up a large portion of the heating surface of the top of the box, and as direct stays, when connecting the flat top of the inner box to the semi-circular wrapper plate, are not always satisfactory, a form of box has been largely used in which these objections are removed. It is called the "Belpaire" from its originator, and is illustrated in Fig. 3; the outer wrapper plate is made flat on the top, and the inner one parallel to it, these are tied together by direct stays similar in character to those employed at the sides of the box, excepting that these top stays are usually of iron. The first two rows have means by which greater vertical flexibility is given to the front of the box, as before described for direct stays. Cross stays are also necessary for the flat sides of the outer wrapper above the inner box. Another advantage this box has is the greater facility afforded for cleansing the top of it, since side washing holes, as well as those at the back, can be put in if required.

In good practice, on the inside of the boiler, a stiffening ring or plate is rivetted round the holes cut in the barrel for the reception of the dome and safety valve seating, as the cutting of the plate interrupts the true circular form, and weakens the boiler at these places.

The chief features in the design of locomotive boilers are to make every part as easily accessible as possible, to facilitate the periodical cleansings such a boiler necessarily requires, and to provide for repairs being executed as cheaply and expeditiously as possible.

The mode of fixing the boiler in the frames of the locomotive next requires consideration. The front tube plate is continued down below the barrel, and rests on and is bolted to the back of the cylinder casting in inside cylinder engines, and to a distance casting and frame stay in outside cylinder engines, thus holding the boiler rigid at this end; but as the barrel necessarily expands when heated, the firebox end is carried by some arrangement of expansion links or brackets. The most common form of "expansion bracket" consists of an angle piece rivetted or bolted to the outer firebox shell about the level of the top of the frame. This angle rests and is permitted to slide on a level bed provided for it; it is kept in place and prevented from rising by a grooved block bearing lightly on its upper surface. The boiler is thus free to expand longitudinally; to steady it laterally, a plate may be secured to the back plate of the firebox with a stout pin projecting and engaging in a suitable socket prepared for it in the foot plate casting of the engine. Another method of securing the boiler from lateral movement is by means of a cross plate bolted to the firebox, and fitting between the frames of the engine, slotted holes allowing longitudinal movement for the ends on the retaining bolts.

In many of the earlier engines a support was provided for the barrel of the boiler about midway of its length, either by carrying up the motion plate high enough to form a saddle or by making a plate connection to the frames, but in modern engines such supports for the barrel are now commonly omitted.

The internal firebox is, as already stated, usually made of copper in this country, the advantages of this metal being its uniformity and homogeneity of texture, freedom from lamination and blister, and general trustworthiness when well selected, its great resistance to oxidisation and the corrosive action of various waters, the manner in which it resists tenacious adhesion of most kinds of scale, its great ductility and malleability which render it capable of being worked with great ease, and its capability of bearing sudden and repeated racking strains. Further, it is an excellent conductor of heat, and is well able to resist the wasting action of a fierce, forced fire; the plates are about ½-in. thick when new.

The joint round the bottom of the box is made by means of a foundation ring of a width equal to the thickness of the water space, or to the distance left when the inner firebox plates are set out towards the outer shell at the bottom; in either case rivets are passed through the two plates and ring to form the joint. The setting of the plates requires to be very exact to ensure a good job, and the radius of the corners of the box should not be too sharp, or the difficulty of making tight joints is greatly increased. The plates are attached to the ring at the corners by putting rivets through at various angles, or by using set bolts for the outer plates, either of these methods being equally good if carefully executed. The ring should not be cut out to take the lap of the plate, but the plate should be drawn down at the bottom and the ring tapered to suit, as shown at A, Fig. 4.

Firehole joints are made in a variety of ways. We show three of the principal. At B, the back plates of the firebox and shell have holes cut through them of the required shape and size, then a ring of the same thickness as these plates are apart is inserted between them, and the whole rivetted together by long rivets passing through the plates and ring. C shows a modification of this: here the firebox plate is dished out towards the shell, and a much thinner ring is rivetted in;

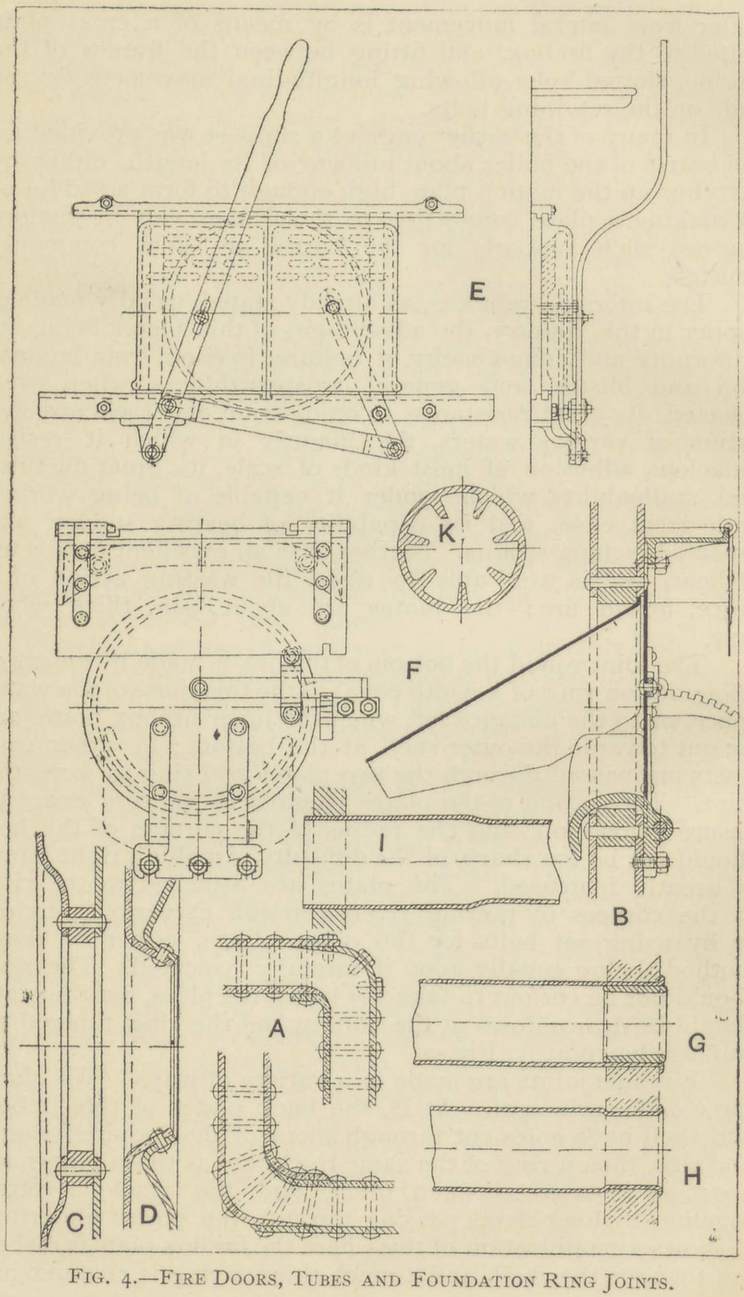


FIG. 4.—FIRE DOORS, TUBES AND FOUNDATION RING JOINTS.

this has been much adopted, as it is claimed to give greater flexibility to the firebox. D gives the third method we shall describe, in this both plates are flanged outwards and form a joint by being rivetted together. The great advantage in this is the removal of the rivets from the action of the fire, but it entails severe working of the plates in flanging.

The position of the firehole is necessarily the same in all ordinary locomotives, being placed so as to be easily accessible from the foot-plate, but the fire-doors vary considerably on different lines. One type largely used is made with two half-doors which slide in grooves, and are worked by a system of levers, so that both are moved to open or shut together.

The doors may be simply plain plates, which must be left partially open for the admittance of air to the fire, or they may be cast hollow, as at E, to allow air to pass up inside the shell then through suitable openings inclined downwards to direct the incoming current on to the fire. Other doors are hinged at the bottom and are opened by allowing them to fall back on to the foot plate, the latch having a sector with notches, so that the fireman can regulate the quantity of air admitted above the fire by partially opening the door on the latch. This door—shown in elevation and section at F—necessitates the use of a flap plate to protect the men from the heat, as well as to keep the flame in the firebox from dazzling the eyes of the driver during darkness. Another popular pattern is made in halves, hinged top and bottom, the bottom portion opening downwards, and the top part upwards, sectors and catches being provided for the top door to admit a greater or less quantity of air as required. Others, again, hinge at the top and open inwards. These act as deflectors for the air admitted during firing, and the amount of opening is regulated as before by catches. In addition to the above methods some doors are made to hinge at the sides, and open similarly to those adopted on stationary boilers.

Air-deflecting plates are provided with those styles ot doors which do not form deflectors in themselves, to direct the incoming atmospheric air downwards on to the fire, and so tend toward the complete combustion of the firebox gases, and also to prevent the cold air from passing direct to the tubes, and causing them to leak by the contraction of their ends in the holes of the tube plate.

The diameter of the tubes or flues of the barrel in British practice is usually from $1\frac{5}{8}$-in. to $1\frac{7}{8}$-in. outside diameter. They are generally 13 S.W.G. thick throughout, but are sometimes made a little thicker for about 18-in. at the firebox end. The metals used are copper, brass, iron, or steel. When of the latter, they frequently have a length of brass or copper, about 6-in. or 9-in. long, brazed on to them at the firebox end in order to make a better joint in the copper tube plate.

With copper, brass, or compound tubes, the joint in the firebox tube plate is made by expanding the tube in the hole prepared for it, beading the end over and driving in a steel or malleable cast iron ferrule to protect the end of the tube from the action of the fire (G). When the tubes are of steel or iron throughout, it is usual to swage down the firebox end to a less diameter than that of the length of the tube, and expand them in the holes, which will, of course, be of smaller size than in the last case, and bead them over, the ferrule being dispensed with (H). The smokebox end of the tubes is belled out to about $\frac{1}{8}$-in. larger than the tube for about 3-in. of its length; it is expanded in the tube plate, but is not ferruled or beaded over (I). The enlargement is made in order to get the tubes in easier, and to facilitate removal when coated with scale; it necessitates the tubes being spaced slightly different at this end than the other. The tubes generally project about $\frac{3}{16}$-in. through the tube plate at each end before beading down.

Carefully conducted experiments and the results of actual practice show that after a few week's work, with ordinary impure water, there is but little difference in the evaporative power of copper, brass, iron, or steel tubes, although their relative conducting powers are 74, 24, 12 and 13. Tubes of the more expensive metals keep cleaner on their external surfaces than iron or steel, due probably to their more rapid expansion and contraction throwing off the scale; but when of copper, they are too soft to resist for long the abrading action of small cinders.

As the hot gases pass through the tubes it follows that the layers of them that are on the outside will give out most of their heat, but through the middle of the tubes a considerable portion of the heat will pass to the smokebox unused; several means of utilising this heat have been devised, and most notable of these is the "Serve" tube, which having longitudinal internal ribs, increases the internal heated surface some 90 per cent., slices up the gases, and abstracts the heat from the centre. K gives a section of this tube. Good results have been obtained with these, although the use of them means a reduction in the number of tubes, as they are made larger than ordinary plain tubes, being 2-in. and more in outside diameter; further, the spaces between the ribs afford a good lodgment for soot, and consequently there is difficulty in keeping them clean.

The evaporative power of a boiler mainly depends upon the efficiency of its heating surface to transfer the heat from the products of combustion within to the water without. For this it relies on both radiation and contact, from two or three hot masses in the boiler, solid incandescent fuel in the firebox, and flame and hot gases in the tubes. The radiation of heat from the solid fuel is greater than that from the flame, while the hot transparent gases scarcely radiate any heat at all.

In estimating the heating surface it is customary to take the area of the firebox and tubes in contact with heat on one side and water on the other, and consider the evaporative power of the boiler as proportionate to the total number of sq. ft. thus found. As all parts of the heating surface, however, do not possess the same efficiency, the heating surface of the firebox being much more effective than that of the tubes, the result so obtained is misleading in practice; adding length to the tubes does not increase the evaporative efficiency of the boiler nearly so much as increasing the size of the firebox.

A flat horizontal surface not too far above the fire, is considered most favourable, and by being made concave to the fire it has the further advantage of being better able to receive and transmit the radiant heat, of boiling off the matters deposited from the water, and so to some extent preventing formation of scale, and of being stronger and more durable. Next in conductive power come the flat sides of the box which are made sloping as they then receive the rays of heat at a more favourable angle, and allow the steam bubbles to escape more freely; they also increase the size of the water space and admit of the use of longer stays at the top of the box where most expansion takes place. The tube plate, although made vertical owing to the rapid impingment of the flame is as effective as the crown, which is too often hampered by the stays, etc.

The great superiority of firebox heating surface is owing to the radiant heat being principally given off there, also to the fact that the more violently the flame impinges on a surface, the greater the ebullition and consequent formation of steam on the opposite side of that surface.

The effective area of tubes internally heated is only half their total area, as heat is mostly given off at the upper surface of the tube, owing to the fact that hot gases being light rise, then on giving off their heat they fall and are replaced by hotter ones; also by the difficulty steam has in escaping from the under side of a tube, and the thickness of soot that too often collects inside the tube at the bottom.

When the fire burns with a long flame the tubes should be larger; but in locomotive boilers by using the brick arch, which retards the passage of the gases to the tubes and so gives more time for the proper combustion of the more volatile parts of the fuel, it is possible to make use of much smaller tubes than would otherwise be the case, and of course get more of them in the barrel and so increase the heating surface. The reduction of the diameter of the tubes is restricted by the flue way it is found necessary to maintain, and which greatly depends upon the strength of the draft. The usual proportion of the collective sectional area of the tubes to grate area is about 1 to 4 or 5. The ratio of the length to the diameter of the tubes is sometimes as much as 120 to 1, and the heating surface is usually about 70 times the grate area.

The general direction of circulation in a locomotive boiler is upwards at the firebox end and forwards in the upper parts of the boiler, downwards at the front end, and backwards at the bottom, and it is obvious that the more freely this natural movement takes place the more rapidly steam will escape, this being also facilitated by the jar of the engine when running. The comparative amount of hard scale is generally a fairly sure index of the value of the heating surface and state of the circulation in the boiler. Where the ebullition is greatest the amount of hard and tenacious scale will be found to be least, though this does not altogether apply to the crown plate of a locomotive boiler where the boiling off of the deposit is impeded by the stays, or to a nest of small tubes closely packed.

In locomotive boilers about 70 lbs. of water can be evaporated from $4\frac{1}{2}$ sq. ft. of grate area in one minute, or 13·5 lbs. of water from 1 sq. ft. of heating surface per hour, and an average of 3 sq. ft. of total heating surface per indicated horse-power may be taken as an approximation. These quantities, however, largely depend on quality of fuel, condition of boiler, rate of combustion, and skill in stoking.

The fire-grate, which forms the bottom of the firebox, consists of a series of bars arranged longitudinally, and with spaces between them for the passage of the air necessary for the combustion of the fuel placed above. The grate may be either horizontal or inclined at the front or back, so that the fuel put on at the back shakes down to the front by the jar of the engine. When the firebox is placed between the frames, as is the general practice here, and the size of grate is restricted by the distance between the frames for width, and the distance between the driving and trailing axles for length, it is only by the help of the draught produced by the exhaust steam that it is possible to burn sufficient fuel on so small a grate in the limited time to produce steam in large enough quantities for the work that a locomotive has to do.

The fire-bars are about $\frac{3}{4}$-in. thick on their upper edge, and taper off to $\frac{3}{8}$-in. at bottom, being 4 to $4\frac{1}{2}$-in. deep, with thickening pieces at the ends, and also in the centre in cases where the bars are long, for the purpose of keeping them the required distance apart. They are usually made of cast iron, though wrought iron when used appears to offer some advantages, its point of fusion is higher, and it will stand more rough usage, being less easily broken, but it bends and twists with heat sooner than cast iron does. The bars are usually made about half the length of the grate, though sometimes they are made long enough to go the entire length of the box. They are carried on bearers of wrought iron, which extend across the bottom of the box, and rest upon brackets fixed either upon the foundation ring or upon the ash-pan, the latter being preferable, as they are more easily removed. A, Fig. 5, shows such an arrangement of bars. The bearers may be made of cast iron, and provided with distance pieces on their upper side; the bars need not then be thickened at the ends, but placed between these projections, so keeping the necessary air spaces between. This arrangement of bearers and bars is shown at B. The rate of combustion of coal on each sq. ft. of grate ranges from 40 to 120-lbs. per hour.

Rocking or movable firebars, actuated by levers worked from the foot-plate are often employed in America on coal burning engines, but their use does not find favor here, probably because the coal is better and does not clinker so much. Water grates are also used, and consist of tubes passing from front to back of the firebox and connecting the water spaces together, but not always arranged in one plane, every fourth one being raised above the others; this arrangement of fire-bars has been adopted for very long fireboxes using hard coal. We have only mentioned the commoner forms of fire-grate and bars used, but many modifications can be met with, including double-bars, transverse, spaced, etc., etc.

In a few locomotives holes are provided through the water spaces just above the level of the fire, through which atmospheric air is induced to assist combustion; and in extension of this principle steam jets have also been employed.

The ash-pan is of box form about 1-ft. deep, fitting under the firebox and made up of iron plates $\frac{1}{4}$ to $\frac{5}{16}$-in. thick; it is provided with doors or dampers often at the front end only for

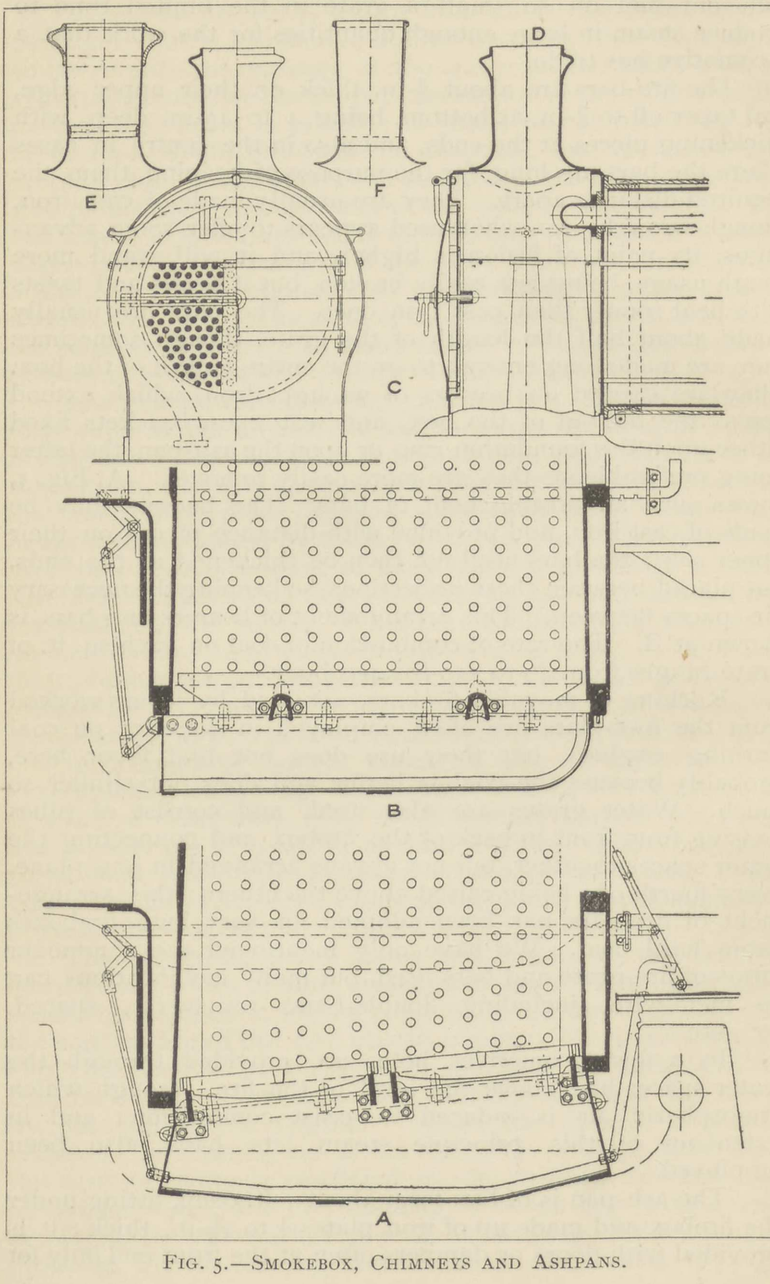


FIG. 5.—SMOKEBOX, CHIMNEYS AND ASHPANS.

engines that run mostly in one direction, as main line, express and goods engines (see B), but at both front and back ends for engines that are designed to run either way as tank engines (see A). The use of the ash-pan, as its name implies, is to catch the ashes that fall through the fire-bars, and also to provide a means of preventing entry of air through the bars when desired. The dampers regulate the quantity of air admitted to the fire, and are under the control of the enginemen; they are opened and closed by means of suitable levers and catches on the foot plate, easily accessible, and through them the ashes can be removed at the completion of the day's work. The ash-pan is attached to the foundation ring by means of pins screwed into the under-side of the ring, projecting sufficiently far to pass through the angle-irons on the ash-pan, and having split cotters driven through the holes in them. It is advisable to make the bottom of the ash-pan with a slight inclination upwards at the ends, so as to prevent the small dirt accumulating there being blown out whilst running on to the motion and moving parts of the engine.

The smokebox, at the front end of the boiler, is in inside cylinder engines built up directly from the upper face of the cylinder castings, but in outside cylinder engines is formed above a box-like stay placed between the frames at this point; the wrapper is made up of two pieces of plate $\frac{1}{4}$-in. thick, rolled to required shape, and jointed at the top. The front plate which has the door hole in it, is either flanged to shape by hydraulic pressure, or the joints between it and the wrapper are made with angle-irons, the flanged plate making the neater and cheaper job. The door is provided for getting at the tubes for cleaning or repairs, and also for washing out the boiler. It is generally circular in form, and dished to give it greater strength; on the inside, about $1\frac{1}{2}$-in. from it, a second plate is fixed for protecting the outer door from the heat. This form of door is hinged at the side, and has at its centre a fastener usually called a "dart," which has a flattened end with shoulders. This is passed with the head in a horizontal position between two bars of iron, about 2-in. apart, which extend across the front, inside the smokebox, and then turned so that the shoulders catch on the inside, the door being then screwed tightly on to its face by the outer handle or wheel. Another common form of smokebox door folds in the centre, and is hinged on either side; this form has been frequently adopted where some obstruction may prevent the opening and shutting of a round door. A third form hinged at the top and opening from below is often met with on engines with low boiler centres.

The main steam pipe from the boiler to the steam chest passes through the smokebox which assists to an extent as a super-heater for the steam. Vertically within, exactly under the centre of the chimney, stands the blast pipe. Spark arresters, when used, are either arranged horizontally across the box forming a diaphragm just above the top row of tubes, or are made conical to fit between the top of the blast pipe and base of the chimney, their use being to prevent the small coal or sparks drawn through the tubes from the firebox being discharged through the chimney. C shows the complete arrangement of a good form of smokebox with vertical front plate; there are cases, however, where the front plate is inclined, this being done to form a line with the front of cylinders which are set at an angle. All joints must be perfectly air tight, or the blast of the engine will not be able to create a sufficiently good vacuum in the smokebox to keep up the rapid passage of air through the firebox necessary for quick combustion, and also because any atmospheric air entering the smokebox direct would cause fresh combustion there by its oxygen combining with the unconsumed carbon which is pulled through the tubes, and the plates would be burnt by the heat so caused.

Extended smokeboxes are largely used in America, on the Continent, and to a less extent here. The addition to the cubical capacity of the smokebox causes a steadier and more regular draught on the fire, and this is beneficial when inferior grades of coal are used as fuel. A small smokebox means a sharp effect of the blast on the fire, and a common remedy in the steam shed for a bad steaming engine is to brick up a portion of the smokebox and so diminish its capacity.

The smokebox, shown at C, must be emptied of the small ashes it collects by hand. Where the construction of the smokebox will permit of it, a good plan is to provide a hopper with a trap door opening downwards under the engine for the automatic emptying of the ashes.

The chimney may be either tapering or parallel in shape. Its length depends upon the height of the boiler from the rail, as the loading gauge in this country will not pass more than about 13-ft. above rail level. The tapering form, larger at the top than at the base, is claimed by many to secure a better passage for the gases, and thus help the draught, and it would seem that this is a good claim, as the shape more approximately follows the outline of the escaping cone of steam from the blast pipe. The design of the top also considerably affects the direct discharge of steam and smoke.

The main uses of the chimney are first, to form an exhausting device in conjunction with the escaping steam from the blast pipe, whereby the contents of the smokebox are withdrawn by virtue of its velocity, causing the draught already spoken of; and secondly, that the smoke, etc., may be carried away above the level of the driver and the train. It may be of cast iron, in one piece, as at D, built up of a cast top, pressed base, and connecting cone of plate, as E, or built up of plate entirely, as F. It has various external shapes, depending more or less upon individual fancy.

We will now refer to the great difficulties to be contended with in the formation of deposit, and incrustation or scale in the boiler.

When this is not more than the thickness of an egg-shell where circulation is most active, it is no disadvantage, but is good rather than otherwise, as it forms a protection to the plates against the corrosive action of the water; but when it becomes thick enough to threaten the closing up of the water spaces, or gathers in large quantities on the tubes and plates exposed to great heat, it causes a wasteful expenditure of fuel, tends to shorten the life of the boiler, and may become a source of danger. The heat from the firebox, when not carried off rapidly, as it should be by the fresh water brought to it by circulation, on account of the scale being a bad conductor, overheats the plates, so that in course of time they may become burnt through.

The formation of scale, when it gives rise to slight overheating, causes unequal expansion, which is one of the principal sources of wear and tear in a boiler.

Most waters used for locomotive boilers contain solid matters in solution, which are deposited by the high temperature, or are left behind by evaporation. The first effect of the precipitation of these solids, unless cleaned out, will be to harden and form scale. There are usually from 20 to 40 grains of such matters to a gallon of ordinary water used for boilers, and it is easy to conceive what an excessive thickness would accumulate over the whole surface of the boiler below the water line if cleaning out be neglected for any length of time.

It may be observed that the production of steam in a new locomotive boiler will increase at first, then remain stationary, and afterwards decrease. This may be, however, in part due to the diminution of priming, generally so great in new boilers, and which becomes less as the grease and dirt is removed.

It has been stated that $\frac{1}{16}$ of an in. of scale on the tubes is equivalent to a loss of 20 per cent. of fuel, and that the loss increases in a very rapid ratio. Another observer has demonstrated that scale $\frac{1}{16}$ of an in. thick demands an increase of 15 per cent. of fuel, and scale $\frac{1}{4}$-in. thick 60 per cent., and scale $\frac{1}{2}$-in. thick 150 per cent. more fuel, and so on; but the circumstances to be considered are not well understood, and are too varied to admit of exact calculation, as the matters that go to form the incrustation are so diverse in their character.

A large number of chemical substances have been introduced with a view to secure the solubility of the salts contained in the scale by decomposing them and their use has been attended by varying degrees of success. The most common of these is the ordinary soda of commerce; white ash or soda ash is often used as it is cheaper, but it is less effective. It is usually dissolved and introduced into the feed water, the quantity being found by experiment and varying with the water used. From 1-lb. to $2\frac{1}{2}$-lb. per day is a usual quantity, but it depends upon the amount of work done, etc. More soda ash and less caustic soda would be required, but though good for detaching scale, most of these substances have a tendency to increase priming. Frequent washing out with water under pressure is the best means of preventing the formation of scale n locomotive boilers.

The exhaust or blast pipe should stand central with the chimney so that the escaping steam shall be discharged directly through it. The most common position for the top or nozzle of the blast pipe is just above the level of the top row of boiler tubes, but this is by no means universal as instances may be found of positions varying from the bottom row of tubes up to the chimney base. It has been observed that the higher the nozzle the more the fire will be burnt at the front of the firebox, and by lowering it the fire will be burnt more at the back. In this country the orifice is always circular in shape, and its diameter depends upon the work the engine has to do, the size of the cylinders, the grate area, and the quality of fuel used. For all ordinary engines having cylinders of 16-in. diameter and upwards, it will be found to be between $4\frac{1}{2}$-in. and $5\frac{1}{2}$-in. in diameter.

The metal employed is generally cast iron, but some will be noticed made of copper, with the base and nozzle either of cast iron or brass. It is common practice to make separate nozzles with a flange, and form the top of the pipe with a similar flange, to which they can be attached; the outlet is thus easy to remove for cleaning, and can also be readily changed should it be found necessary to alter the size. These separate nozzles are often cast in brass, with a hollow chamber round the top, to which steam can be admitted and discharged through a ring of holes forming the blower, which will be referred to later on.

In designing a blast pipe care should be taken to make it so that the cone of escaping steam just enters the lower end of the barrel of the chimney, and not strike the base of the chimney or the top of the smokebox wrapper plate, as by doing this the draught on the fire is greatly impaired; the distance from the top of the blast nozzle to the base of the chimney will therefore depend on their relative sizes. Varying opinions exist as to the cross section of the pipe, and also as to its form at the upper part, but it would seem advantageous to secure as easy a passage for the exhaust steam as possible from the cylinder ports to the top of the pipe, and therefore all awkward bends should be eliminated. The outlet should be exactly central, with the centre line of the chimney for the last foot of its length. Some designers make the last $1\frac{1}{2}$-in. of the bore parallel as at A, Fig. 6. Others will only have $\frac{1}{4}$-in. parallel, and some bring the taper of the pipe up to the top, with very little, if any, parallel at all, as at B. A contracted orifice is a frequent cause of back pressure in the cylinders, but sometimes the exhaust steam from one cylinder passing over and interfering with that from the other will cause equal trouble, and to overcome this many engines have two exhaust orifices, one for each cylinder, the pipe having two flanges and made "breeches" shape, with legs joined at the top and terminating in a single nozzle. American builders make the exhaust steam from each cylinder entirely free from this interference by providing each cylinder with an independent pipe and separate nozzles; the disadvantage of this arrangement is that it does not give an orifice exactly central with the chimney.

Ordinary blast pipes at each stroke of the piston discharge a cone of steam through the chimney. This steam is surrounded by the products of combustion which are withdrawn from the smokebox by the velocity of the steam, but nozzles are made which collect the gases both inside and outside the exhaust steam. These are variously termed "vortex," "expansion" pipes, etc., and are cast to a shape which discharges the exhaust through an annular outlet, drawing the gases from the lower tubes through the centre of it. This design is claimed to give a more regular draught over the tube area than the ordinary pipe. C shows the Adams' form of vortex blast pipe in section

Another device discharges the exhaust in a hollow ring, but the centre is occupied by the waste steam from the ejector for the vacuum brakes, which is thus assured of being exactly air with the chimney centre line.

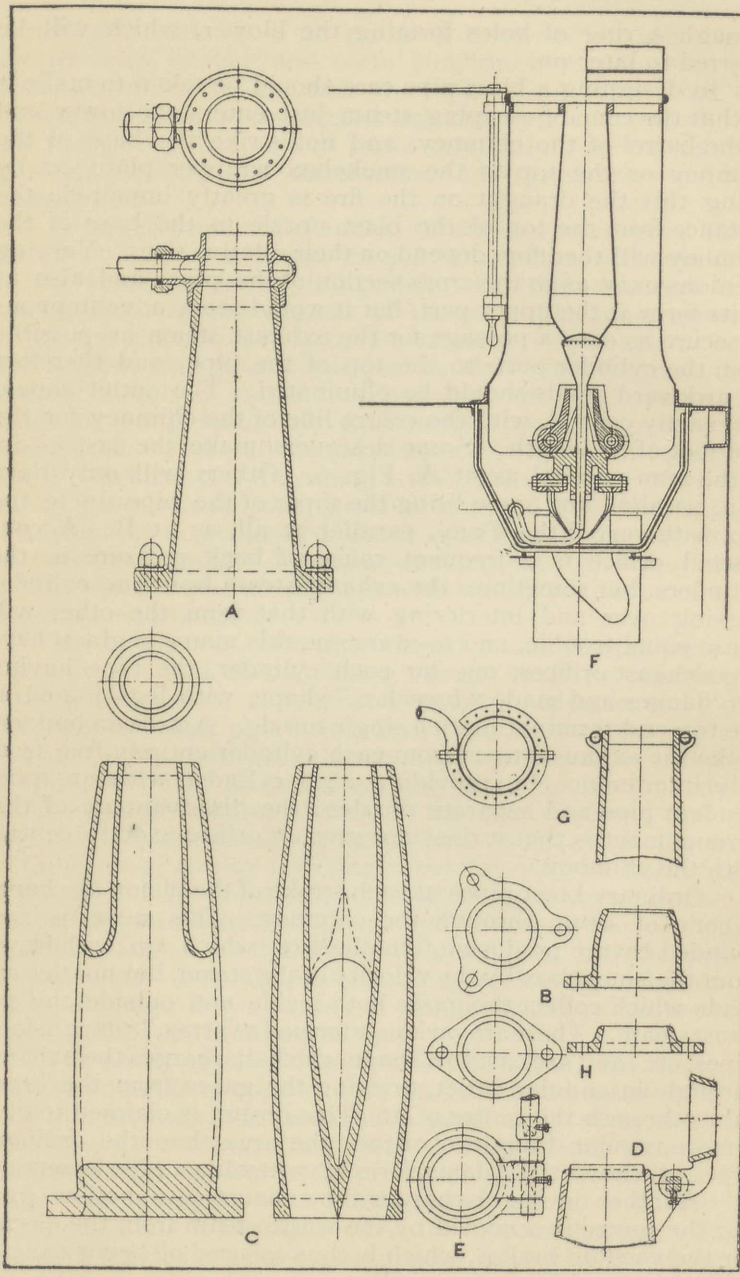


FIG. 6.—BLAST PIPES AND STEAM BLOWERS.

Variable blast pipes are also largely used, and the advantages of being able to vary the opening of the exhaust orifice are obvious, as, when an engine is provided with but one outlet, this has to be designed of a size small enough for the hardest forcing required of the engine, and irrespective of the fact that a large proportion of its work will be performed under much more favourable conditions. When a driver has facilities for using a larger nozzle he can considerably reduce the back pressure when opportunities occur and lessen the draught through the fire. One style of pipe which has been largely adopted is of cast iron, and has a cap hinged at the front, that is nearest the smokebox door, controlled by levers, and worked by a rod passing to the cab, where a handle and clamp enable either large or small outlet to be used at will. The diameter of the cap is that of the ordinary pipe for the same class of engine, and that of the pipe is about 40 per cent. larger. D, Fig. 6, shows a variable nozzle of this description in section, known as Macallan's pipe, with the cap moved off its seat, allowing the steam to escape from the larger opening. E shows a plan of the pipe with cap on, so that the exhaust steam has to pass the smaller opening. It will be seen from these views that the pipe has two lugs cast on it, and the cap has one, which is made to fit between them, and a pin passes through, made square in the hole through the cap lug.

We describe this form somewhat fully owing to its large application, but we can only find room to mention one or two others in actual use, as the designs for variable blast pipes are simply legion, and descriptions would fill pages of letterpress.

A simple device has the nozzle made up of strips of elastic steel arranged conically, and encircled by a cast iron band; the size of the outlet can be altered at will by raising or lowering this band. Providing a solid taper plug in the interior of the nozzle, the raising or lowering of which will allow of more or less opening, is a third arrangement; whilst a fourth has double concentric openings at the nozzle, the inner being shut off from the outer when desired by a ring working inside the pipe; for a large outlet and soft exhaust both nozzles are open, whereas for a sharp draught the connection may be closed, and steam only permitted to escape from the inner pipe. In the majority of variable blast pipes sliding surfaces are relied on, which must be more or less exact. These are not to be recommended for use in such a position as a blast pipe occupies, as they so easily become choked with soot, etc.

An arrangement much used on the Continent is to provide the outlet with two hinged flaps, one on each side of the pipe, so that its size can be varied by opening or closing these flaps by means of suitable rods and levers. As will be seen, however, the shape of the escaping steam will be different for each variation. This form of pipe is shown at F. Another method is to have the outlet of the pipe made serrated by vertical cuts, a ring is made to revolve on the top of this, having on its internal diameter similar nicks; thus, when the ring is turned so that its teeth coincide with the teeth on the pipe the outlet is largest, and when the teeth of one covers the gaps of the other the outlet is smallest. This also is open to the objection stated above.

A novel arrangement of exhaust pipe and chimney is adopted on the P. L. M. Railway, France. It is remarked that the internal portion of the cone of steam issuing from an ordinary blast pipe is not utilised, but passes away as a wasted power, and in order to use it the diameter of the chimney is in this case made much larger with a copper cone up the centre over the exhaust pipe, small at the bottom, swelling out towards the middle, and reducing again at the top, thus the area through which the exhaust steam has to pass is about the same as that of an ordinary tapering chimney, although here the chimney itself is made parallel. When the steam leaves the blast pipe it strikes the bottom of the cone and spreads and fills the annulus between the cone and chimney. It is claimed that this secures a much steadier and softer draught on the fire. On referring to the drawing F, which shows this device in section, it will be seen that there is a pipe provided by which steam can be admitted at will to the lower part of the cone, which has a ring of holes around it, thus forming a blower.

It should be observed that all the nuts that are used for holding down the blast pipe should be made of brass, and form caps to protect the ends of the studs from the corroding action of the steam and burnt gases; on referring to A these nuts will be seen.

In America it has been the practice to make the blast pipe very short, and above it, up to the chimney base, provide "petticoat" pipes, sometimes one, and in many cases four or five, as they are said to give a more equable draught over the whole tube area. This has now become a common practice here with the high pitched boilers now in vogue, and their consequent very short chimneys.

It is a fact, well known to enginemen, that any obstruction placed in the blast pipe will materially add to the draught on the fire, and this knowledge has been made use of in the case of bad steaming engines by placing a bolt across the pipe through holes drilled in the pipe, or suspending any heavy piece of metal inside by means of hooks, and even by stretching a piece of wire across the top of the pipe. These practices are however to be condemned, as the liability of dropping obstacles down the pipe, and thus causing damage by getting into the moving parts, is very great.

The blower is provided to create a draught by means of a steam jet, and assist the fire when raising steam, or when the engine is stationary, standing at stations, etc. It is usually made by a ring formed round the outlet of the blast pipe, which has a series of holes in its upper surface, so that when steam is admitted it will escape through these holes, pass up the chimney and cause a draught. This ring may be either cast in one with the nozzle, and have suitable unions by which a pipe can be attached to it from the blower cock, as at A, or the blower may be entirely separate, of copper pipe, which is bent to a circular form as far as possible and laid on a ledge, or in some cases on lugs cast on the pipe for its reception, holes being drilled as in the last case at its upper face. G shows a plan and section of this form of blower. A second arrangement is to have a single pipe laid up alongside the blast pipe, discharging up the chimney, but this is not so good as the first.

In some engines the steam used for exhausting the air from the vacuum brakes by the small ejector can be at will discharged through the blower, thus answering two purposes; but in most cases it is "live" steam that is used, and then it is good practice to take it from the dome by means of an internal pipe, so as to insure dry steam in all cases. The blower is entirely under the control of the men in charge of the engine.

The internal capacity of the boiler may be said to be divided into two parts, the water space or portion below the water line, and the steam space or that above it, in which the steam generated is collected; authorities differ as to the exact proportion that these should bear to each other, but as a general rule the water space is about $\frac{2}{3}$ of the total capacity of the boiler. A large body of water gives a steady supply of steam, and ample steam space lessens the liability to "prime," a trouble referred to later on.

A usual method of increasing the steam space without carrying the water too low in the boiler, is by adding a dome, also by making the firebox wrapper plate of a larger diameter than the barrel. This may be done in two ways, the plan usually adopted in this country, known as the raised firebox, has the throat plate extended over the top of the barrel

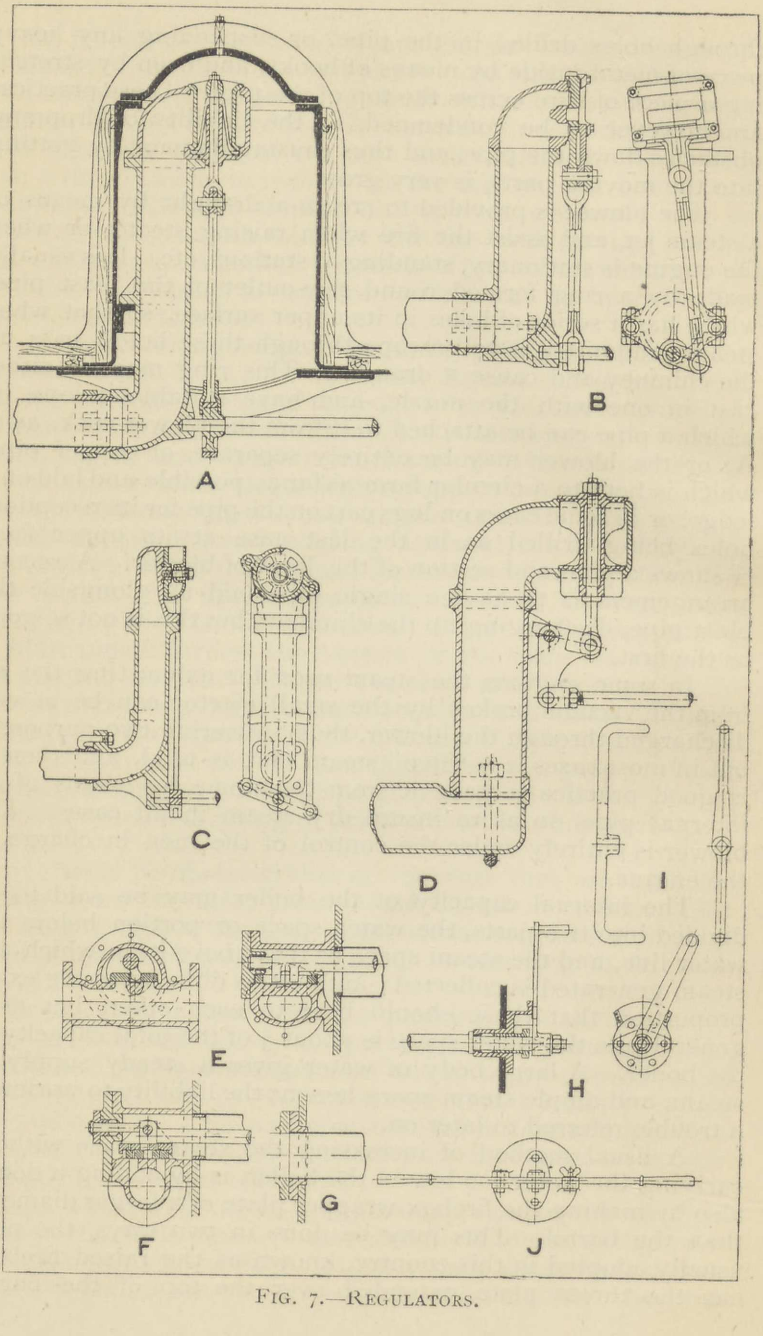


FIG. 7.—REGULATORS.

forming a joint with the wrapper plate; whilst the "wagon top" arrangement, common in America, has the last plate of the barrel sloped upwards to meet the wrapper plate to which it is attached, and which carries the dome. Here, the dome is usually placed upon the barrel often at the front end when the barrel is made in two lengths, or, at or near the centre of the middle plate when the barrel is composed of three. The latter practice of having the dome nearer the centre would appear to have the advantage of being above the water at its most uniform level, as in starting, the water will wash towards the back and necessarily rise higher. Engines with the dome near the chimney end, especially if tank engines, will be liable to prime when starting in back gear for this reason.

The regulator, by means of which the steam is controlled and allowed to leave the boiler for the steam chest, is usually placed in the dome with the inlet at the upper part so that the steam shall be taken as far from the surface of the water from which it is generated, as possible. When no dome is provided the steam is collected in a pipe some 5-in. or 6-in. in diameter, fixed in a horizontal position along the top of the inside of the barrel, and running its entire length; this is perforated at its upper side to allow the steam to enter there.

The design of regulator shown at A, Fig. 7, is called the Ramsbottom, from the name of its originator, it is fixed in the dome and is of the double beat type; the valve, which is cast in brass, having two seats, the upper one being slightly larger in diameter than the lower, and made with a boss to which the rod for lifting is connected; it has four radial wings to allow the steam to pass to the lower seating. To open this regulator the valve is raised, thus opening the upper part, then steam also has access through the inside of the valve to the lower seat, allowing a large opening to steam for a slight lift of valve. The movement of the handle in the cab is transmitted to the valve by means of an eccentric. This is a very easy regulator to work, and it is much liked by drivers.

The form shown in section and elevation at B, is also fixed vertically in the dome in a similar manner to the last example, but is of the sliding type, the top head of cast iron having two ports which are covered by a valve of brass having one similar port through it, also a smaller port covered by another slide of cast iron, these two valves are connected through a prolongation at their lower end by means of a pin passing also through the fork end of a connecting rod; in the larger valve the hole is slotted, but in the smaller one it is round. The rod from the foot-plate fits at this end into a socket cast on the pipe, and has a crank to which the other end of the above-mentioned connecting rod is attached. To open the regulator the handle in the cab is moved, this raises the connecting rod, and the pin being a fit in the small valve it is lifted at once and uncovers the small port allowing the steam to pass through the large valve into the pipe, admitting pressure to the inside of the large valve, and thus tending to a state of equilibrium, so that when the pin has travelled to the top of the slotted hole, it will lift the large valve more easily than would be the case if no pilot valve were fitted. It will be observed that the large valve has a lug cast upon its upper end, which overhangs the head, so that should any of the mechanism be disconnected or broken the valve will drop until the lip catches, and this is the position when both ports are covered; the small valve is also sometimes provided with a similar lip, but this practice is by no means universal. It should also be noticed that two plate springs pass across the backs of the valves and hold them to the faces, so that should the engine be subjected to any sudden jolt they cannot fall back and leave the ports open to steam. The head is arranged so that it is not exactly vertical but slightly inclined, to allow the crank on the rod below to be always working in an advantageous position.

In the next example, at C, the regulator as before is located in the dome, and the ports, four in number, are arranged around a centre, upon a pin at the centre a butterfly valve is made to revolve, and is provided with four similar ports and blanks between them, sufficiently large to cover the ports in the head. The valve has two lugs cast upon it at opposite sides for connecting rods from the horizontal rod from the cab; to open it the valves are turned until the holes uncover the ports. The design shown is that for small engines, but larger engines have similar ones with a pilot valve so fixed as to allow steam gradual admittance to the steam chest.

D shows a section of the usual design used in America, in which the head has two holes, one at the top and one at the bottom, and two valves upon a common spindle, and as the top valve is made of a larger diameter than the lower one the amount of work necessary to overcome in opening them, is only equal to the difference in the area of the two. It is general with this design of regulator to have the rod from the cab of the "pull out" type, and connected to a bell crank, as clearly shown in the sketch. The usual position of the driver on American engines being at the side of the firebox, and not, as here, at the back, this form of handle is more convenient. The handle is worked upon a sector with notches as in reversing levers, but arranged horizontally, and in these notches a catch engages.

At E is shown a regulator fixed in the smokebox on the front tube plate, and to it the steam is conducted by means of the internal pipe described earlier; in this form two ports are arranged lengthwise of the engine covered by a valve riding crosswise, so that to open them the movement of the handle is exactly similar to those shown at A, B and C. This class of regulator is not always provided with a relief valve, as more leverage is available; but it has the disadvantage that the long connecting rod to the handle is liable to twist.

At F another arrangement fixed in the same position on the boiler as the last is shown, but in this case the ports are arranged transversely, and covered by a valve with a large port and two smaller ones; above this is a riding or pilot valve with similar openings. The handle in this case is of the "pull out" form, and in operation the first movement opens the small ports, then the projection upon the small valve engages the larger one and moves the two together until the large port in both valves allows steam to pass into one port of the head, and also to pass by the front end and so down the other one. The end of the rod is provided with a stuffing box, so that the weight of it may not rest on the valves, and also the valves may not be lifted from their face without first removing the cover plate.

The joints at the regulator end of the internal steampipes for the designs at A, B, C and D are all coned, the casting being turned and the pipe, which is generally of copper, having a brass cone with a shoulder brazed upon it, a band of iron, or more properly, two half bands are placed round it and behind the shoulder, the bolts uniting the two half bands pass through an eye formed at the end of two bolts, which pass through holes in lugs on the regulator casting; screwing up the nuts on these bolts will cause the brass cone to be forced tightly into the cone of the regulator. A slight modification is shown at C; here, instead of the bands the bolts have hooked ends which are placed behind the shoulder, and tightening the nuts pulls the cone home.

The joints at the tube plate end for the above are made by belling the pipe out to fit the hole in the tube plate, which hole must be large enough to allow for the passage of the cone and shoulder at the other end of the pipe, and then driving a ring of steel turned accurately to size into it, and making a joint similar to tube ends, when ferruled up. Another method is to fit a flange on to the pipe with a portion of it made large enough to enter the tube plate hole, in this case, of course, the pipe is parallel; this joint is shown in section at G.

A common form of stuffing box through which the regulator rod has to pass at the firebox end of the boiler is shown at H. It consists of a cast iron box, with flange and a projection at the top of it forming a guide and stop for the handle; a neck ring fits at the base of the inside of the box, and a gland at the outside, the joint around the rod being usually made with hemp packing.

The handles are either double or single, a usual form of a single one is shown at H, one end of which fits upon a square at the end of the regulator rod where it is held in position by means of a nut. A particularly neat form of double handle is shown at I, consisting of a round bar with a boss to fit the square on the rod as before, and a rectangular portion to engage the stops on the stuffing box flange. A double handle, of course, gives the driver more power over the regulator than a single one, this being very useful in the case of a "sticking" valve.

At J is shown a double handled "pull out" arrangement. The rod end has a fork which is connected to the centre of the lever, a hinge for this lever being on one side of the stuffing box flange, and on the other a sector through which a screw affixed to the lever passes with a thumb nut at the top, so that the driver can clamp it in any position he may wish. A securing device of some kind is necessary for the forms of regulator shown at E and F, as they have no tendency to keep closed by their own weight as the vertical patterns have.

Priming or foaming is caused generally by the presence of greasy matters in the water, and it may be remedied, if so caused, by the addition of a lump of unslaked lime to the feed water in the tank, or a piece of bluestone (sulphate of copper), but the two should not be used together. Water carried too high will also cause priming; this is not always because the level is nearer to the point at which the steam is drawn off, but because the higher the water is carried the less will be the area from which the steam has to escape.

Safety valves are provided to prevent the pressure of steam in the boiler exceeding the predetermined limit arranged for by the designer. The valves are adjusted to lift and permit the surplus steam to escape as soon as the pressure attains the appointed figure, and close when the necessary reduction is accomplished. Every boiler should be fitted with at least two valves, three are provided at times to reduce to a minimum the possibility of explosion through valves sticking and consequent excessive pressure.

The double valves are generally 3-in. in diameter, whilst the third, if provided, is a smaller one of 2-in. diameter, screwed down to blow off at 3-lb. per square inch higher pressure.

The best position upon the boiler to place the valves would appear to be upon the wrapper plate, it being there farthest from the dome where steam is being drawn off through the regulator to the cylinders, as when an engine primes it generally causes an unusual generation of steam which escapes at the safety valves; this in its passage is liable to accumulate and lift the surface water and foam, thus the further they are placed from the dome the better, as they will then tend to diminish the evil of priming at that end rather than increase it as they probably would do if placed there.

It is very necessary that the pressure should not exceed the desired limit and to prevent tampering with the safety valves, ferrules or washers are fitted under the holding down arrangements, so that whilst it may be quite easy to relieve them and allow steam to blow off before the fixed pressure is reached, it is almost impossible to exceed it without employing means which are easily detected.

The most common form of safety valve to be met with on British locomotives is that introduced by Ramsbottom in 1855. It was originally, and is still in some cases, constructed of brass, but now it more usually consists of an iron casting forming two hollow pillars, which stand vertically upon a circular plate, these are in communication with the boiler at the base, whilst the valves close them at the upper ends; the valves are held down by means of a spring pulling on a lever which crosses the pillars and rests on each, the lever has a lug upon it projecting downwards between the pillars, to which the upper end of the spring is attached. Near the base of the pillars a bridge piece is cast between them, an eyebolt passes through a square hole in this and is secured by a nut underneath: the eyebolt has two holes, the lower one being for the reception of the lower end of the spring, and the upper one to connect safety strips mentioned later. Between the shoulders of this eyebolt and the bridge is inserted a washer, made the exact thickness required after adjustment to form a lock. The valves are made of gun-metal and are of the wing type, deeply coned at the top for the reception of the bearing points of the holding down lever. When the casting is of iron the valves take their seats upon bushes of gun-metal inserted into the upper ends of the pillars. The lever, or, as it is often called, the "cowtail," is made of a piece of flat wrought iron, with a hinged joint to take the bearing on one valve, whilst a plain projection upon the lever holds down the other, one end of the

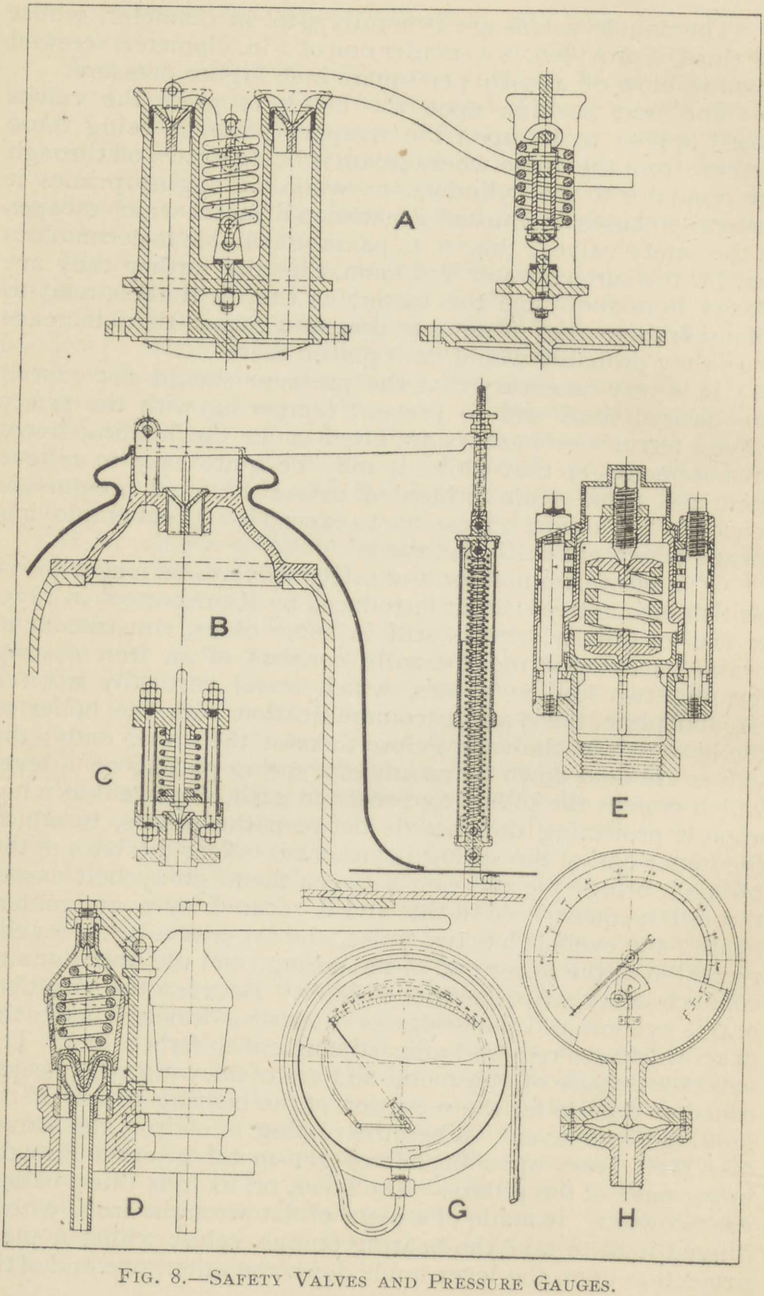


FIG. 8.—SAFETY VALVES AND PRESSURE GAUGES.

lever is continued and brought down to a convenient height, and when the valves are located on the firebox wrapper plate, it is carried through into the cab for the engineman to reach when he requires to "try" his valves to make sure that they are in working order. The usual method of setting this form of valve is to raise the pressure of steam in the boiler, which, in addition to the usual steam gauge has, temporarily, a second fitted to it as a check, the valves are then gradually loaded by adding tension to the spring by screwing up the nut under the bridge until they just lift at the required pressure, then the distance between the upper side of the bridge and the shoulder of the eyebolt is accurately measured, and the steam let down to enable the washer mentioned above to be fitted. A casing of thin metal is placed round the entire arrangement on many engines, which prevents any interference with the adjustment by unauthorised persons. The safety or side connecting strips above referred to are employed as a precaution to prevent the loss of the valves and lever in case of the breakage of the spring. They have holes for the reception of pins for connection at the bottom to the eyebolt and at the top to the lever, which has a slotted hole in the central projection, so that they do not interfere in any way with the action of the spring, but ensure the lever standing in an exactly vertical plane, and so prevent any unfair pressure on the valves. This pattern of valve is shown in longitudinal and transverse section at A, Fig. 8, the particular form illustrated is for an engine with girder stays, and is placed upon a manhole seating. When, however, direct stays are employed, no manhole is provided on the wrapper plate, and the safety valve casting instead of rising from a circular plate, has two pillars branching from a common base fitted to the curve of the boiler, and attached to it by studs. The Ramsbottom valve has the advantage of being simple and effective, and is, further, difficult to tamper with.

Another form of safety valve is the Salter spring-balance, this, however, is not now so common as the last mentioned, but in the earlier days all locomotives had one or more fitted to them. When used it is usually placed on the dome, of which the casting containing the valve seatings is made to form the top. The valves are two in number, placed side by side, and similar in shape to those last described; they are often made with a centre pin instead of wings on the Continent. The valves are held down by levers, pivotted, or working under knife edges passing through projecting lugs on the castings and loaded by springs enclosed in cases, a pointed distance piece being placed between the valve and the lever.

The casing for the spring is made in two lengths, one sliding within the other, and the springs are attached to plates at the ends of each cylinder. The smaller cylinder is graduated to show the steam pressure in lbs. per square inch, so that as tension is applied to the springs by a screw at the top it pulls the larger cylinder higher up the inner one and exposes the various figures. Two springs are generally arranged in each case, coiled right and left handed one within the other, the lower end of the spring case is attached by suitable pins to a bracket fixed to the boiler, as shown at D, which represents this form of safety valve in section. To set the valves to blow off at any required pressure steam is raised as before, and the springs screwed up to the required tension, when the distance between the nut and the shoulder at the base of the screw is accurately measured, then the pressure relieved, and a ferrule made to fit over the screw which cannot be removed while steam is up, it is then easy to release the valves and allow steam to blow off before the maximum pressure is reached, but more tension cannot be applied to the spring to enable a higher pressure being carried. This form of valve is simple and not liable to get out of order, but is not so good as the Ramsbottom, the valves not being able to get an opening large enough to release steam rapidly, as the distance between it and the end of the lever is necessarily great. Another disadvantage is the possibility of it being held down to secure increased pressure, and boilers when fitted with this valve should also have a smaller one locked up as an auxiliary and a safeguard.

A directly loaded valve for use in conjunction with the above is shown at C. In this case the valve is also of the wing type, and is held down by a coiled spring bearing on a plate fitted to a spindle, which has at its base a point engaging the valve, the upper end being carried through a hole in the holding down plate as a guide. The proper tension on the spring is obtained as described for the other cases, by trial, ferrules being fitted over the holding down bolts between the top and bottom plates.

The spring loaded valves above described possess a serious disadvantage, inasmuch as when the valves lift the load on them increases, due to the increasing tension on the spring, just the reverse of what theory would tell us to be the desired action of a perfect relief valve. With the Ramsbottom valve it is necessary to set it to blow off just under the limited figure, and even then it is quite possible to exceed it by 10-lbs. per sq. in. when blowing off hard. Many attempts have been made to overcome this disadvantage both in the spring balance types and the direct loaded. In the Naylor valve a curved lever was introduced, so arranged that as the valve lifted the joint of the lever, where connection with the spring was made, approached the fulcrum, thus tending to keep the load constant. On the German railways, where a spring balance is used, a jointed connection at the screw end is provided to secure the same object, and a modification of the Ramsbottom valve, known as the Wilson, has been largely used for similar reasons; it is illustrated in section and elevation at D. It consists of a casting with the valves and seatings and a centre pillar, to the top of which the lever is pivotted, this has attachments for engaging the upper ends of the springs, which are here in compression, and all enclosed in casings. The valves themselves are of a peculiar design, they are double, with a sliding cone and a pipe leading down some distance into the boiler, this is open at the lower end, and in free communication with the boiler pressure, outside this internal cone is the valve seating. When the steam pressure rises higher than that required, it lifts the valves by its action through the internal pipe on the under side of the valve, allowing the surplus steam to escape at the annular seating; thus, it is not the steam which lifts the valves that escapes, as in all the previous types described. With this arrangement it is claimed the valves work more uniformly and regularly.

At E is shown in section another valve designed to overcome the disadvantage before mentioned. It is known as the "Pop" safety valve. Two of them are usually fitted to each boiler, and in America are placed on the top of the dome. These valves are more sensitive, and give a more rapid release than other spring loaded valves. The particular form illustrated is the Ashton Pop, and it operates as follows:—The steam, rising to the required blow-off point, lifts the large wing valve and escapes slowly into a space called the pop chamber, between the bevil of the valve and a knife edge ring which surrounds it, and takes a seat on the casting; this increased area on which the steam pressure can act causes the valve to lift suddenly, and instantaneously relieves the boiler. A unique feature of the Ashton valve is the provision of a regulating device to the pop chamber; it consists of a plug which enables the steam to be retained in the pop chamber to any wished for extent. As the sudden release of high pressure steam may cause a considerable noise, a muffler is usually added to deaden it, this is a thin metal case perforated with holes through which the steam escapes quietly. Sometimes, instead of having perforations, the case is made solid, with a connection for a pipe to lead the discharged steam to the feed water tank for heating purposes.

To indicate the pressure carried in the boiler a steam gauge is fitted. A common form is the Bourdon gauge, the action of which depends upon the fact that a flattened tube, it subjected to internal pressure, will endeavour to assume a circular section, and, in its attempt to do so, will straighten itself; thus in the sketch at G, Fig. 8, it will be seen that a pointer indicates the pressure per sq. in. carried in the boiler, on a dial, and the case contains a flattened tube, connected at the one end to a casting, which has a union for a pipe from the boiler upon it, and closed at the other with a hinge for attaching a connecting rod which actuates a lever on the spindle carrying the pointer; as the pressure within the pipe tends to straighten it, the closed end with the connecting rod will move outwards, turning the pointer round on the dial. Instead of having a connecting rod direct, the movement can be made by means of a pinion and quadrant, the former being on the pointer spindle, and the latter pivotted and connected to the end of the flattened tube. There are numerous variations of this pattern of gauge, but the principle involved in them is practically the same, and our illustration shows the simplest. It is absolutely necessary with this gauge that the pipe connecting it to the boiler should be formed into a syphon, so that condensed water may always be in the tube; if the hot steam was allowed access to it it would materially affect the tube by expansion, etc., and further cause it to soften. The usual way to form this syphon is, as shown, by carrying the pipe round the gauge and then make connection, but sometimes a coil is made in the pipe below the gauge.

Another form of pressure gauge is shown at H. Here the action depends upon the elasticity of a thin corrugated metal plate or diaphragm, supported round its edge, and subjected to pressure on one side, the extent of the movement of this flexible diaphragm depending upon the pressure applied. A vertical rack rises up from the diaphragm, having a ball and socket at its base, and controlled by guides, engages into the teeth of a small pinion on the same spindle with a quadrant, which in its turn engages a pinion on the pointer spindle, the diaphragm as it rises lifts the rack and the pointer is moved round the dial. The diaphragm has a series of concentric corrugations in order to increase both its sensibility and life. This form of gauge does not require the syphon pipe as the last does, but may be coupled direct to steam if desired. The illustration is of an ordinary Schaeffer gauge, modifications of it may be met with, but all embody the same principle of action.

Water gauge columns are provided at the back of the outer firebox to enable the level of the water in the boiler to be readily discerned. They consist of suitable brass mountings, the upper one communicating with the steam space, and the lower with the water, a glass tube connecting the two, and occupying the range within which the water level must be kept. The best level for all practical purposes is about two-thirds of the distance up the glass when the regulator is open; carrying the water higher than this increases the tendency to prime, especially when the water is not clean. Should the water disappear below the bottom of the glass it may be assumed the crown plate of the firebox is dangerously near over-heating, and it would be advisable, if the level of the water cannot be raised, to at once draw the fire or smother it with sods of earth or ballast thrown on it, and shut the damper. At A, Fig. 9, is shown an ordinary pattern of column, consisting of an upper cock fixed to a flange studded on to the boiler, and a lower one similar to it, with a third cock at the bottom for allowing the glass to be cleaned by blowing steam through it. A drain pipe is attached to this last, and is carried down to the ashpan. The top and bottom fittings are provided with glands and stuffing boxes, through which the glass, which is from ½-in. to ⅝-in. diameter, passes. The cocks are ordinary ground-in plug cocks connected together by a rod, so that when a glass breaks the two can be simultaneously closed. Both fittings have small plugs immediately opposite the holes in the firebox fronts, through which a wire can be passed for cleansing purposes.

As there is considerable danger of being scalded by the water when a glass breaks, several methods have been devised to automatically close the water and steam ways when such a mishap occurs. At B is given a form which has been introduced by Messrs. Dewrance, of 158, Great Dover Street, London, S.E., and is now in very extensive use on most of our British railways. These columns are made of gun metal, and the top fitting contains a small valve, which has a hole through it for the passage of steam to the glass, the bottom one having, instead of the valve, a ball resting in a small cup-shaped support immediately below the opening through which the water reaches the glass. The usual third cock is provided for blowing through when necessary. All three cocks are of Messrs. Dewrance's well-known asbestos packed pattern, so constructed that the plugs are not in direct contact with the metal of the casings, and consequently can expand without becoming fast and immoveable as so frequently happens with plain ground-in cocks. The operation of the automatic valve

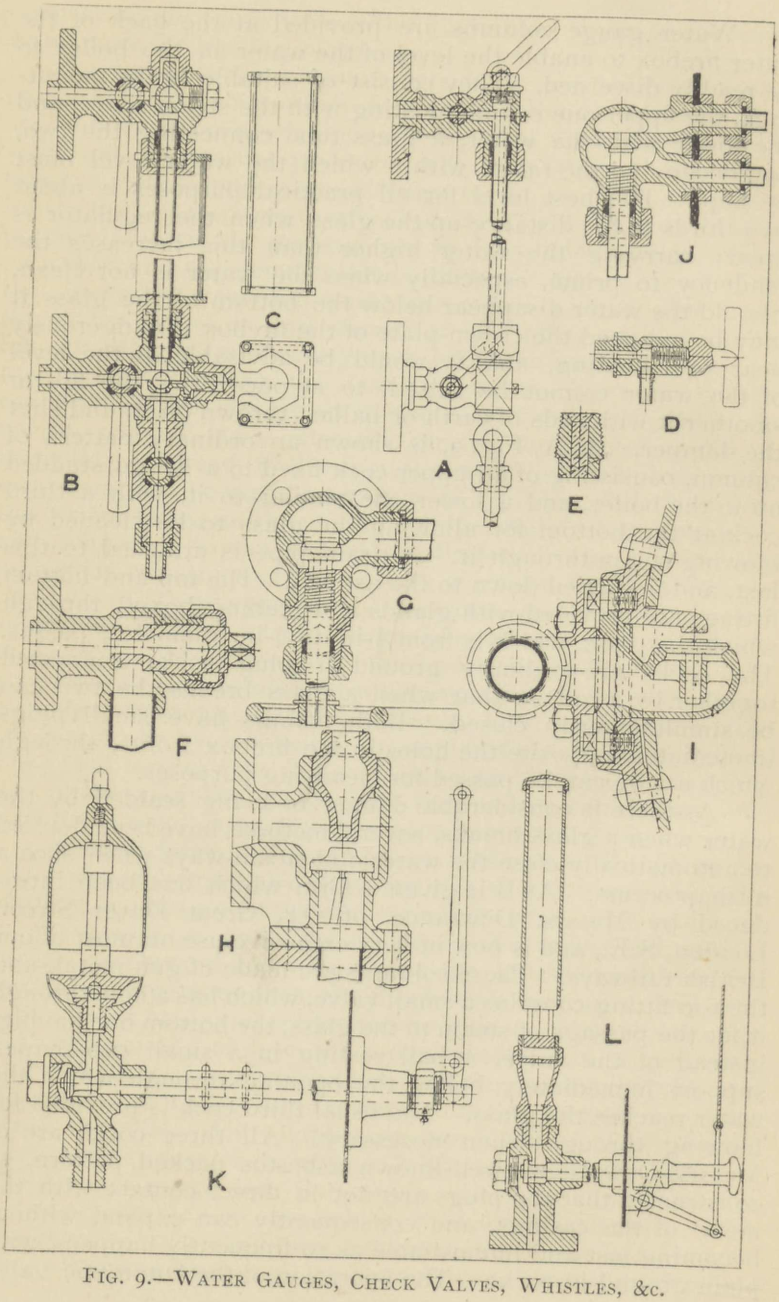


FIG. 9.—WATER GAUGES, CHECK VALVES, WHISTLES, &c.

is as follows:—When a glass breaks the sudden rush of water lifts the ball and carries it from its support to its seat, effectually stopping the flow of water; the steam similarly forces the top valve down, and only escapes in a tiny stream through the small hole; it is, therefore, an easy and safe matter to approach, close the cocks, and fit in a new glass. This is done by removing the plug at the top of the upper fitting, and lifting out the valve. Stuffing boxes of an approved style are provided for the glass, as in the last example. In addition to the risk of scalding, that of being hurt or even blinded by the particles of glass exists, and protectors are now fitted to obviate this and save the glass from cold draughts and accidental blows. Wall's patent, made by Messrs. Dewrance, consists of two or three pieces of plate glass fixed to end plates of gun metal, shaped to engage the gland nuts so that it can be easily and quickly adjusted. This form of protector is shown on the column B, and also detached at C. Hulburd's protector entirely encloses the gauge glass and has a pipe connection to convey away all water and fragments of glass into the ashpan.

In addition to the columns described, the boiler should be provided with at least one test cock, by means of which the water level can be known, if the glass fails and becomes useless. This test cock, or the lower one, if more than one are supplied, should be placed some four inches above the level of the crown plate so that dry steam issuing from it denotes that the water has reached its lowest limit consistent with safety. In cold countries, where glasses will not stand, three or even four of these test cocks are provided, and are arranged to discharge into a funnel with a pipe passing down below the foot plate. A simple form of cock is shown at D, in which the body screwed into the boiler plate contains a seating with a screw valve, having a T handle and a mushroom collar just below it to intercept any steam that may escape past the thread.

It was a universal custom to fit locomotive boilers with a fusible metal plug in the crown plate, so that should the water level fall below the sheet the heat would melt the composition and allow steam to enter the firebox and extinguish the fire, but as these plugs were not always reliable many railways abandoned their use. E represents a simple form where an ordinary mud plug is drilled through, with the hole countersunk at the top and filled with a composition which melts when exposed to the heat without the protection of the water. This composition consists of an alloy of lead, tin, and bismuth. When employed these fusible plugs should not be allowed to run too long, as the metal is apt to become affected and will not then be reliable for the purpose intended.

A blow-off cock for allowing the water to escape from the boiler for cleansing is usually fixed at the lowest point possible, and is constructed after the manner shown in section at F, a flanged casting contains a thread and seating, with a screw valve closing the exit. The stem of this latter is carried through a lantern nut, and is provided with a square to take a spanner. An overflow pipe is generally taken down below the bottom of the ashpan.

The injector steam cock is for admitting steam to the feed injectors, and is fitted to the boiler in a convenient position for manipulation One is shown in section at G, it is flanged for attachment to the boiler, and has a screwed union for the pipe to the injector. The valve is forced to its place, against the steam, by the screwed spindle. To open it the screw is turned back, and steam enters the pipe. The adjusting wheel usually has an arm or prolongation of one of its spokes for increased leverage.

The clack box or boiler check is attached to the boiler at the end of the feed pipe from the pump or injector, and opens against steam pressure. A common form is shown in section at H. It is provided with a flange for fixing to a seating rivetted to the boiler, with another flange for attaching the feed delivery pipe. The valve shown is of the wing type, with the wings cast spirally, so that the entering water will cause it to revolve and wear an even seating. The amount of lift is regulated by the plug screwed in the top. A ball instead of this wing valve is often employed.

The clack box and feed delivery should be provided at the front end of the boiler if possible, and there are examples where this has been arranged in the smokebox, the feed pipe being carried round this to gather heat from the waste gases.

An improved form is made with a casting fixed to the boiler, and has a valve seat and stop inside the boiler, so that should the pipe be knocked off by accident the boiler pressure is still retained. This valve is shown at I, and is largely used on the American railroads, where the liability to head-end collision is much greater than it is here, owing to the fact that there is a greater number of single lines. The feed pipe is attached to it by a lantern nut, which greatly adds to its appearance. Injectors, with steam valves and clack boxes combined, are now being largely adopted, and a description of some of the most familiar forms will be given when the injector is under consideration.

The amount of live steam admitted to the blower or steam jet in the chimney can be regulated by a valve which as a rule is fixed to the smokebox wrapper plate and worked by a rod from the cab, where the controlling handle is placed. The pattern shown at J is cast in gun metal and has two connections for pipes inside the smokebox and a flange outside. The steam from the boiler is allowed access to the cock through one of these pipes and passes the valve as required to the blower through the other. The valve has a screwed stem and a stuffing box is provided to prevent the escape of steam when the blower is at work. Various other types are to be met with, notably one in which a fitting is placed in the cab of the engine, and forms a small ejector for the vacuum brake as well, and steam can through it be supplied either direct to the blower or through the ejector first and then through the blower.

Steam whistles are provided not only to attract attention and act as a warning for the passage or approach of trains, but are also employed as important adjuncts to the signalling arrangements of the railway, the destination and route of trains being made known by codes of signal sounds, drawn up for each district. Further, the whistle is often used as the means of communicating with the driver by securing the engine end of the cord running along the train to some suitable connection to it. The form shown in section at K consists of a gun metal bell reversed with its mouth downwards, and with its sharp edge immediately over an annular opening in the base, through which steam issues and impinges on it, causing the bell to vibrate violently and give out sound; the smaller the bell the shriller the sound, and *vice versa*, the larger, the deeper. The valve admitting steam to the whistle is kept closed by the pressure of the steam in the boiler, and to open it a lever is provided in the cab, to which a cord is often attached. To withdraw the valve for examination the plug shown must be removed, and it can then be taken out. Another style of whistle is shown at L. It is similar in its action to above, but different in shape. Instead of using a large bell to deepen the sound a long pipe is employed with the same result. The action of the controlling gear can be easily followed from the sketch, as also the connection for the communication cord which comes in over suitable pulleys from the train. Many railways fit two whistles on their locomotives, one for signalling purposes, and a second for warnings only. When the whistle is placed on the cab roof—which is, perhaps, the best place to be found for it—the valves are arranged to work vertically with the gear above the whistle.

There are many other fittings on the boilers of locomotives, but most of them are for the brakes or other special appliances, and these will be described in their proper place.

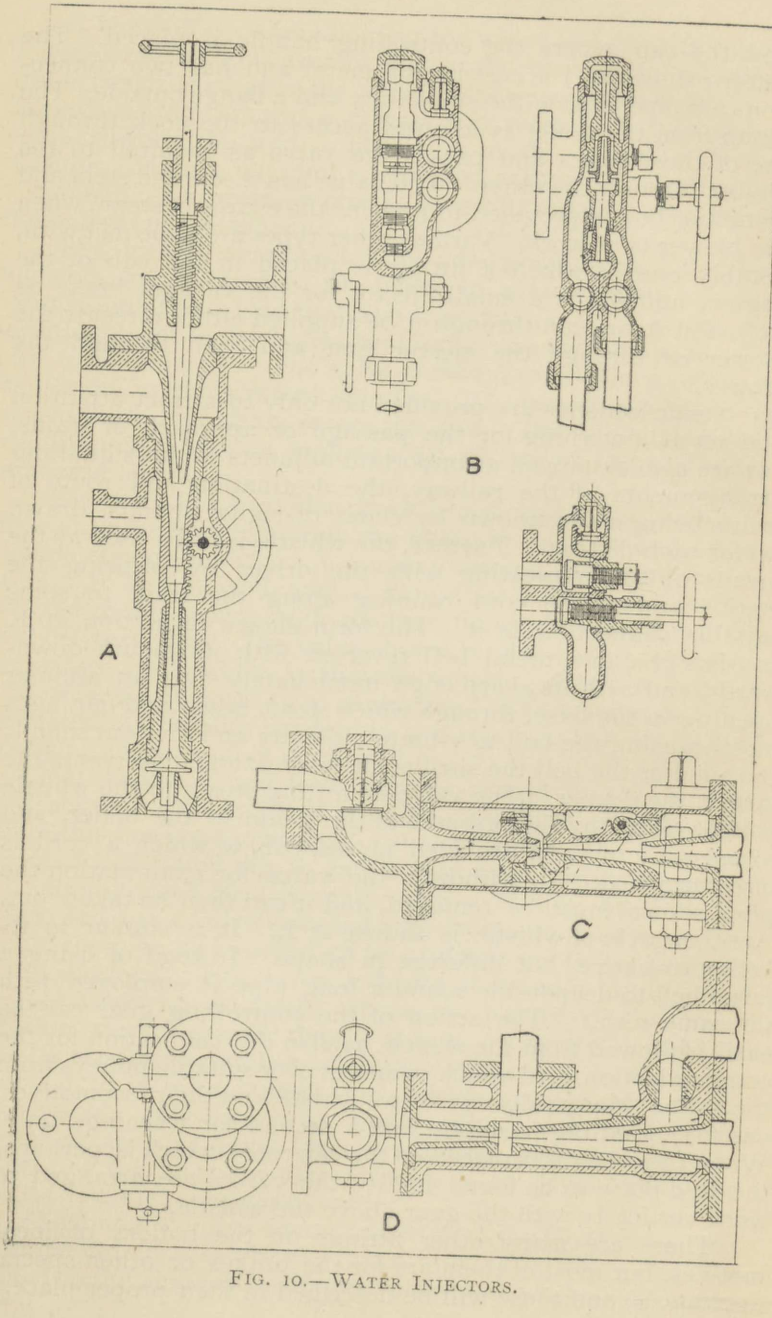


FIG. 10.—WATER INJECTORS.

The supply of water to the boiler is maintained either by means of injectors or pumps, the former being worked by steam, either high pressure or exhaust, and the latter generally from some moving part of the engine. Briefly, the principle of the injector's action is as follows: A jet of steam issuing from a contracted nozzle under a given pressure possesses more velocity than a corresponding jet of water would do at the same pressure, and if a jet of steam is suddenly brought into contact with a flow of water, a portion of the steam is condensed, and its velocity becomes imparted to the water to a sufficient extent to enable the combined steam and water to lift the clack valve and enter the boiler.

It is necessary that the water should not be too hot, as the jet of steam would then pass completely through it without condensing, and would not be able to enter the boiler at all; on the other hand, the colder the water the better the injector will work. As, however, the aim of all designers of boilers is to get heated water into them, and so avoid local straining, due to expansion and contraction at those points where the colder water is introduced, improvements have been made in injectors enabling them to work with warm and even hot water.

The earliest form of injector was invented by Giffard, and first fitted to locomotives in 1859, and the original form, slightly modified, has survived to the present day, a number of engines still carrying them. A common pattern is shown at A, Fig. 10, standing vertically. It has three arms and an open base, being there fitted with a non-return valve; inside are three sets of cones, the top one being for steam, which enters through the top branch, the second cone is in communication with the water, which finds admission through the next branch, and in this the steam meets the water, and is condensed; the third cone, which has its small end towards the small end of the last mentioned, with a space between, where the third branch is in communication, is provided as an outlet for all water and steam that does not correctly pass the opening between the two cones, and is called the overflow. To start the injector, water is turned on at the feed cock on the tank, then steam is admitted, and the quantity regulated by means of the screw plug shown inside the steam cone; the water is controlled by the raising or lowering of the combining cone by means of the hand wheel which is attached to the pinion engaging the rack on it. These are adjusted until there is no overflow, and the injector is then fully at work. The non-return valve at the foot is placed there to prevent any steam or water from blowing back if the boiler clack should be leaky. It is no doubt owing to the simplicity and general adaptability of this injector, for it can be adjusted to suit almost any pressure of steam, that it has survived so long in favour.

If the above-described injector should "fly off" as it is liable to do when the engine is passing over points or crossings, or if stopped suddenly, and the continuity of the stream of water is broken, the steam and water must be shut off, and the injector re-started. To overcome this disadvantage, many means have been employed. Among the best known of these is the injector made by Messrs. Gresham & Craven, in which the combining cone is provided with a movable portion, which, when the injector stops, moves and allows the pressure to escape at the overflow; when so relieved the steam jet forces it back, and the injector starts again, without any external regulation, whence the name "re-starting" to this class of injector. One form is shown at B in three sections; it is called the "combination" injector, because in one fitting are grouped the steam cock, water regulating cock, warming cock, and stop valve, with all necessary handles for controlling them. The steam is brought to it from the dome, as is necessary for all injectors, and the delivery pipe is carried in through the back plate, over the top of the firebox towards the front of the boiler. Only one joint is made on the boiler; steam enters the lower hole and passes up the centre of the cones, which are arranged in the opposite direction to those in the last example, that is, with the steam cone lowest, water and combining cones and movable valve next, and the delivery cone uppermost; the three first mentioned are diminishing cones, and the latter an enlarging one. When necessary to examine the clack under pressure, the stop valve may be screwed home to enable this to be done. To warm the feed water the cock on the overflow pipe must be closed, and the water valves opened, the steam then blows through to the tanks.

The principle of this re-starting device is applied to injectors placed horizontally as well as vertically, with equally satisfactory results.

Another well-known form is shown in vertical section at C, in which the steam enters at the right-hand cone, water by the cock shown next, both enter the combining cone, and pass together across the overflow gap into the receiving cone, thence upwards, lifting the back pressure valve, and along into the delivery pipe. The principle on which this injector "restarts" is that of the "flap nozzle." The combining cone is seen to be split axially, and hinged at the largest end; when the stream of water is broken, as before, by jolts, etc., and the pressure between the point of the combining cone and the steam cone becomes too great for the steam to overcome, the flap opens and at once relieves the pressure; then the steam, passing along, creates a partial vacuum in the cone, and draws down the flap, making it practically a solid nozzle. The overflow has a pipe affixed to the flange shown. Generally two injectors are fitted to each engine, in which case one would be fitted with a plain pipe to the overflow, and the other with a screw-down valve, so that when it is desired to warm the feed, the overflow can be closed, and the steam blown through the injector as before mentioned.

A third method is to have a series of passages or outlets in the combining cone, so arranged that when the injector is working properly the water passes by them, but when stopped suddenly the pressure relieves itself by escaping through the outlets to the overflow pipe.

Holes are drilled in other cases for a similar purpose, and their action is precisely as last explained.

D shows in horizontal section, a simple form of injector, very largely used; it has fixed nozzles, and is not of the restarting type, so that if stopped by jerks it must be readjusted the same as the Giffard injector.

In designing injectors the cones are generally settled as to shape by actual trial, and the size of the smallest part of the delivery cone settles the size of the injector, its diameter being measured in millimetres. The reason the first two cones are made diminishing is because the pressure of the steam has to be converted into velocity; then, when the water has been carried across the overflow gap into the delivery cone, this velocity is no longer required, therefore the next cone is made expanding, transforming the speed back again into pressure. A large number of injectors are made with flap valves covering the overflow orifice to prevent air being drawn up by the action of the stream of water passing the overflow gap and being forced into the boiler. A release cock is fixed above the first non-return valve, for letting out all condensed water that collects in the delivery pipe, and sometimes, instead of this cock, an elbow is provided with a union for attaching a pipe to the cab, to be there fitted with a cock and flexible pipe for watering the coals, etc.

Exhaust injectors working by the aid of steam that otherwise would pass up the blast pipe, are largely adopted on some railways. For working these the blast pipe has a union fixed at or near its base, and a pipe is led away to the exhaust portion of the injector, where it meets the water and heats it up to a considerable temperature, and passes it along to the

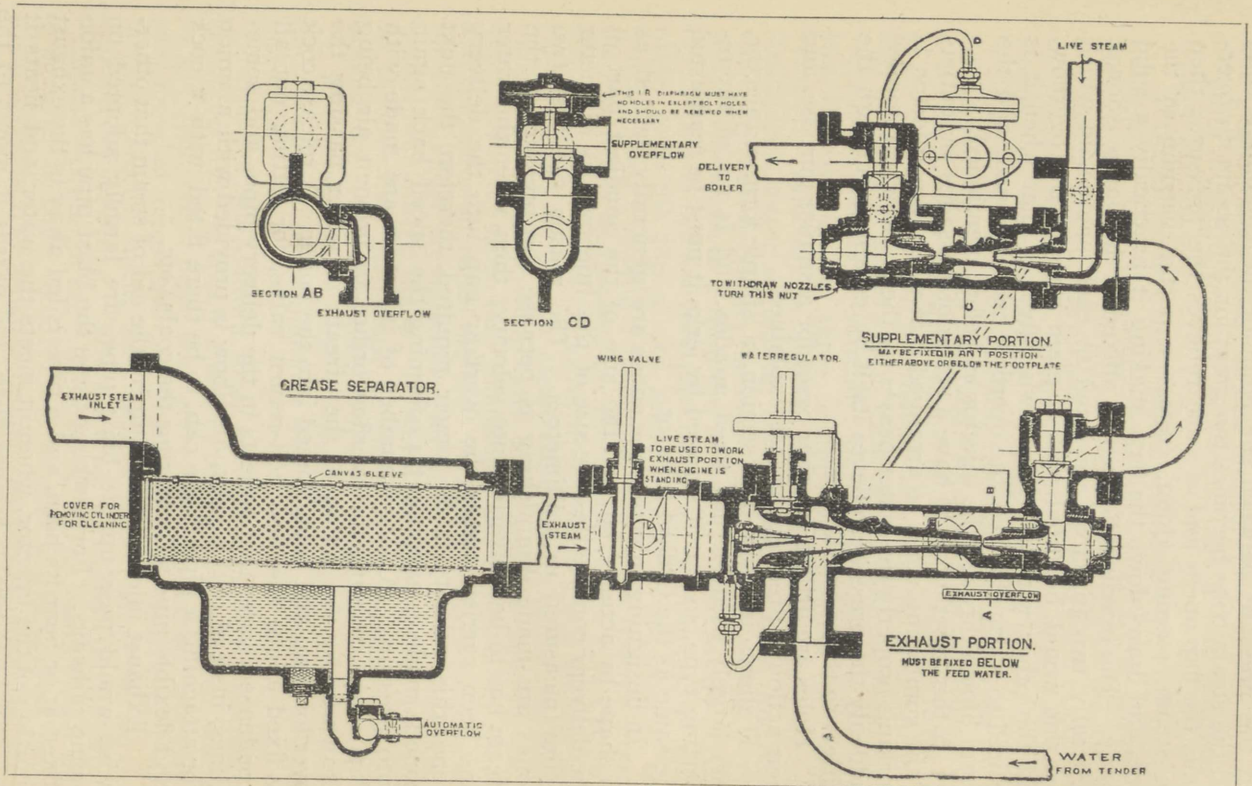


FIG. 11.—EXHAUST STEAM INJECTOR.

supplementary steam injector, which is specially designed for dealing with hot water, and which delivers it into the boiler. In the case of Davies & Metcalfe's injector, illustrated in Fig. 11, the steam is passed through a grease separator, which collects all oily impurities, water, &c., and allows the steam to pass along to the exhaust portion, where it meets the water; to assist the exhaust steam, a small jet of live steam is supplied from the supplemental valve. As it is most important that there should be no air in the pipes between the blast pipe and injector, all joints must be carefully made to exclude it, and the overflow pipe is fitted with a flap valve; the reason for this care is that the exhaust steam passes along the pipe at so small a velocity that it can only induce a small amount of vacuum in the combining cone, and into this the water flows and condenses the steam, more steam then enters, this collects more water, and so the injector works. The combining cone is fitted with the flap nozzle, described earlier, for automatically reducing the pressure within, if it should become too great; a non-return valve is situated at the end of the exhaust injector, by which the heated water is passed at a temperature of about 200° F., and a pressure of 70 lbs. As this is insufficient to enable it to enter the boiler against the high pressure now common on locomotives, the supplementary portion, worked entirely by live steam, then takes it and delivers it to the boiler, and in doing so heats it up to about 270° F. Thus the economy claimed is that the feed water is heated and delivered to the boiler almost entirely by means of waste steam, and a large quantity of water is used twice over; further, as it is not necessary to decrease the exhaust outlet, the steam drawn off by the injector reduces back-pressure in the cylinders. A wing valve is placed in the exhaust steam pipe, just before the injector, and a branch from the injector is provided for the attachment of a pipe from a small valve on the boiler, so that when the engine is standing or running with regulator closed, and there is no exhaust steam, the wing valve may be closed, and a small quantity of live steam admitted direct from the boiler to do its work. The exhaust portion must be placed below the level of water in the tank, and the quantity admitted to the injector is regulated by sliding the water cone, so as to decrease or enlarge the space around it, this being done by a wheel with an index fixed in the cab of the engine.

The combustible most commonly employed on locomotives is coal, although wood and petroleum are extensively used in various districts. Of coal, many varieties are used, the particular grade burned by a certain railway depending chiefly on its geographical position, although the working of some roads necessitates the adoption of a special class of coal, as for instance the running of engines inside the suburban districts of large cities, where a smokeless fuel is a desideratum. Briquettes are largely used on Continental railways, and have been experimented with here. They are made up of coal dust mixed with pitch and other ingredients, and compressed into blocks. Welsh coal, being more liable to crumble and be broken during transportation than the harder varieties, supplies a large percentage of the dust made up into briquettes. Liquid fuel has been adopted to a large extent on some of our railways, and is the exclusive fuel in some countries, notably Southern Russia, South America, and the far East, where the supply of suitable oil fuel is practically unlimited. The English method, or Holden system, is to spray it into the firebox by means of a steam jet, and intermix it with the air for combustion above a base of incandescent solid fuel or material laid over the firebars, whilst the Russian process is to similarly spray the oil fuel by steam into a brickwork furnace built in the firebox, the coal-burning arrangements having been entirely removed. In the English system steam can be readily raised with a wood and coal fire as usual, but with the Russian apparatus the oil burners must be started and worked from some independent source until steam is made in the boiler. The first method has the advantage of heating the plates of the firebox more gradually, which are consequently strained less than when an intense heat is maintained in a comparatively cool firebox.

Before considering the principles of combustion involved in the firing of our locomotive boiler we must first ascertain the composition of the chief fuel. A good coal is made up of a large percentage of carbon, combined with hydrogen, oxygen, and other gases and mineral ash. The quantities of these vary considerably in different grades, an almost endless variety of qualities of coal being obtainable in different parts of the world, but a fair sample has the following analysis :

Carbon	86·32
Oxygen	7·21
Hydrogen	3·75
Nitrogen	0·41
Sulphur	0·10
Ash	2·21
	100·00

The specific gravity is 1·3.

The carbon is most relied on to produce the heat in combination with oxygen, the hydrogen being most useful as more easily ignited; these two, hydrogen and oxygen, will sometimes combine in small quantities and form steam, especially at the first ignition of the coal. The nitrogen does not enter into the combustion of the coal, but escapes up the chimney in the form of nitrogen gas, the sulphur escaping as sulphurous acid, or sulphuretted hydrogen. The mineral ash is made up of various incombustible matters, principally sand and clay, and is the only really incombustible portion of the coal; it should not exceed $2\frac{1}{4}$ per cent. of the total weight of coal in good samples. Cinders are partially burnt coke, and are still combustible at a high temperature and a sharp draft.

The air in the ordinary atmosphere consists of a mechanical mixture of approximately one-fifth of oxygen to four-fifths of nitrogen, with small quantities of carbonic acid gas, ammonia, and watery vapour. It is the oxygen alone that is required for purposes of combustion, and it is worth noting that four-fifths of the air admitted to the fire is useless, it having to be heated to the temperature of the fire and then discharged from the chimney.

The products into which the combustible parts of the coal are converted in passing through the firebox and tubes of a boiler, are as follows:—first, steam, which is formed by the combination of the hydrogen from the coal with oxygen from the air in the proportion of 2 to 1 by weight, and is highly rarefied, invisible, and incombustible; second, carbonic acid, formed by carbon from the coal mixing with oxygen from the air in the proportion of 6 to 16 by weight, and is invisible and incombustible; third, carbonic oxide, formed from that portion of the carbonic acid which, after it is formed in the fire, takes up a further portion of carbon from the burning fuel on the bars, and changes its nature from a non-combustible to a combustible, this additional weight of carbon so taken up being exactly equal to the carbon in the carbonic acid, requires for its combustion the same quantity of oxygen as went to the formation of the acid, and it is invisible but combustible; and fourth, smoke, which is made up of such portions of the hydrogen and carbon of the coal gas as have not been combined with oxygen, and so have not been transformed into either steam or carbonic acid; this hydrogen, so escaping, is transparent and invisible, but the carbon on being separated from it returns to its natural state of a black finely-divided body, and then becomes visible and gives the colour to the smoke: it is only partly combustible. The former two are the product of perfect, and the latter two of imperfect combustion, generally caused by an insufficient supply of air, which can be remedied to an extent by the further opening of the fire-hole door.

In chemistry, which enters so largely into the explanation of the causes and effects of combustion, it is understood that all bodies not divisible by any means at our command into different substances possessing distinct properties, are distinguished by the name of simple bodies or elements; and those which are formed of two or more elements combined are called compound bodies. These elements will only combine with each other in certain definite proportions of one to another to form compound bodies. The smallest possible division an element can be reduced to is called an atom, and the weight of this small portion is called the atomic weight of the substance. In comparison with hydrogen, which is taken as 1, the atomic weight of the other components of ordinary fuel are—carbon 12, oxygen 16, nitrogen 14, and sulphur 32. When two or more atoms of elements combine together and form a compound body, the smallest division of it is called a molecule, and this cannot be further reduced in its compound form.

To form these compound bodies the combination must be chemical, as distinguished from mechanical in which the elements are simply mixed together; thus, carbon and oxygen may be mixed as intimately as it is possible, but unless the temperature is raised sufficiently they will not chemically combine. The heat at which bodies will so combine is called their ignition temperature, and this for carbon and oxygen is about 1,800° F., so that if our mechanical mixture be subjected to this heat the two elements will unite if allowed free access to each other in the proportion of 1 of carbon to 2 of oxygen, forming carbonic acid, and giving off intense heat in the operation; if, however, the air supply is contracted, then the 1 part of carbon may combine with but 1 of oxygen and form carbonic oxide, with the bad result to be described later.

For the purposes of comparison it is essential to have a system of units, and the unit of heat is taken as the quantity of heat required to raise the temperature of 1-lb. of water 1° F. Thus if 1-lb. of water is of the temperature of 60° F., and a source of heat is applied to it until it reaches 61° F., then one unit of heat has been absorbed in it. The unit of work is the amount required to raise one lb. one foot high, and is called one foot-pound, so that if a piece of iron of the weight of one lb. is lifted one foot, one unit of work has been performed. It being a mechanical fact that heat and work are mutually convertible, it is only necessary to have a rate of exchange; this is found to be 772 foot-pounds of work; so that if a weight of 772-lbs.

is dropped 1-ft., it will supply sufficient heat to raise the temperature of 1-lb. of water 1° F. Similarly, if the quantity of heat abstracted from 1-lb. of water in lowering its temperature 1° F. were properly applied it would raise a weight of 1-lb. 772-ft. high, or 772-lbs. 1-ft. high.

In burning, 1-lb. of carbon will, if properly consumed, yield 14,500 units of heat, and it has then taken up two atoms of oxygen for each atom of itself, and formed carbonic acid; if, however, insufficient oxygen is present, it will combine with the oxygen, atom for atom, and form carbonic oxide, and only give up 4,400 units, and thus 10,100 heat units are lost from this cause alone, from which it will be understood how important the necessity for a sufficient air supply is, the oxygen of the air being as much a portion of the fuel burnt as the coal itself.

To chemically saturate the carbon contained in one pound of coal 12·1-lbs. of atmospheric air are required, but under ordinary working conditions this quantity is quite insufficient, and a large production of carbonic oxide and heavy smoke would be the consequence, and it is therefore usual to arrange means by which a larger amount can be admitted, from one and a half to twice the above quantity is generally found to be necessary, depending upon circumstances; for instance, a much greater quantity of air is required to combine with the more volatile distillates from the coal when it is first put on to the fire, but the supply below the grate can be reduced as the carbon is thoroughly ignited, and more admitted above the fire through the firedoor.

It must not, however, be assumed from the foregoing that the quantity of air may be indefinitely increased, as the evils of a too large supply are as great as a too small one, for this excess acts, not by interfering with the perfect combustion of the carbon, none of which can escape under these altered conditions transformation into carbonic acid, but by lowering the temperature of the firebox by the mixture of cold air, which, after being raised to a high temperature, is passed out of the chimney, robbing the boiler of heat that should have been employed in raising steam; from this it will be seen that it is most necessary to regulate the supply of cold air to secure an exact combination of it and the volatile gases of the coal for perfect combustion.

We will now refer to the illustration, Fig. 12, by which the application of the foregoing principles to a locomotive boiler will be more easily followed.

The firehole is generally fitted with an air-deflecting device for directing incoming air downwards on to the fire,

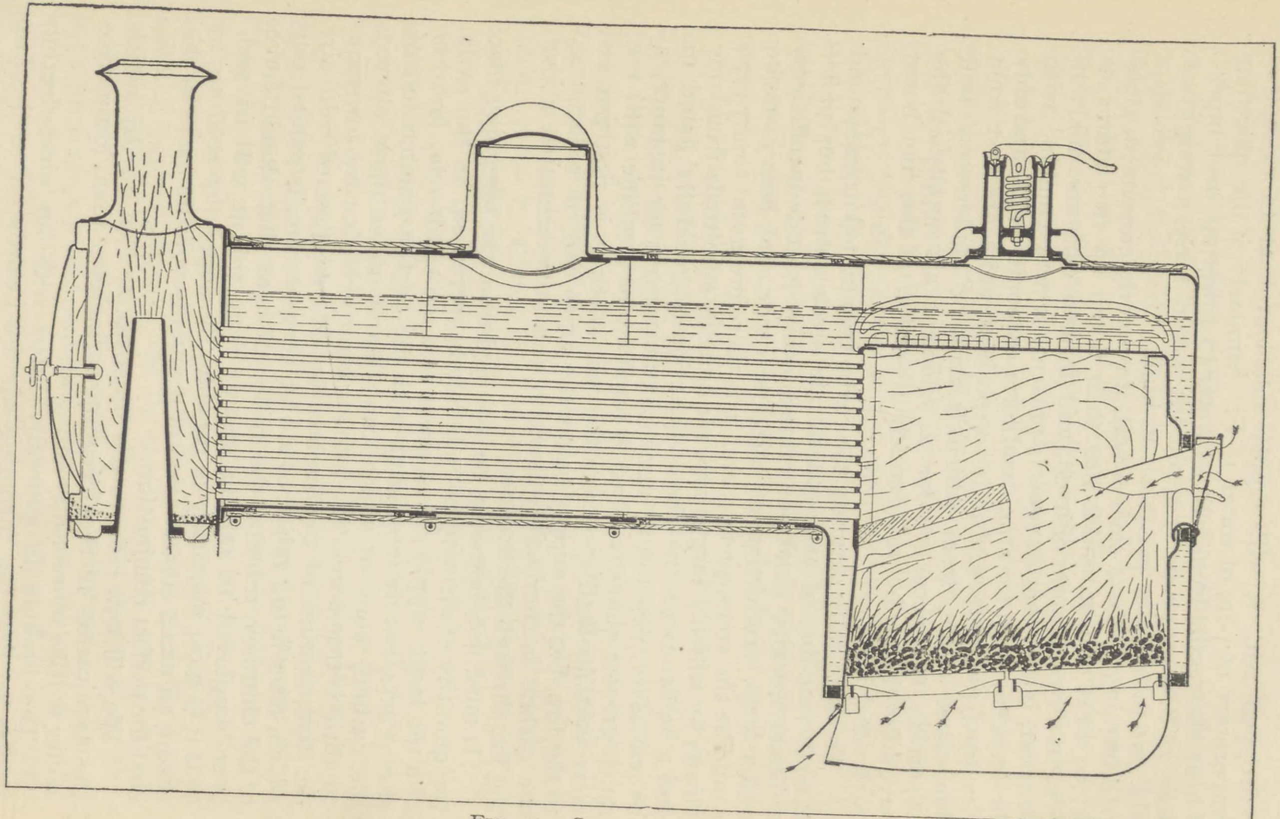


FIG. 12.—COMBUSTION DIAGRAM.

and the construction of this has already been mentioned when dealing with firedoors. The best form appears to be the plate, bent to shape, and introduced independently of the door, as it can then be more easily removed and replaced than if it forms part of the door itself.

A firebrick arch is built up across the front portion of the box, just below the bottom tubes, and reaching over towards the firehole, is inclined at the same angle as the air deflector, and forms an arch across the box, hence its name. It is supported on a row of copper studs or in some cases an angle iron on either side of the box. Its object is to deflect the fire over towards the back of the firebox at the top, and so, by retarding the escape of the more volatile gases contained in the coal, ensure perfect combustion; it also causes the heat to be more equally diffused over the whole of the inside of the box, and by preventing cold air passing over and striking the tubes reduces leakages there. Firebricks or firelumps are generally employed for building these arches. On many Continental and American engines a water bridge takes the place of the brick work.

The damper is opened to the extent found necessary for the admission of sufficient air for burning the required quantity of coal, whilst a further supply is admitted at the firehole door to complete the combustion. The latter should be as large as possible having due regard to the working of the engine and the state of the fire.

The coal should never be thrown into the firebox in large lumps, but should be broken up to about the size of a man's fist, and spread evenly over the grate, if anything the sides and corners should have most. Holes are to be avoided as they allow cold air to enter the box, cooling it, and causing leakages. The fire should not be too thick, as then a heavy blast is required to form proper combustion, nor too thin, admitting too much air, and "lifting" when the engine is running. The proper thickness, of course, depends upon the quality of the coal and the nature of the work to be done, and is best found by practice, but should not be more than 9 inches as a rule, and in many cases it may be much thinner. The bars must be kept clear from clinker, as this retards the passage of air through the fuel, and causes the great loss of heating effect mentioned above, when the carbon is only supplied with half its proper quantity of oxygen. A few flint stones thrown on the grate when the fire is thin will assist in the removal of clinker when formed.

Care should be taken to have a clear fire before an engine starts on a journey, so that it will not be necessary to introduce fresh coal while the blast is strong, as then an immense quantity of cold air is drawn in through the firehole, cooling down the firebox.

When coal is first thrown on the fire, it, being a great absorber of heat, has a cooling effect, then its gases escaping, the hydrogen takes up its proper amount of oxygen and forms water vapour, causing the carbon to mix with only one atom of oxygen, or only half its proper amount, and to give off dense smoke if the air supply is not large enough, or if the air supply is sufficient then it will be found much too great shortly afterwards, when the lighter gases have all escaped, leaving only the carbon, or coke behind.

The drawing, Fig. 12, shows, in a graphic manner, the general direction of the gases in a locomotive boiler, working under ordinary running conditions, the blast from the exhaust pipe, up the chimney, draws from the smokebox a portion of its contents; to supply the partial vacuum so caused, the air rushes in at the damper and firehole, that through the former passing through the fuel and supplying the oxygen requisite for combustion, and that through the latter regulated to chemically saturate those gases that have not been able to obtain their proper equivalent through the damper.

SECTION II.—THE ENGINE.

HAVING explained the construction and details of the boiler, and shown how the steam is generated, we take next in order the mechanism by means of which the energy of the steam is transformed into useful work; this, in the case of a locomotive, is the propulsion of itself and the load to which it is attached.

Primarily the engine consists of cylinders into which the steam is admitted, thereby moving the pistons, whose reciprocating motion is transformed through the medium of the piston and connecting rods into a rotary one at the crank axle, propelling the engine either backwards or forwards as required. There being usually two cylinders, there are correspondingly two cranks, to each of which one of the pistons is connected. These cranks are arranged at right angles, so that when one is at the end of its stroke and doing no useful work, the other is working at its best advantage.

To actuate the valves, distributing the supply of steam to the cylinders, a "motion" is required which admits steam alternately to either side of the pistons, and allows steam on the opposite side to discharge through the blast pipe to the atmosphere. Owing to the work that a locomotive has to do, it is absolutely necessary that the "motion" should be reversible, to enable the engine to travel in either direction; the various descriptions of this will be detailed later.

The cylinders are the heart of the machine, and are usually fitted at the front of the engine, either between the frames, when the engine is called "inside cylindered," or on the outside of the frames, when it is known as "outside cylindered." The first is most common in Britain, whilst the latter is largely adopted on the Continent, and is universal in America. The advantages claimed for the cylinders between the frames, are, greater rigidity to the whole structure as they act as a frame stay, and the motion being transmitted between the frames, the engine is inclined to be steadier, further the width over all may be less; the disadvantages are, the cranked axle and the difficulty of getting large cylinders in without cramping the steam chest. For the outside cylinders the great accessibility of all parts is an important argument.

The size of the cylinders depends on the work for which the engine is designed, and it will range from 8-in. diameter by 10-in. stroke to 20-in. diameter by 26-in. stroke; almost every size between these are to be met with, as well as examples smaller and larger. The metal employed is cast

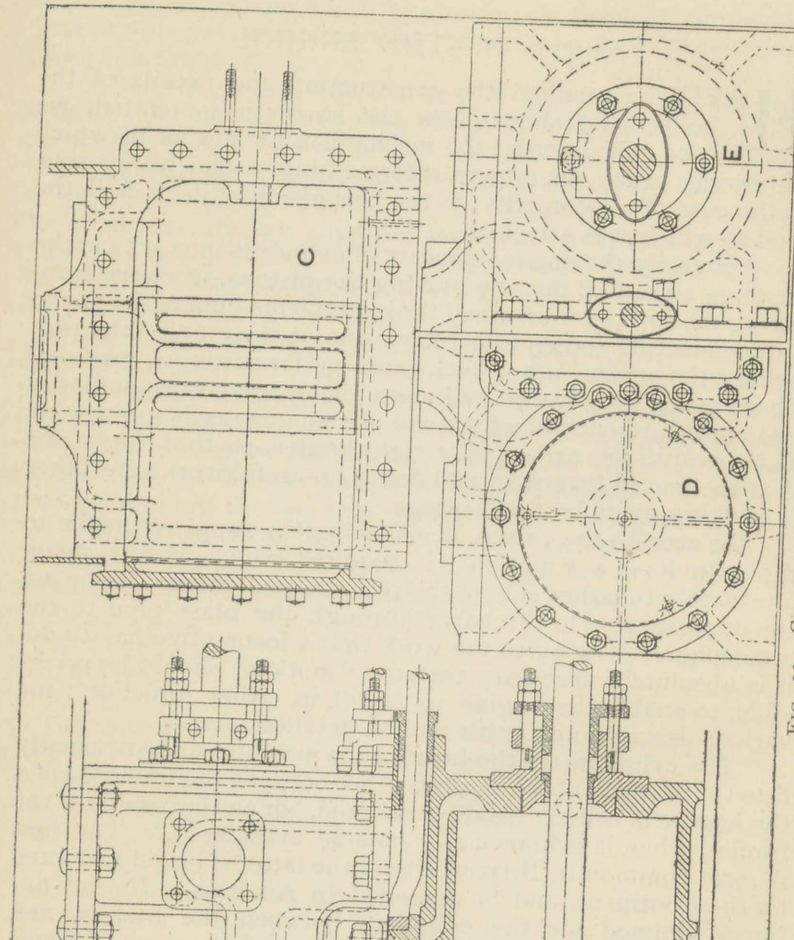


FIG. 13.—CYLINDERS.

iron of best selected close-grained quality, and as hard as can be worked. In the illustration, Fig 13, several views of a pair of inside cylinders of common form are shown. They are suitable for all classes of engines requiring them not larger than 18-in. diameter. The steam chest is placed between the two cylinders, which has made it customary to cast them in two portions, to facilitate the machining of the ports; the two halves being then accurately faced up and bolted together. Improvements in the machine tools employed have, however, made it possible now to cast the cylinders of this design in one piece, thus obviating the necessity for a troublesome steam joint between them.

At A and B a pair of cylinders is shown, the channels by which the steam gets to the chest are best seen at A. It will be noted that the passage branches out and supplies steam to both ends of the steam chest simultaneously, this is most necessary on this type of cylinder as the valves and their buckles take so much room; if steam were only allowed to enter at one end the other port would be insufficiently supplied and give the engine a weak beat. The exhaust outlet is shown at the centre, and above it the blast pipe stands. At B the other cylinder is shown in sectional plan with the slide valve in mid-position, so that the shape of the ports and covers may be seen, with the valve; the face on which the slide works is raised about $\frac{1}{2}$-in. above the surrounding metal to allow for wear and, if necessary, refacing. The metal forming the cylinder barrel is made thick enough to allow of more than one re-boring, as wear takes place unequally, the barrel being worn more opposite the ports, especially at the front end, and then allowing steam to pass the piston when the engine is commencing its stroke. At either end the bore is enlarged or recessed so that the piston wears no shoulder at the finishing points of its stroke. The covers are made to follow the contour of the piston, so that too much steam shall not be imprisoned there. The distance between the cover and the piston is termed the "clearance," and is usually $\frac{3}{8}$-in. at the front end and $\frac{1}{4}$-in. at the back end; this allows for wear and tear and the expansion of the piston rod. The metal employed for the front cover is usually cast iron, but steel both cast and stamped is sometimes used. The back cover containing the stuffing box is always cast iron. The faces for the cover joints are carefully scraped up true and then made tight with thin red lead and boiled oil. In tightening the joint the nuts should not be screwed full up on one side before some pressure is applied opposite or the joint will not be tightened up all round.

Large ports are to be recommended, as the steam will not then be wiredrawn in entering, or choked in leaving the cylinders and a free running engine will be secured. The valve never completely opens the port to the admission of steam, but allows the exhaust, after the piston has done its stroke, the full area to escape and thus reduce back-pressure.

At C one cylinder is represented detached from its fellow, and the ports are plainly seen. The valve is not shown, but the steam entrances will be noticed at the top on either side of the exhaust outlet.

D is a front elevation of one cylinder and half the steam chest, showing one method of making the joint of the two covers where they intersect each other; another is to divide the covers in a straight line, so that half the holes through which some of the studs pass may be in each cover, one nut then holds both to the face; this, however, requires the two covers to be of exactly the same thickness, otherwise there will be a tendency for one to blow and even the flange to break off the thickest cover.

E is a back end elevation, showing the glands and stuffing boxes for the piston rod and valve spindle, and also the place for attachment of the slide bar. The ledges shown on the top of the casting at each end are where the front tube-plate of the boiler and front smokebox plate take their bearings, these being bolted to the casting to form a joint. Round the barrel of the cylinder, ribs are cast for strength, and the whole is attached to the frames by bolts, as shown on A.

When the diameter of the cylinders is more than 18-in. it is a common expedient to place the valves and steam chest above or below the cylinders, whilst some designers have placed them on the outside of the frames. The best, perhaps, is to have them below, as then they are better drained of all condensed water, and further, the valves drop from the faces when steam is shut off whilst running and thus reduce wear.

Drain cocks are fitted at either end of each cylinder and on the steam chest, controlled by rods from the cab, so that the driver may open them to allow water to escape, they are screwed into the bosses shown on the sketches at B, D and E. The nozzles of these cocks usually turn toward the front of the engine and upward, so that issuing steam and water shall not strike the ballast and throw it up into the motion.

Fig. 13A gives views of one of a pair of outside cylinders having their steam chests placed between the frames for the valves to be operated by direct valve gear without the intervention of rocking shafts. With cylinders of this type it is customary to form on the casting a face and projection, which is machined up to exactly fit the hole provided in the main frame. An accurate fit is necessary to prevent any movement of the cylinders in the frame plate, the effect of which would be disastrous to the successful running of the engine; substantial cross-stays are requisite for outside cylindered engines owing to the great distance between the centres of the cylinders, often 6-ft. 3-in. After the cylinder castings are set in their places the holes through the flanges and frame plates are reamered out, and bolts, turned a tight driving fit are put in and screwed up. A gives a cross section through the centre and shows the exhaust passage which terminates in a flanged joint above the cylinder barrel, to this flange one leg of the base of the blast pipe is connected. B is a sectional plan showing the piston and piston rod in position, as well as the valve and steam ports. A tail rod prolongation of the piston rod is shown provided with a covering tube attached to the front of the stuffing box cover. Metallic packing of the "Earl" type is shown here for all the rods. C is a view of the steam chest with cover and valve removed exposing the ports; the outline of the casting will be readily followed from this sketch as will also the position of the retaining bolts. D is the front cylinder cover whilst E is the back one which in the case of outside cylinders is usually made separate from the main casting. The cylinder in this case is shown lagged with sheet metal having an intervening air space, but in many cases a covering of wood or asbestos is put on before the cleading plates are wrapped round. The front end is also usually finished with a plate filling the inner edge of the flange of the cover. It is customary in some cases to entirely case the flanges over with dished metal covering caps which impart a very neat appearance to the engine, these caps being held in position by a central nut or the lubricator if such is provided for the cylinders. When the outer cleading is fashioned with a curve to meet the smokebox, it is advisable to place a footstep about midway for the use of the enginemen when passing round the engine.

The pistons are usually made of cast iron, wrought iron or cast steel, brass being occasionally used. The shape is necessarily determined by the size of the cylinders and the metal employed. For all sizes up to 17 inches, cast iron is most common; for larger, steel or wrought iron are now largely adopted, on account of their greater strength, which enables the weight of the head to be materially decreased, this reduction in the weight of the reciprocating parts being a very important consideration, especially on engines designed for

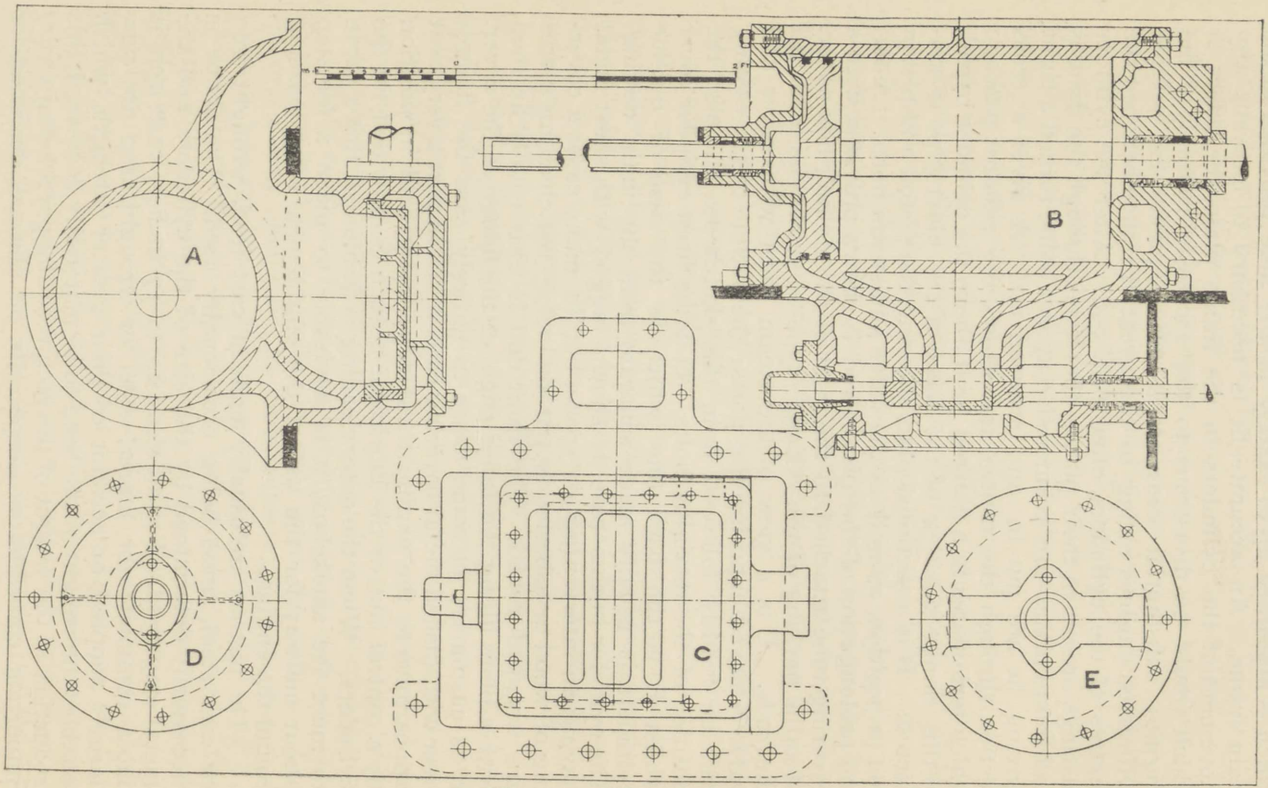


FIG. 13A.—OUTSIDE CYLINDERS.

high speed. They are made with a thickened boss, through which the end of the piston rod passes, the hole being usually tapered and recessed slightly at the largest end for the reception of a shoulder turned on the rod; the taper is generally about 1 in 8, the rod being sometimes ground in, but generally simply turned to the same taper as the hole, a good fit with from $\frac{3}{16}$ to $\frac{1}{4}$ of an inch "draw," and it is then pulled home to the shoulder by means of a nut placed on the screwed end of the rod, the nut is often octagonal to occupy less space. When the nut is fast, a hole is drilled through it and the rod for the reception of a rivet or taper pin, the ends of which are hammered into countersinks, preventing the nut from slacking loose in working. Instead of the rivetted pin, the end of the rod may be rivetted over to secure the nut; in either case it is generally necessary to split the nut for removal. The rim of the piston is widened and turned up to $\frac{1}{32}$ inch less in diameter than the cylinder, and has a recess or recesses turned in it for the reception of one or more rings, one being used for small pistons, and two or three for larger ones. A, Fig. 14, shows a piston used for cylinders from 17 to 18½ inches in diameter. It is made of cast iron, but if steel were used the disc might be made thinner. It is turned to take two rings. B is one intended for three rings, and may be in either of the above metals. C is a piston for much smaller cylinders, and has one ring only. The advantages of having more than one ring are—less liability of the steam passing, and greater flexibility, as one ring being necessarily stiffer, has a much greater tendency to cut the cylinder.

The rings can be made in cast-iron, steel or brass, the first being the metal by far the most commonly employed. A barrel of the necessary diameter, and about one foot long is cast, and then turned to ½-in. larger in diameter than the cylinders which the rings are to fit, and the pieces wide enough to form rings are turned off with a parting tool; two holes are drilled at a distance of about 1½-in. apart, and the piece between them removed. The rings can then be sprung into the cylinder a good fit, they are kept from turning on the piston by pins screwed into it, but these are not exactly in the same place for both rings, so that should steam pass one ring it is not likely to get by the next; the ends, too, are also kept away from the ports in which they might catch. When steel or brass is used it is often made in bars of the required section, and the rings are bent to shape, the joints being simply cut across diagonally and butted together. The first-named metal is used for very hard cylinders, and the latter for soft ones.

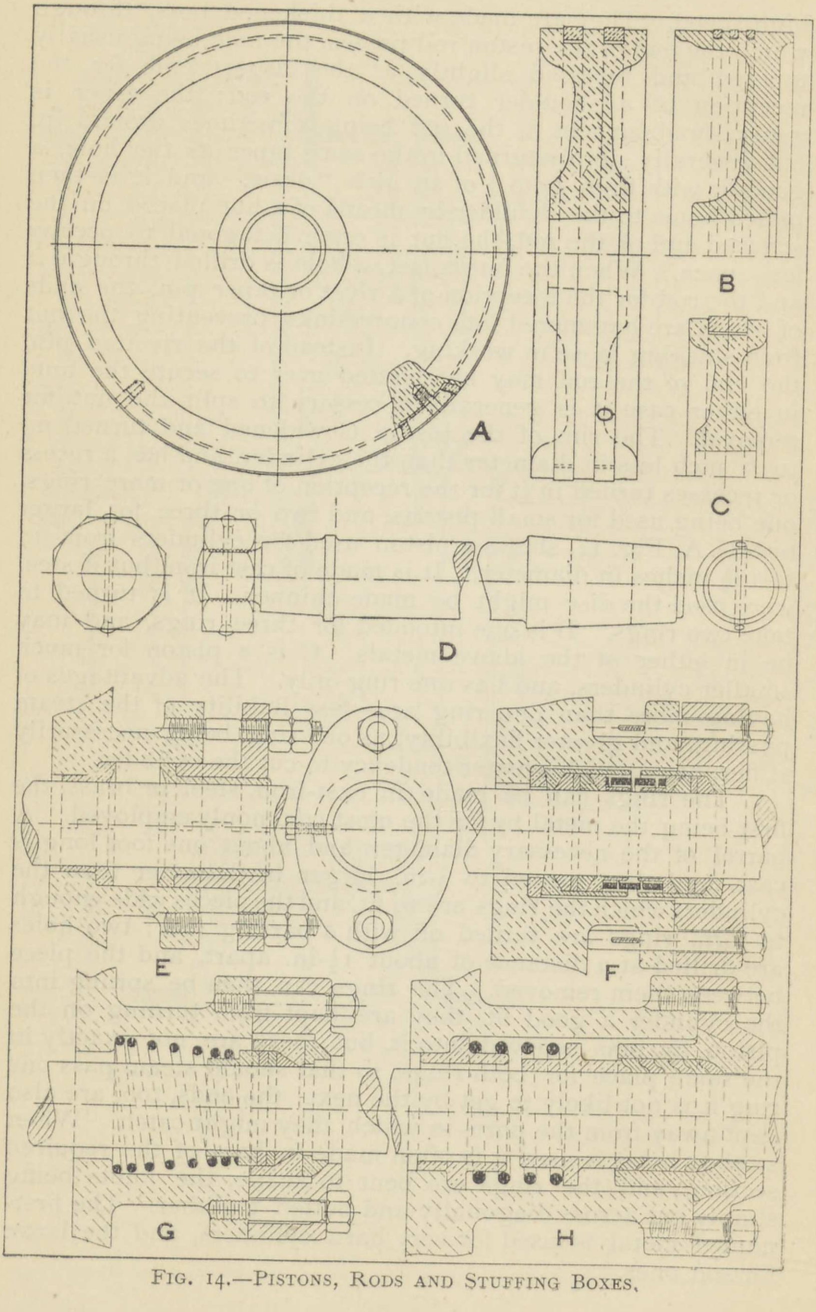


FIG. 14.—PISTONS, RODS AND STUFFING BOXES.

Many elaborate patterns of pistons and rings are in use in America, with springs to keep the rings tight in the cylinders, but the Ramsbottom rings above described are universal in Britain, for in addition to being equally efficacious they are very much simpler in construction and cheaper to maintain.

The piston rods are made of steel or wrought iron, and are from $1\frac{1}{2}$ to $3\frac{1}{2}$ inches in diameter. One for engines with 17-in. cylinders and larger is shown at D. It has a taper shoulder and thread at one end, and a taper at the other on a portion of larger diameter than the rod, so that the cotter hole may not weaken it there. The joint at the front end, attaching it to the piston, has already been described; at the other end the crosshead embraces it, and the rod is ground in until it is within $\frac{1}{16}$ of an inch of being "home," the cotter being then driven in to do the rest. The taper at this end is about 1 in 16. Sometimes the end of the rod is swelled out to form the crosshead. On small engines the ends of the rod are simply turned down to the required taper, and no shoulder formed, but for larger engines the weaker portions are generally thickened up.

The rods are passed through a stuffing box at the back end of the cylinders, and many means have been devised for allowing them to work through freely without permitting steam to pass. On the cylinder drawing, Fig. 13, a simple stuffing box is shown, having a solid neck ring and gland. This design could only be used for engines which have the piston rods with the crosshead end of the same or less diameter than the rod, as a large end could not pass through the holes in gland and neck ring. Fig. 13a shows a tail rod for the piston.

At E, Fig. 14, another pattern which has been largely adopted for rods with large ends is shown in section. The neck ring is split along the dotted line, and half put on either side of the rod, and the two pushed home, holes being frequently drilled and tapped in the front of each to receive the ends of a wire for use when it is necessary to draw them. The gland is bored out large enough to take a bush, also in halves, put on the rod as before, then pushed into the gland, and held by the set screw shown in the front view. Packing, consisting of hemp or some preparation of asbestos, is put in and compressed by the gland being forced home by nuts on the studs, lock nuts being used to prevent the first nuts from slacking back. The neck ring and gland bush are usually of gun metal, the gland, however, may be either of cast or wrought iron. This design of stuffing box has been until very recent years the general practice here, but now metallic packing is being largely adopted, the great advantages of which are increased freedom for the rod, saving in wear of glands, and reduction of labour in packing, whilst extra first cost is its only drawback.

At F, a pattern called the "United Kingdom Metallic Packing" is shown in section. The stuffing box is bored out, and a ring of brass inserted, having a flat face to bear on the bottom of the hole, and a curved face on which the next portion of the packing bears. At the outer end of the stuffing box, a cover, instead of a gland, is required, bored out and having a curved face similar to that on the neck ring. These two curves each form portions of two concentric spheres, so that the rod with its packing on it has free movement in any direction without difficulty. The packing itself consists of two cases of brass bearing at the outer ends of each one, on the curved surfaces before mentioned, and being hollowed out to receive each three or more white metal rings, and a seating for the ends of a flat steel helical spring, which, being compressed when the joint is first made, presses the two inner brass seatings outwards, and forces the white metal rings down to the rod by means of angular faces provided. When the joint leaks it can be repacked by taking off the cover, and inserting another ring of white metal. The front joint is made steam-tight against the stuffing box with a ring of sheet asbestos or a piece of round soft copper wire.

At G, the "United States Metallic Packing" is drawn in section. It consists of a cover fastened to the front of the stuffing box, somewhat similar in shape to the previous example, with a ring of brass inside bearing against a spherical surface upon it. This ring has a flat side, on which bears a cast iron ring containing a conical cavity on its inside, into this white metal rings are inserted. These are cut into several pieces or sections, and a solid brass ring is forced against them by a spring, which at its other end rests against the base of the stuffing box to press them into the cone, close them on the rod, and form a steam-tight joint; the steam also assists the spring in pressing the rings into the cone. By means of the ball joint just mentioned, and the flat surface on the opposite end of the first brass ring, the rod has freedom to move in case it should by any means get out of line.

A third form of metallic packing is shown at H, and is known as the "Jerome." It has a similar stuffing box and cover to the previous examples, with a neck ring to act as a bearing surface for a spring, which, pressing on a collar, forces several white metal rings into a recessed bush, fitting closely to the piston rod at its outer end. The action of the spring here is precisely similar to those already explained.

There are numerous other methods of packing piston rods, but the principles involved are generally as already described.

The valve spindles have stuffing boxes which may be the same as those for the piston rods, but generally with metallic packing they are simplified by leaving out the arrangements introduced for securing flexibility, not being so likely to get out of truth.

With large cylinders the piston rods are often carried through the front cover, the tail rod thus formed being intended to assist in carrying the weight of the piston and save wear of the bottom of the cylinder. Valve spindles are treated in a similar manner, and an advantage may be claimed for this practice that it is possible to fix the valve centrally over the ports by means of the glands if by chance the back spindle gets broken inside the steam chest.

Of the frames proper we shall deal later, when describing the carrying gear of the locomotive. The motion or "spectacle" plate extends across between the frames of engines with inside cylinders at a point about 4 feet behind them, forming a transverse stay and a means of attachment for the slide bars and various parts of the motion. It may be built up of plate, strengthened with angles, or, as is more usual in new engines, cast in steel with suitable lugs on it for fixing the slide bars, etc., to.

The slide bars are intended to keep the movement of the piston rod in a straight line, as the crosshead is fixed to the end of the piston rod to which the small end of the connecting rod is attached, and which would be continually forced upwards when the engine was working forwards, or downwards when the engine was reversed; this, if permitted, would be fatal to the piston rods. There may be either one, two, three or four of these slide bars to each crosshead, according to the fancy of the designer. When one is used it is usually made in wrought iron, about 3-in. thick by 6-in. wide for 18-in. cylinders, case-hardened and afterwards ground to shape, or it may be of steel; it is fixed above the piston rod, and the crosshead encloses it. When two are provided, one is placed above and one below the piston rod, and the crosshead works between them; they may be in either of above metals or of cast iron. Three are used on some engines doing most of their work in one direction; the top bar is of cast iron made wide to allow a good surface for the slide, and the two lower ones—one on each side—support the crosshead when the engine is running backwards. Four bars are arranged, two above and two below, and the crosshead works between a slide block on either side running between two bars; any of above metals

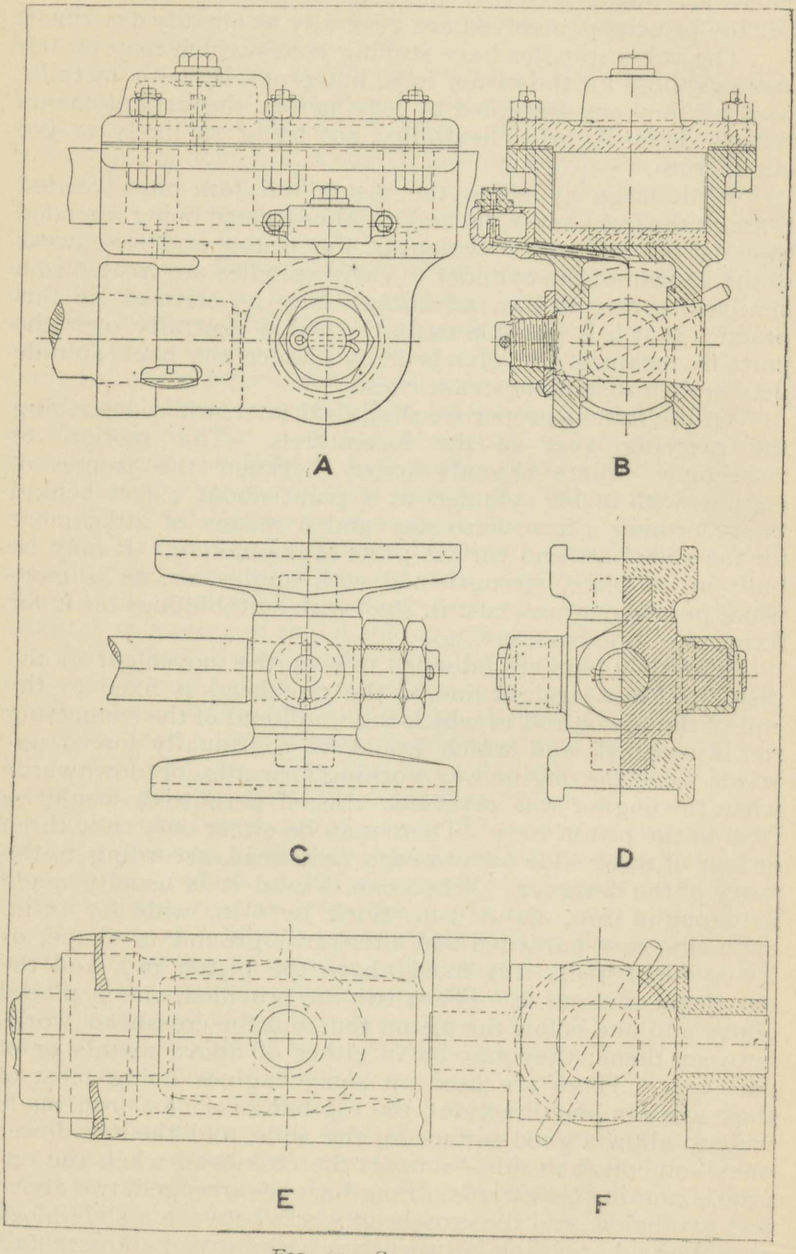


FIG. 15.—CROSSHEADS.

may be used for these, but case-hardened wrought iron is most common. It is usual to fit these guides up to the cross-head and piston, and have liners, of gunmetal, between them and the lugs on the cylinders and motion plate, so as to enable the distance between them to be adjusted when wear takes place. This, of course, can only be done when two or four bars are used; with single bars the crosshead has to be either white metalled or let together when slack, so as to fit the slide bar.

At A, Fig. 15, one form of crosshead, suitable for single bar engines, is shown in elevation. It is of cast steel, but a somewhat similar design may be frequently met with in cast or wrought iron. The socket for the reception of the piston rod end is on the left, the rod being ground in and held by the cotter shown. The taper of the rod end is generally 1 in 16, and of the cotter 1 in 32; the latter is of steel $\frac{5}{8}$-in. thick, rounded on both edges and kept from slacking back by means of a split pin or cotter passed through the end just below the crosshead; it is set at an angle so as to be more accessible when it is found necessary to remove it with the crosshead in position. The cover and bottom wearing plates are of cast iron, well supplied with oil grooves, and often having white metal let into holes on their surfaces. At the sides, pieces of gunmetal are inserted for wearing strips, which are easily replaced when worn. Cheeks are carried down on either side to take the ends of the gudgeon pin, on which the small end works. The shape of this pin can be best seen in the cross section at B. It is coned where it passes through the cheeks so as to be always tight, and it is held in place by means of a nut on the thread at the smaller end, a split pin preventing this from slacking; the centre where the small end works is parallel. This pin is usually of wrought iron, case-hardened, and is lubricated from a cup fixed to the side of the crosshead. The small end is usually of the "solid eye" type for this form of crosshead.

At C and D another design is shown, being one suitable for engines fitted with two slide bars. The centre portion is of steel, having four lugs upon it, and a tapered hole through which the end of the piston rod passes; this part can be entirely finished in the lathe. The piston rod end is tapered and secured by means of a nut, check nut, and split pin. The top and bottom lugs are for the attachment of the slide blocks or slippers, which are of cast iron, and have holes recessed in them for the lugs, no further means of securing them being adopted. The side lugs are for taking the small end of the connecting rod, which is of the "forked" type. Caps of gunmetal are fitted on the lugs, as seen in section at D. These are held in position and prevented from turning by means of pins or cotters passing through them and the lugs; thus all the wear takes place on the caps, which are easily renewed when worn out.

The crossheads for two slide bars may be met with in greater variety than perhaps any other form; in some examples they are opened out, and the rod end works between, a gudgeon pin similar to that at B being employed. Another type is made solid with the piston rod, the crosshead and the small end being "forked," with a gudgeon pin; the taper is then in the rod, and the wear takes place in the crosshead, which is bushed for the purpose. In America two bars being largely used this crosshead is employed, being known as the "alligator" type, and on express engines the upper face is often made longer than the lower, it being worn most by the engine running chiefly forward; it is made of cast steel, having wearing plates fitted above and below for renewal when worn.

At E and F another form of crosshead is shown, it is of a type used for four slide bars, and consists of a socket which has also two cheeks continued back, and a gudgeon pin passing through them. Between these the small end of the connecting rod takes its bearing, whilst on the ends which are reduced somewhat in diameter and project about 3-in., the slide blocks are placed; the pin is prevented from turning by having a key or set pin inserted. The socket and pin are generally of wrought iron case-hardened, the slide blocks are of cast iron, hollow if large, and often provided with holes filled with white metal upon the sliding surfaces. With this form of crosshead it is necessary to have a small end with half brasses and a strap, as the pin cannot be drawn out to accommodate a solid eye, although some engines have provision for this, by having a long pin with a head and thread at its opposite end; this can be passed through the two blocks and secured with a nut, the pin being prevented from revolving as before, by a key or feather.

In any of these forms large bearing surfaces are an advantage, but it must always be borne in mind that heavy crossheads, being reciprocating parts, are difficult to balance, therefore they should be as light as possible, consistent with strength, and all wearing surfaces should be bushed, or provided with wearing strips, as it is then much easier, as well as cheaper, to renew them; case-hardened wrought iron is perhaps the best metal, the wearing surfaces being ground up after the hardening operation has been performed, which is liable to slightly distort the metal. The slides should be amply lubricated to ensure easy working, and also to keep them free from dust and grit, which is very liable to get upon the bars whilst the engine is running.

A crosshead used for the Vauclain compound has four slide bars, the high and low pressure cylinders being arranged one above the other with a separate piston and piston rod for each. These are connected at their outer ends to a common crosshead which has two sockets to receive them, one above the bars and one below. The bars are arranged similarly to those shown at F, with the centre of the crosshead swelled out and sliding between them. This is cast in one piece of steel, and the wearing surfaces are covered with block tin $\frac{1}{16}$ inch thick. Other American forms resemble that at A, excepting that the wearing strips or "gibs" are provided at top and bottom with means by which they can be set out to take up wear.

The connecting-rods are the mediums through which the reciprocating motion of the crossheads is converted into rotary motion at the cranks, and consequently the wheels; at one end they work upon the gudgeon pins of the crossheads, which have been already described, and at the other on the crank pins. Various designs and shapes for the ends are in vogue, experience having taught that the end of the rod nearest the crank is the most liable to breakage when working, and therefore this end is always made the stronger, and being the larger of the two it is known as the "big end," whilst the other, or crosshead end, is called the "small end." It has also been found that welds are unsafe, it not being always certain to make a good job of such a large weld, accordingly rods now, when of wrought iron, are always forged from one "bloom," welding being entirely eliminated. Cast steel is largely employed for connecting rods, but whichever metal is used, great care is taken in examination, to prevent defective rods being put under an engine, as it is most important that none but the best metal and workmanship be allowed in these important members of a locomotive, the breakage of which is liable to be one of the most disastrous failures that can occur to an engine when running. The section is generally rectangular with the corners well rounded off, but some small engines have them round, and when cast steel is used they are often made fluted, or of H section, this giving the greatest strength for the area of metal employed, and also allows for some reduction in mass, and consequent lessening of the reciprocating weight. The area of the cross section of metal at the centre of the connecting-rod is by empirical rule, made

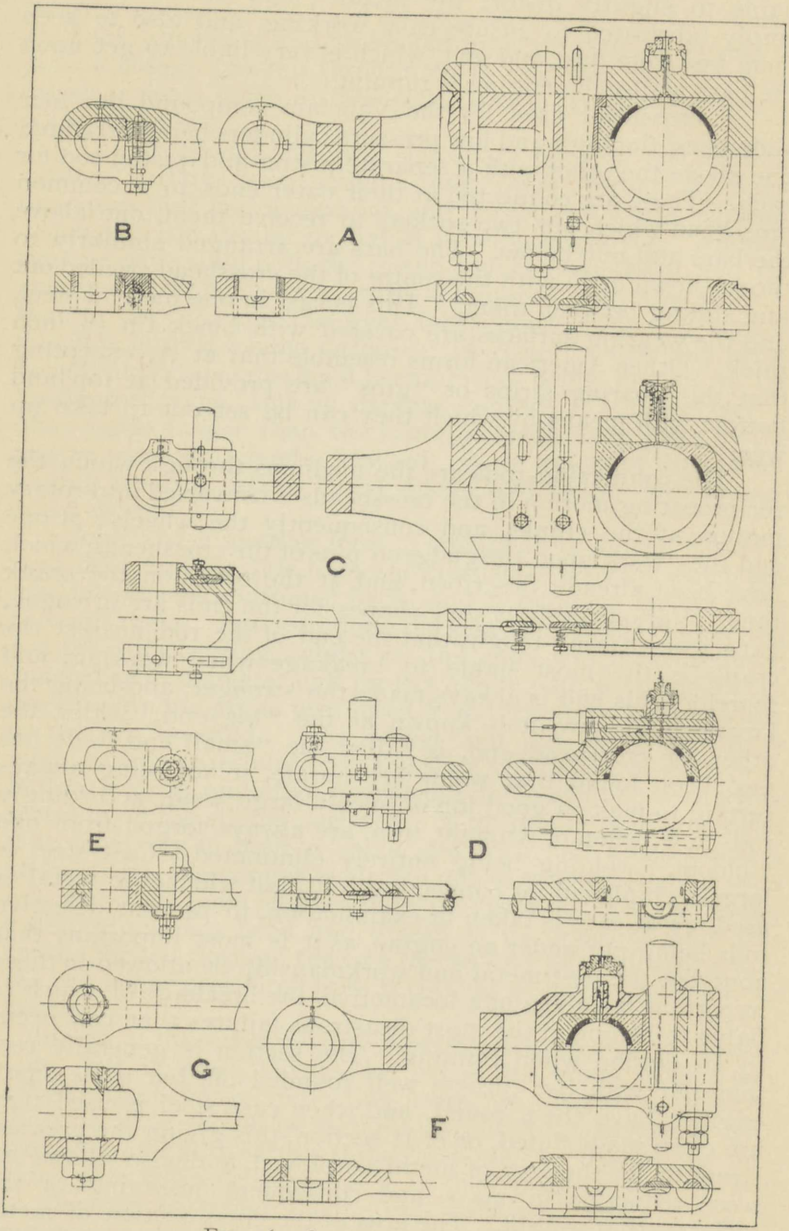


FIG. 16.—CONNECTING ROD ENDS.

from 1·1 to 1·3 times the area of the piston rod, and the length of the rod, between the centres of pins at either end, should be from $2\frac{1}{2}$ to 3 times the stroke of the engine, although small engines often have them shorter than this; the longer the rod, however, the smoother the engine will run.

Fig. 16 shows several forms of rod ends. At A a rod having a "strapped" big end and "solid eyed" small end is shown. The jaws of the strap fit over the two half brasses, and on to the end of the rod, being held by two tapering bolts, fitting accurately into holes, and secured by two nuts with a small cotter below; the two brasses encircle the crank pin, and are held together to the necessary tightness by a long, flat, tapering cotter, a push plate being inserted between the cotter and front brass; the cotter is prevented from slacking by means of two set bolts in the strap above and below the rod end, and a small cotter through its lower end. The oil cup is forged solid with the strap, and machined to proper shape; the brasses each have two hollows into which melted Babbit metal is poured, so as to reduce friction. The rod end has a large hole cut through it to reduce the weight. The small end is a part of the rod proper, and is bored out and fitted with a bush, which is prevented from turning by the insertion of a key. An oil hole and hollow are provided on the upper side to admit oil fed from a cup on the side of the crosshead. The rod, strap and bolts are of the best Yorkshire iron, and are machined all over. The cotter, push-plate, and small end bush key are of steel, the "brasses" and small end bush being of gun metal.

At B another small end, also solid eyed, but provided with means for adjusting and neutralising wear, is shown. It has two brasses and a wedge, which can be raised or lowered, this being done by means of a screwed bolt having a hexagonal head below, and which is prevented from turning, when set, by a locking plate placed over it, and held up by a split pin. The screw is held by a pin passing through the rod end, and engaging in a groove in the screw. It is, however, doubtful whether any corresponding advantage is gained for the extra expense incurred in fitting up this adjusting gear, as the solid bush is much cheaper, and can be easily renewed when wear takes place.

The rod shown at C also has a strapped big end, but the means employed for holding it to the rod are different: instead of the two bolts one cotter is used, and the rod end formed with recesses, under which the ends of the strap are held; the two brasses, as before, are retained by a long cotter, checked by two set screws, and a small key below, and instead of the push-plate a gib is employed. The oil cup is forged and fitted with a spring button and a pin, instead of worsted trimmings. The small end is of the forked type and each branch is fitted with a strap, which contains a hole in which the gudgeon pin works, these straps being held by cotters and gibs. No bushes are inserted in the holes, as this rod is used in combination with the crosshead shown at C and D, Fig. 15, where wearing caps are employed, which can be renewed when worn. The rod and cotters are of steel, the small ends of wrought iron. The set screws are of steel in all the above examples.

D shows a pattern known as the "marine" big end, from its similarity in shape to those usually employed on steamships. The rod end is swelled out to take two bolts, one above and one below the crank pin; these pass through a cap, forming the rod end. The bush is circular outside and in two halves, being prevented from turning by the two bolts just mentioned, which partially intersect it. Holes are provided in the bearing, into which Babbitt metal is run, as shown. The bolts are of large diameter for strength, and holes are drilled up the centre of the plain part to reduce the strength there to that of the screwed portion. The oil cup is solid on the cap, and as the top bolt prevents an oil hole from passing direct to the bearing, two holes are made passing round the bolt. The small end is of the strapped type, and has one bolt and adjusting cotter; two bolts are often provided with this form of small end. The rod itself is circular in section.

Another small end with adjustable wedge is shown at E. The brasses are in halves, and a block of steel bears upon the back half, this being in turn held by a wedge placed horizontally and drawn to necessary tightness by a screwed portion passing through a washer and having nuts upon it. As will be seen from the sketch, a safety catch is provided to prevent the wedge falling out, should the locking device fail. Serious damage to the engine might ensue if this wedge were lost, for if the piston was travelling towards the back cylinder cover, either it or the piston would certainly be broken.

At F other methods of making the two ends are shown, suitable for outside cylindered engines. It will be seen that the bearing is not nearly as large in diameter as in the previous examples, as, the crank pins being outside the wheels, it has only to transmit the necessary turning power to them; whereas in inside cylindered engines the crank pin forms part of the axle, and in addition to the propelling has to take its share in supporting the weight of the engine. This example has a forked "big end," open at the end, and fitted with a block held by a tightly-fitting taper bolt locked by two nuts and a small key below. The brasses, in two halves as before, are held together by a long taper cotter and push-plate, Babbitt metal being provided as in the previous examples. The oil cup is forged on solid. The small end is of the solid eye type fitted with gun metal bush, which is turned to a taper, and pressed tightly into place, no key being used.

A forked small end is shown at G, which differs from that at C in having a gudgeon pin forming part of the small end, instead of part of the crosshead as is usual. It fits into a taper in each cheek of the rod end, and is prevented from revolving by a small key with a projection on it fitting into a hole in the pin to prevent the key from working out. The other end of it is provided with a thread for a nut, and hole for a small split pin. The crosshead in this case is bushed with softer metal than this pin, to be easily renewed when worn.

Interesting modifications of all the above-mentioned types may be met with, as well as a large number of different construction, the majority, however, have no means of taking up the wear of the small end, it being considered unnecessary, although nearly all provide facilities for adjustment at the big end, as a bad knock there is very detrimental to the life of the engine. All the long cotters provided for taking up wear should have a recess cut in the sides where the set screws press, about $\frac{1}{16}$ of an inch deep; this is usually cut by a slot drilling machine and prevents "burring" by the set screws.

The admission of steam to the cylinders on either side of the piston and the discharge of the exhaust steam from the opposite end is controlled by means of a slide valve moving over the face of ports in the steam chest, alternately opening and closing them to steam or exhaust.

At A, Fig. 17, is shown an ordinary slide valve in section and plan. It consists of a rectangular casting, either in hard gunmetal or iron, with a cavity under a raised central portion and flanges on either side to cover the ports against steam as it passes backwards and forwards over them. Bridges or ribs are cast across the cavity of the valve, both inside and out, to strengthen it, and sometimes holes are drilled in the back of the flanges down to a depth equal to the scrapping thickness of the valve, so that when steam blows through, the driver is warned by the sound that the flanges are thin, and the valves require renewing.

The valve is encircled by a buckle formed in one with the valve spindle; this latter passes through a stuffing box, and has means by which it can be attached to the moving power

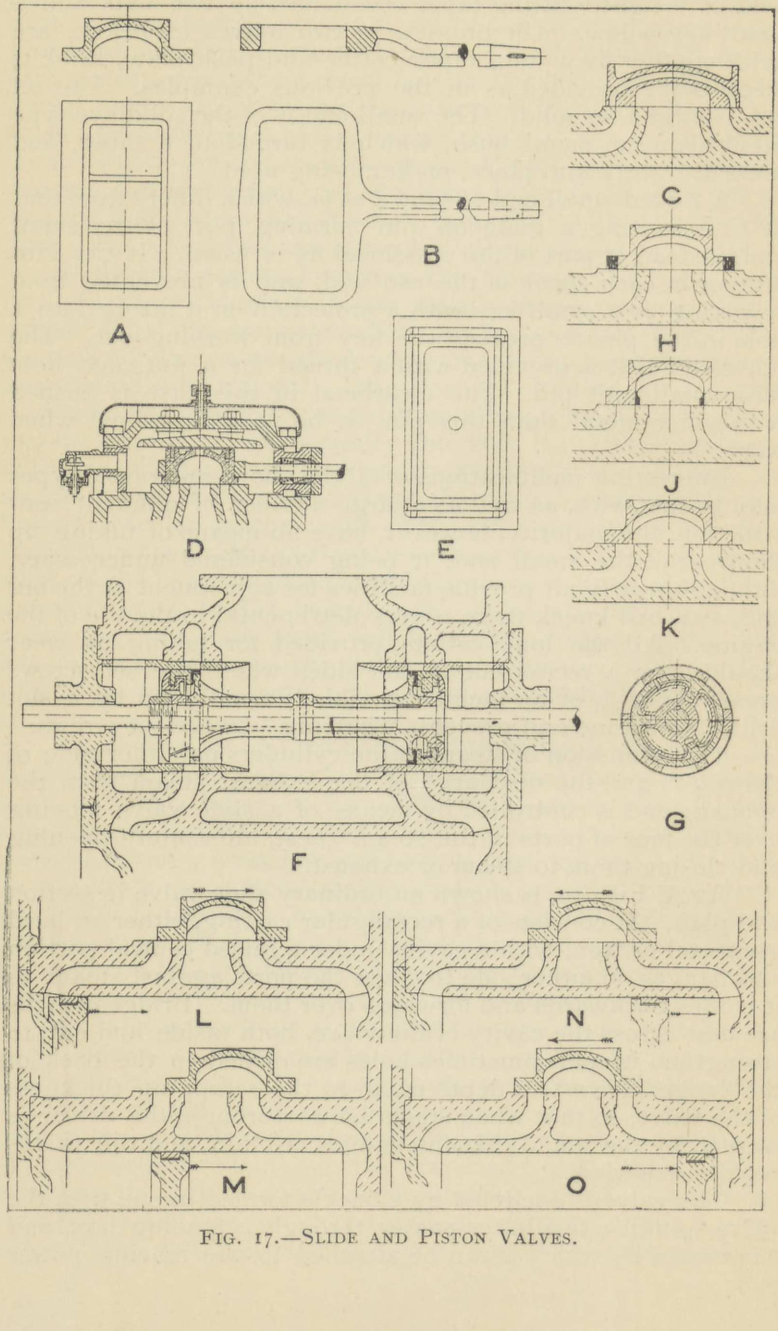


FIG. 17.—SLIDE AND PISTON VALVES.

or "motion," usually by a taper end fitting into a socket, and held by a cotter passed through.

At B a buckle suitable for engines with valve chest between the cylinders is shown; if the chest were either above or below, the spindles or shanks could be made straight, but when between, the glands have to be pitched wider than the distance between the valves to get the stuffing boxes in, hence the necessity for setting the spindle as shown. When the valves are placed below they drop away from the faces when steam is shut off, and so wear is reduced; but, to prevent them from falling too far away, and possibly allowing a layer of steam to get between them and the face, or when worn thin from being lifted up so sharply as to break them, small coiled springs are inserted into sockets in the buckle to hold the valve more or less near the face.

As the steam exerts its pressure upon the back of the whole valve it presses it upon the face with considerable force and causes it to require a large percentage of the power of the engine to move it, and various contrivances have been employed with a view of remedying this. At C a device known as the "Trick" or "Allan" valve is shown; it has the flange and cavity as before, but in addition a channel passes round above the cavity from one face to the other, so that the valve has to travel a smaller distance for the same port opening, as the edge of the flange opens the port a little, and at the same time the channel opens at the reverse end beyond the face, and steam enters and passes over into the port opened. This device does not lessen the pressure upon the valve, but reduces the travel and consequently the total friction to be overcome.

At D a section through a typical American steam chest is shown, the valve in this case being balanced upon the "Richardson" system: four strips are let into four planed grooves on the back of the valve, and projecting upwards bear upon a planed plate held so as to be parallel to the valve face, the strips being pressed up by means of springs; the area enclosed is under exhaust pressure only, as a hole through the crown of the valve places the back in free communication with the blast pipe; from this it will be seen that even should the strips leak it is not possible for pressure to accumulate at the back of the valve. At E is shown a plan of the valve, showing the strips and method of making the corner joints, this being to a slightly larger scale than the sectional arrangement. Continuous bands, both rectangular and circular, have also been used for balancing, but the four independent strips seem to answer best, as they can adapt themselves to any slight irregularity better than more rigid means can. This device is peculiarly suitable for American engines, where outside cylinders with steam chests above are invariably used, but it would be difficult if not absolutely impossible to fit it to our engines with steam chests between the cylinders, though it could be used on those engines having their steam chests above or below.

As an engine, when running with steam shut off, and the motion left in gear—that is fore gear running forward and back gear when moving backwards—has a continual tendency to withdraw air from the steam chest and discharge it up the chimney at each stroke of the piston, thus forming a partial vacuum within the steam chest, with a retarding effect on the engine, a small relief valve is fitted to the chest, as will be seen at the left hand of D, where a circular vertical valve takes its seat upon a bush, and whilst its under side is in free communication with the atmosphere its upper side is acted upon by the pressure within the steam chest, so that when the pressure above is less than that below the valve lifts and air can enter and destroy the partial vacuum.

Another remedy for the excessive friction referred to, and one applicable to the class of engines precluded from the use of the Richardson and similar balanced slides, is found in the employment of piston valves. A successful and favourite form of these for locomotives is shown at F, and is known as Smith's patent. It has no large surfaces exposed to steam pressure, and consequently no great power is required to move it. The ports are made with a cylindrical face, and a bush is inserted, having holes through it opposite the port, and being bridged over at intervals, as otherwise the rings would be likely to catch in it and cause damage. A stuffing box is provided at each end to ensure the piston working fair. The rod or spindle has a collar forged upon it, and against this a cap of cast steel with three radial grooves is threaded, and is prevented from altering its position by a key let into the rod; then the piston ring itself, in three pieces, is placed on, each of the three pieces having a radial feather projecting inward, and engaging into the grooves of the cap. The ring is made of hard gunmetal in one bush, and turned to size and shape, then cut across into three pieces, the joints being kept by means of the grooves and feathers against blank places in the bush, so that no steam may escape through them into the ports. Next a ring of softer metal is placed in position, and effectually covers the side of the cuts, preventing steam from passing into the exhaust chamber. This ring is split, the joint in it being made by a feather half in each side of the cut, and it is kept from turning by means of a set screw in the cast iron distance socket, which is placed upon the spindle next; then a wrought iron liner, of the required thickness to keep the pistons the right distance apart, is put on; then another distance socket, the soft metal ring; then the gun metal ring in three segments, and another steel cap, the whole being held by a nut screwed on to the spindle and tightened up to the steel cap. It will be seen that the three segments are held to the valve face by the steam pressure, which acts inside exactly as in the ordinary flat valves, but here the surfaces exposed to pressure are much smaller in comparison. Another great advantage of the Smith valve, is its provision for the escape of any water which may accumulate in the cylinders. When an engine is fitted with ordinary slide valves, and trapped water has collected in such a quantity as to more than fill the clearance spaces, it can force the valve from the face, and escape into the steam chest; to do this however the pressure must be very great when the regulator is open, as the area of the port under water pressure, tending to force the valve off the face is small compared with the area of the back, upon which the steam exerts pressure. If ordinary piston valves are employed with solid rings, similar to those used in the cylinder, trapped water would be absolutely prevented from leaving the cylinders, and as water is incompressible, damage would be almost certain to ensue, but with the valve under consideration the three segments are always free to leave the face and fall inwards, and when the pressure outside overcomes that upon an equal area inside they collapse and allow water to escape; thus, this piston valve performs two separate and important functions—reducing the power required to move it, and also acting as a release valve for water trapped in the cylinders.

It has been estimated that the resistance due to friction is one-ninth that of the ordinary slide valve, and this has to some extent been verified in practice by noting the relative wear of the two forms of valve. This reduction of friction prevents heating of eccentric straps, etc., and minimises the risk of failure of working parts of a locomotive valve gear. In the event of breakage of a cylinder cover or connecting rod, the valve on the disabled side of the engine may be fixed in mid-position as usual, and the engine brought home with the remaining cylinder. There is no fear of broken segments of the valve entering the ports, as all broken portions are held in place, whereas with an ordinary slide valve, when broken, damage is often caused by fragments getting through to the cylinders.

At G is shown a cross section of the valve where the radial feathers upon the rings and the sockets of the cap may be plainly seen.

It now becomes necessary to explain a few terms used when speaking of slide valve motions. The lap or over-lap is the amount that the valve projects over and beyond the port opening when the valve is in its central position. It is shown in black at H to be more easily recognised. It is provided to give a varying point of cut-off, so that the expansion of the steam may be utilised in the cylinder.

Inside lap is a projection inside the valve and over the inside of the steam port, and is used to delay the release of the steam in the cylinder; it is similarly shown at J.

Inside lead, or negative lap, shown at K, is provided to hasten the release of the steam, and is the reverse of inside lap, as the width of the cavity is greater than the distance over the ports.

Inside lap is seldom used on locomotives, but inside lead is met with on some engines, especially compounds. As a rule, however, locomotives have the inside width of the cavity equal to the distance between the outside edges of the bridges or port bars which separate the ports.

The cycle of operations for each revolution of the crank is as follows:—First steam is admitted to the cylinder, called "admission," then the valve closes, termed "cut-off"; the steam shut in the cylinders then exerts its pressure by "expansion." Next the valve opens to exhaust, called "release"; the distance between the cut-off and release, through which the piston is propelled by the expansion of the steam, is known as the "expansion period." The valve closes the port to the exhaust at the end towards which the piston is moving before the piston reaches the end of its stroke, and the steam left in the cylinder is compressed, forming a "cushion" to assist in bringing the piston to rest without shock, and as the valve here opens a little to live steam, called the "lead," the piston is ready to perform its return stroke as soon as the crank has passed its "dead centre." Admission, cut-off, expansion, and release then take place from the other end, bringing the piston back to the point of starting. All the above operations are repeated for each revolution of the driving wheels.

At L the piston is shown at the extreme end of its stroke, and the slide valve is open to "lead." At M the piston has travelled along some distance—about half the distance to the point of cut-off—and the valve has opened its maximum width to steam; it then commences to close, and when the piston has reached the point of "cut-off"—shown at N—the valve closes, and then the piston still moves along, reaching the point of release as shown at O, when the port is opened to exhaust, and the port at the other end closed, causing "compression."

The point at which the steam is cut off can be varied by means of the reversing gear, as we shall fully explain later. The point of "cut-off" is usually measured in terms of the percentage of the entire stroke of the piston ; thus, cutting off at 25 per cent. means that the valve closes to steam when the piston has reached 25 per cent. of its entire stroke, 50 per cent. when it has travelled half its stroke, and so on. All the other functions of the slide valve then take place earlier or later in the stroke, according to whether the engine is cutting off early or late.

The necessary movement is imparted to the valves by means of the "motion" or valve gear, as already mentioned. This may be of a great variety of types. On the first locomotives, which only ran at some four or five miles per hour, a collar was fitted at each end of the rod, actuating the three-way cock which did duty for a valve, and a projecting arm upon the crosshead caught the collar when the piston reached the end of its stroke and reversed the direction of the steam; similarly, when the other end was reached, the arm struck the other collar, and again reversed the cock. For starting the engine it was necessary to observe the position of the cranks and move the valve rod by hand, so that the steam could be admitted to the required side of the piston, after which the engine took up the movement automatically. No advantage could be taken of the expansive properties of the steam, as the full steam pressure was maintained throughout the stroke. When the success of the locomotive was assured, and its speed increased, the need for improving the valve gear became apparent, and amongst the advances leading up to the present motion was the employment of a single eccentric for each valve and cylinder, loose upon the axle, and having catches at the side to engage studs upon the axle when moved laterally. A lever and gear worked by a treadle on the footplate controlled the position of the eccentrics. When starting the engine, the driver put the eccentrics out of gear by the treadle; then by means of a lever he raised the small ends of the eccentric rods, and noting the position of the cranks, or if more convenient the balance weights in the wheels, he, by means of another handle, moved the valves to open the necessary ports to steam, and worked them by hand until the engine was moving, then, with the treadle, he threw the eccentrics over to engage the studs, at the same time dropping the small ends of the rods to engage pins upon the valve spindles so that they continued to keep up the movement of the valve. It follows that the valve levers upon the footplate were constantly moving backwards and forwards while the engine was running and the eccentrics were in gear.

The next advance was to fit the engine with two eccentrics for each cylinder, and have forks at the ends of the eccentric rods with means by which they could be raised or lowered so as to engage or disengage with pins upon the valve spindles, either fork could then at will be made to communicate its motion to the valve; by having the lever in mid position neither acted, and the valves remained stationary. These forks were found to be a continual source of trouble and expense, as they broke off frequently, and to improve the gear the two rod ends were connected by a curved link, so that the valve spindle was always coupled to the link, and the raising and lowering of the rods and links brought the valve under the influence of either eccentric as required. This with modification is the "link motion" most commonly used to this day for locomotives. It is called the "shifting link" or "Stephenson" motion, because it was introduced by the firm of Messrs. R. Stephenson & Co. in 1843, and fitted to the engines built by them.

Another valve gear is called the "stationary link" or "Gooch's" motion, being invented by Daniel Gooch also in 1843, and fitted to all engines designed by him. It has a link hung with its curvature the opposite way to that described above, and to reverse the engine the valve rod is moved up or down, the link remaining hung in one position vertically, but free to vibrate backwards or forwards about the centre of a suspension link.

A compromise between the two is known as the "straight link" or "Allan" motion from its inventor's name. In this gear the link is made straight, and has a limited vertical movement, the valve rod is also provided with a lift, so that to reverse the engine the link rises, and the valve rod falls, or *vice versa*, as the case may be.

These three are the most common forms of link motion applied to locomotives. Another gear, a favourite one on the Continent, is Walschaert's valve gear, which has one eccentric and a slot link, and takes its valve movements mainly from the crosshead.

To entirely dispense with eccentrics many gears have been devised. The best known of these, perhaps, is that of Joy, in which the valve receives its travel from the connecting rod, and a curved slot link. In Morton's gear the motion is obtained from the connecting rod and crosshead combined. These two latter gears are particularly suitable for engines with the valves above the cylinders.

The shifting link, being the most common in Britain, will be considered first. It is illustrated in Fig. 18 as applied to an engine with inside cylinders, having the steam chest between them. Two eccentrics are fixed upon the crank axle between the cheeks of the cranks, being held by keys let halt into ways in the axle, and half into the eccentric sheaf. This latter is in two portions, held together by means of two bolts passing through, with heads sunk into the smaller portion; cotters are driven through holes in the bolts at the other end, securing the two half sheaves tightly together. Each eccentric is separate from the others, and four keyways are cut in the axle. To simplify this arrangement many builders now cast the eccentrics in pairs, so that only two keyways are necessary, and in some cases, to entirely dispense with keyways, which are always a source of weakness to the axle, the eccentrics are cast in pairs, and the outer ones have lugs on their outer sides, which project over and take a bearing upon the cheek of the crank. This latter method cannot, however, be employed when the cheeks are oval, as shown, or circular in shape, but only when flat.

Steel or case-hardened iron set screws screwed through the sheaf, having sharp cupped ends to cut into the axle, and checked by a nut upon them, were at one time the only means employed to hold eccentrics upon the axles. They are now retained on some railways in addition to the keys as a further precaution, but they are often dispensed with altogether. When the detached eccentrics, as in the sketch, are employed, the larger portion is of cast iron, and the smaller of wrought iron, but with the double eccentrics they are entirely of cast iron.

The straps are made in brass, wrought iron, or, as now most frequently, of cast iron; when of wrought iron, brass or cast iron liners are frequently used. Flat faces are provided upon them, on which the butt ends of the eccentric rods are fixed by two bolts. Oil receptacles are cast on those of cast iron or brass, and forged upon or attached to the wrought iron ones.

The eccentrics are set upon the axle in such a position that the valves may have their proper amount of lead, with suitable allowance for lap. If there were no lap or lead allowed the valve would be made the width between the outer edges of the ports, and the eccentric would have to be set to exactly 90° or a quarter of a revolution in advance of the

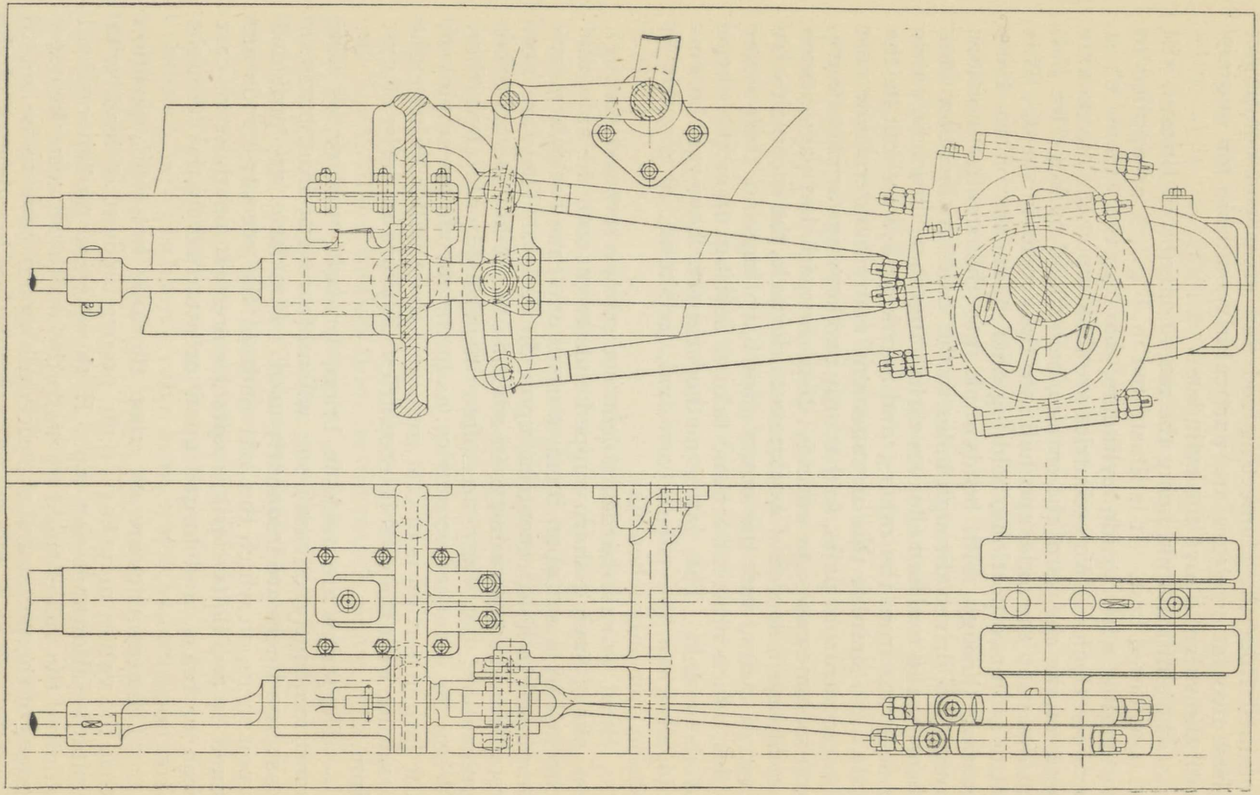


FIG. 18.—STEPHENSON OR SHIFTING LINK MOTION.

cranks, in order to open and close the ports at the proper times, but as both lap and lead are always allowed on locomotives, the sheaves have to be set slightly in advance of 90°, and this quantity is called the angle of advance, or angular advance of the eccentrics; it will be seen on examination of the sketch how much is usually allowed.

The throw of the eccentric, of course, primarily depends upon the width over the ports and when the eccentric rods are coupled up to the top and bottom of the link respectively, as in the sketch, so that the link can never be placed with the intermediate valve spindle and eccentric rod in one straight line, the travel of the eccentric must somewhat exceed the travel of the valve. Many makers have the eccentric rods coupled on to bosses on the back of the link, so that the throw of eccentric may be lessened.

The link or quadrant is forged of iron, and after being machined all over is well case-hardened, the wearing surfaces being ground up and the pin holes in most cases fitted with bushes, which can be renewed when necessary; these latter are often of steel. The pins are also of case-hardened iron, and are held in position by small taper pins passing half through them. The link is hung by suspension links, one on each side, from a weigh shaft placed above them and running across between the frames. Lugs are rivetted with cold turned rivets, tightly fitting the holes, on to each side of the link, and have pins, usually called the saddle pins, upon which the suspension links are placed. The centre of the point of suspension should be upon the centre line of the link, both vertically and horizontally, in order to get the best results. The curvature of the link is equal to the length of the eccentric rods.

The eccentric rods are of wrought iron with case-hardened ends, and are usually coupled up to the link with the fore gear rod to the top, and the back gear rod to the bottom. When coupled up as in the sketch, with the crank on the back centre and the eccentrics nearest to the link, the rods are described as open rods; if, however, the cranks and eccentrics remained as now, and the fore gear rod was coupled to the bottom and the back gear rod to the top, they would be called crossed rods, and the effect would be to reverse the amount of lead. With open rods an early cut off involves more lead, whereas with crossed rods early cut off requires less lead. Crossed rods are very seldom employed on locomotives in Britain, but sometimes in America.

The whole weight of the link and hanging gear, as well as part of the eccentric rods, etc., has to be raised when the engine is moved from fore or mid gear into back gear, and to assist in lifting this it is usual to either put a spring upon the weigh shaft or place a weight upon an arm on the opposite side to the suspension arm; the spring is recommended as it reduces weight and is not likely to become detached.

The intermediate valve spindle is passed through a guide fixed to the motion plate, and, within a forked end which encloses the link, it carries a quadrant block fitting in the slot of the link; a pin passes through this and the forked end, and is secured against coming out by small taper pins, as mentioned above. The other end of this spindle is formed into a socket to take the spindle of the valve buckle. As the valves, when situated between the cylinders, are necessarily very close together, and the centres of the links have to be wider apart, this difference is got over by making the spindle large at the link end, then carrying it forward on one side of the longitudinal centre line, finishing with a socket larger and yet further from the centre, if necessary. This is plainly shown on the plan.

Owing to the fact that the valve is greater in width than the over-all breadth of the ports by twice the lap, the maximum point of cut-off is seldom more than 75 per cent. of the stroke, whilst the minimum cut-off is similarly restricted, although slightly greater in fore than in back gear; further, there is a difference in the cut-off on the front and back strokes, the angularity of the connecting rods making it later at the front end. These results, however, largely depend upon the amount of lap and the travel of the valve, less lap giving later cut-off.

As the quadrant block in the fork of the intermediate valve spindle is prevented from having any vertical movement, and the suspension link is hung from a centre above, the slot link necessarily rises and falls, as the ends and centre of its stroke are reached, and causes a certain amount of "slip" upon the block, the faces here are worn if the engine runs for a long time notched up at one particular point of cut-off. It is found that the slip is least at the point of suspension of the link, and for this reason the links are hung from the centre, for slip and wear combined would cause the distribution of steam to be irregular. A short link with long eccentric rods will allow more slip than a long link with short rods.

Where the valves are placed above the cylinders, either the faces may be inclined downwards to the axle and the gear work direct, or the faces may be made parallel with the pistons and a rocking shaft employed; in the latter case a stout shaft is placed across between the frames with arms below to take the quadrant blocks, and arms above to work the valve spindles. With the valves below it is usual to incline the faces upwards to the centre line of the axle. When the faces are inclined either above or below the cylinders, the eccentrics are not altered with regard to each other, but both are simply shifted round the crank until the centre line of the whole four, which in the illustration is coincident with the centre line of the piston, is upon the centre line of the inclination when the crank and connecting rod are upon their centre line. If a rocker is used, the eccentrics have to be placed reversed on the axle relatively to the position of the crank. Thus, if the crank is placed horizontally, and no rocker is used, the eccentric is put upon the side of a vertical line through the centre of the axle, furthest from the crank pin; but upon the side nearest the pin when the rocker is employed, as it alters the relative movements of the valves with regard to the pistons. The rocker is sometimes used on British railways and is universal in American practice.

The stationary link, or Gooch motion, as applied to an outside cylindered engine, is illustrated by Fig. 19. In this, two eccentrics are placed as before upon the driving-axle, but as there are no crank webs by which it would be possible to secure them, as in inside cylindered engines, keys must be employed. The eccentrics and straps are here shown of a different construction to those in Fig. 18, the large portion of the eccentrics being of cast and the smaller portion of wrought iron as before, but set screws in addition to the keys are shown. The straps are of wrought iron and are recessed on the inside to receive a cast iron liner made to fit and so prevented from having side movement; to keep them from turning in the straps, the latter are made in two portions and distance pieces are inserted at the junctions of the straps and project down to the sheaf, and the two half-liners butt upon them. These distance pieces serve another purpose, as they can be reduced in thickness when it is found necessary to let the liners together to take up wear. It is not usual to use these distance pieces when the straps are entirely of cast iron, as these can be let together, they being scrapped when worn out, whereas the wrought iron straps can be used over again with fresh liners. The butt ends of the eccentric rods are secured to the straps by studs. Oil cups are forged upon the straps and fitted with oil syphon pipes. Of course, it will be understood that the other methods of building up the eccentrics and straps can be equally well applied to the stationary as to the shifting link motion.

The link itself is of the "box link" type—it consists of two channels of the proper section and curvature required,

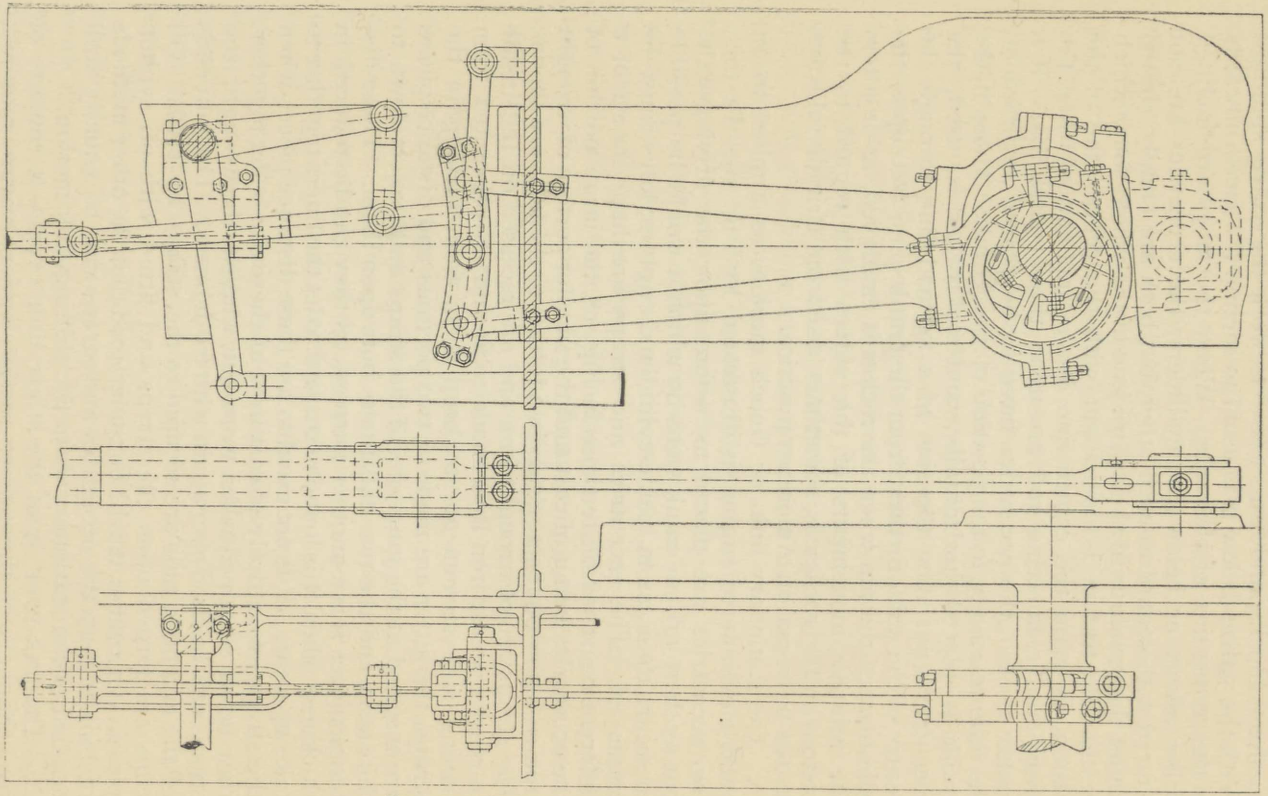


FIG. 19.—GOOCH OR STATIONARY LINK MOTION.

placed with their flanges projecting towards each other; filling or distance pieces are inserted and secured at each end, for keeping them the desired distance apart. The quadrant block is in two pieces, one of which is in each channel, with a pin passing through them and the end of the radius rod between them, or the radius rod may have projecting lugs upon it, to take the blocks. Projecting lugs are also formed upon the outsides of the link to take the forked ends of the eccentric rods and the ends of the suspension link respectively. The curvature of the link is made equal to the length of the radius rod.

The box link is employed when it is desired to get a short eccentric throw, as with it the travel of the valve in full gear approximately equals the diameter of the eccentric circle. Ordinary links are also used, especially in inside cylindered engines, when the width of the box links makes it difficult to place them closely enough together, especially if the valves are between the cylinders.

The eccentric rods are similar to those used for a solid slot link, excepting that the fork is made in two pieces and joined together by means of bolts; either this expedient must be resorted to or the link must be taken to pieces every time the eccentric rods are taken off or put on; it therefore follows that this end must be coupled up first, then the butt end placed on the studs and secured.

The suspension links are hung from a point above the link and should be as long as possible, so that the rise of the link at each end of its stroke should cause the least interference with its proper movement. A length equal to that of the radius rod is considered best as it also minimises the slip, but it cannot always be obtained on locomotives on account of the height of the boiler.

The radius rod is usually forked to clear the valve spindle, which is continued through a guide, this assists it to withstand the thrust of the radius rod, and ensures it working fair. The raising or lowering of this rod is effected by bell cranks upon the reversing shaft as shown, and the engine is reversed by bringing the valves more under the influence of either eccentric as required, by raising or lowering the quadrant block in link. On the sketch it is not in mid-gear, but is shown slightly raised towards the fore-gear eccentric rod end, to make the drawing clearer, as the two centres, if coincident, would be liable to lead to confusion.

As the radius of the link is equal to the length of the radius rod, when the crank is on its dead centre and the port open to lead, reversing the motion simply lifts or lowers the

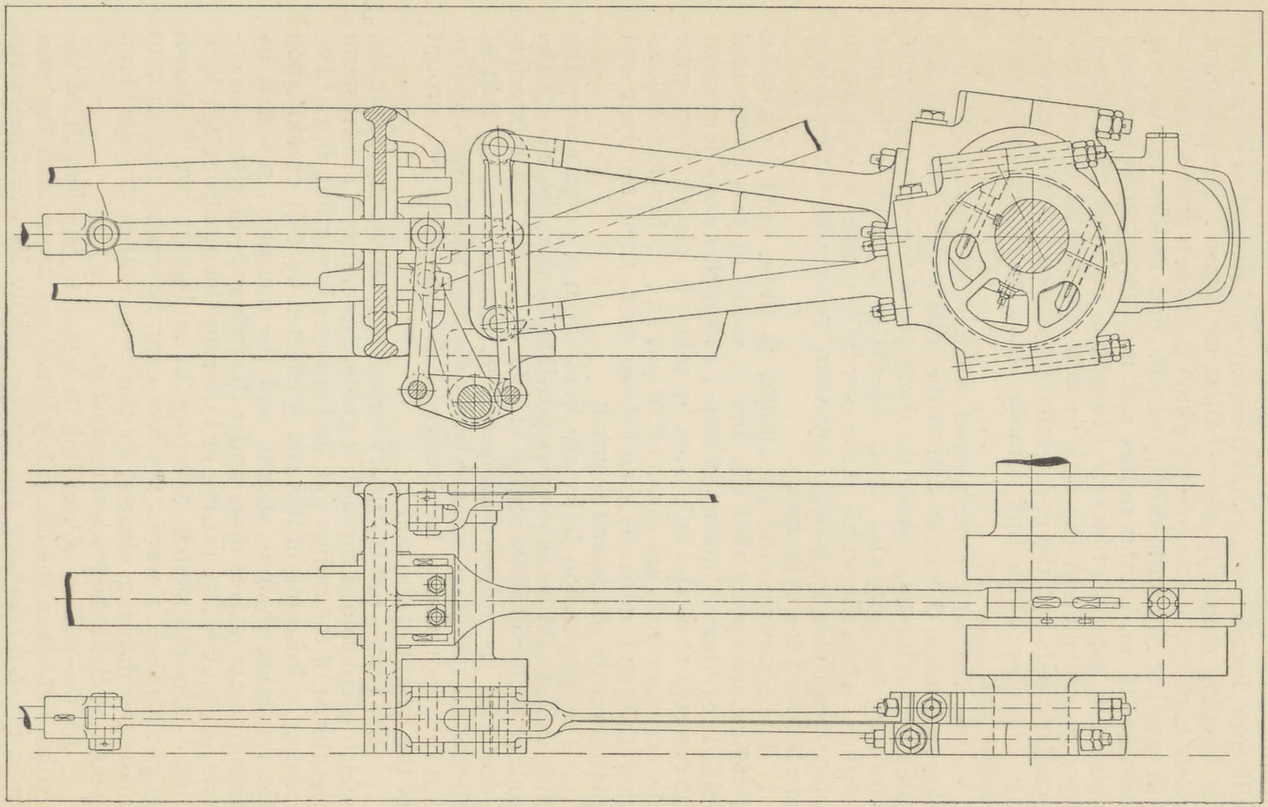


FIG. 20.—ALLAN OR STRAIGHT LINK MOTION.

radius rod and does not move the valves, hence the lead is constant for all gears with this motion, and open or crossed eccentric rods can be employed without affecting its peculiarities.

To minimise the slip of the block in the link which this gear is liable to suffer from if allowed to get slack and worn, it is usual to modify the method of setting so as to make the distribution of steam most correct in the forward gear, especially in express or main line goods engines, and in practice this can be best done by hanging the link with its centre just below the centre line of motion, and lengthening the back gear eccentric rod, at the same time reducing the angle of advance of the back gear eccentric—this arrangement being shown in the illustration. Slip cannot be entirely obviated, as the radius rod has not the power to hold the quadrant block with the same vertical rigidity as the valve spindle guides employed with the shifting link motion have, and for this reason the open link with the eccentric rod eyes at the ends of the link cannot be employed with this gear; sometimes, however, the eyes are formed immediately behind the position the quadrant block occupies when it is in its extreme position at the top or bottom of the link.

This form of motion at one time found great favour in this country, but it has now been almost entirely superseded by other gears, although it is still used very largely on the Continent. It is seldom, if ever, met with in America, for one reason, it requires such a long distance for the radius rod that it cannot well be used in combination with a rocking shaft, with which all engines there are equipped, for actuating the valves above the cylinders. It is much easier in reversing than the shifting link motion, as the radius rod only requires to be moved, whereas in the other the link, eccentric rods, etc., have to be lifted, and the friction of the eccentric straps overcome; therefore no balance weight or springs are required, unless for special reasons the radius rods are exceptionally heavy.

An objection to both the stationary and shifting link motion is, that as the centre of motion of the valve is moved farther and farther from the centre of the link, due to the link or radius rod respectively being raised or lowered, the distribution of steam in the forward stroke is different to that in the backward stroke.

The Allan or "straight" link motion is shown in Fig. 20 as applied to an inside cylindered engine; in this both the link and the radius rod are moved when reversing, but in opposite directions, and as the action is more direct the slip upon the block is greatly reduced.

This motion has two eccentrics upon the axle similar to the previous types described, and the eccentric rods are coupled direct to the top and the bottom of the link respectively. There is also a radius rod with a block swinging in a forked end, and working in the slot of the link, and a reversing shaft which has arms on opposite sides of it; these arms have suspension links pivotted on them, which are coupled to the link on one side and to the radius rods on the other, so that a partial revolution of the reversing shaft moves them both simultaneously in opposite directions. The shaft may be placed either below the motion as illustrated, or above, as found most suitable for the other details of the engine to be fitted.

The respective lengths of radius and eccentric rods, &c., must be so proportioned that the arcs described by the radius rod and link shall be always tangential to each other so that the block shall move in a straight line when the engine is reversed if it is desired to get an accurate distribution of steam; hence a straight link is necessary, and well-designed examples have a practically equal lead in all gears, but all possess at times slight inequalities in one or both of the full gears, this is, however, very little with long radius rods and relatively short travel.

The different lengths of the arms upon the reversing shaft, for supporting the links and radius rods are essential to a proper suspension of these parts, the exact ratio between them depending upon the dimensions of the other portions of the gear, and being coupled up to the heavier links and eccentric rods upon the short arm, they balance the lighter radius rod upon the longer arm, equalising the weight and thus greatly aiding the reversing of the motion from one full gear to the other without requiring the aid of balance weights or springs.

The open or box link may be used, and the point of suspension be either at the top, bottom, or centre of the link as the other proportions, etc., may render it necessary, and open or crossed rods may be employed.

By this gear the inequality of distribution of steam in forward or backward strokes, incidental to both the shifting and stationary links, is greatly reduced as the slipper block is never far from the centre line of motion.

The straight link motion is not employed in America, as, like the stationary link, it requires a long distance for the radius rod, making it difficult to use in conjunction with a rocker. It is, however, extensively used both in Britain and on the Continent.

The motion details are generally made of wrought iron, and well case-hardened at all wearing points after being machined up to shape, they are then accurately fitted together by being ground up with emery powder and oil. The pinholes in the links, etc., are usually bushed, either with steel or gun-metal, for renewal when worn. The pins are prevented from turning in the holes and becoming loose by having holes through them and the rod ends, into which taper steel pins are fitted, and split at their small ends to prevent them from working loose and falling out. Oil holes and grooves must be liberally provided as it may be difficult to get at some when the engine is moving; care should be taken in practice to keep these clean.

The setting of valves operated by link motions must next engage our attention, the mode of procedure may be as follows:—The eccentrics are set and fixed to the axle in the required position, as determined by the lap and lead, etc., and the straps fitted to them; then, the engine being ready for the wheels and axles, these are run under and secured in their appointed position, the valve motion being next hung up in its place.

Before coupling up the eccentric rods to the links, the valve spindles are marked to show the position of cut-off for each port; this can be done, if the valve cannot be seen as when the steam chest is between the cylinders, by holding a thin piece of tin in one port and carefully pushing the valve, which is in its buckle, up to it, then marking the valve spindle outside the steam chest with a trammel having two points at right angles to each other. The point at the end of the longer arm is placed in a centre punch mark or "pop" in the back of the steam chest or upon the motion plate, as may be found most convenient to the operator, and a line is then "scribed" by the point of the short arm on the valve spindle, and a small pop made. The tin is next taken out and placed in the other port upon the same cylinder, and the valve drawn back or pushed up to it, and the spindle again marked for that end; the same process is then gone through for the second cylinder.

The eccentric rods are then coupled to the links, and the links to the valve spindles, and the engine squared or placed "plumb," then the driving wheels are slightly lifted off the rails, rested upon suitable rollers upon each end of a shaft reaching across the pit over which the engine stands, and which has a reversible ratchet upon it, so that the wheels may, by its means, be turned in either direction at will.

The reversing lever is now placed in the position allowed by the particular builder to be that in which most of the running is eventually done; this is usually less than half the full distance from the central position of the lever, and it is here that the motion should be most accurately adjusted. The wheels are slowly revolved by the apparatus described above and known as a "jigger," it being particularly observed that they are turned the proper way—that is, forward when the lever is in fore gear, and backward when it is in back gear.

The spindles are "blacked" by having soot from a torch lamp deposited upon them at those portions about to be marked by the trammel, to enable the marks to be easily discerned. As the extreme travel of the spindle is approached, the long end of the trammel is placed in the pop upon the cylinder or motion plate, and the shorter point is continually passed across and across the spindle, removing the lamp black, this process being continued until the spindle commences to return; thus, the point of extreme travel beyond the point of cut-off may be taken from these indications by a small pair of dividers from the original small pop upon the valve spindle, and a plate is then marked with this distance. The wheels are turned until the other dead centre of the valve spindle is reached, and the point taken as before, and the two being marked upon the plate, the difference can be measured, and the rod lengthened or shortened as required, it being usual to leave the rods a little short, about $\frac{1}{32}$ of an inch, to allow for the expansion of the spindles, etc., when heated, and also for the settling of the engine upon the springs, especially when the cylinders are inclined.

After adjustment the rods are fitted up again and tried over, both in forward and backward gear, and any error that cannot be entirely eliminated is usually divided to reduce its effect as far as possible.

The pistons and rods having been placed in position and the cylinder covers put on, the pistons are pushed to each end of the cylinder to get the extreme points to which the pistons can be forced, the slide bars being marked from the crossheads at these points. Then the connecting rods are put on and coupled up, and the wheels revolved to get the extreme points of travel, and thus ascertain the amount of clearance between the pistons and covers at each end of the cylinders.

To obtain the dead centres a pair of compasses and a trammel are required, and a "pop" is made in the slide bar, in a convenient place, into which one leg of the compasses is placed, whilst with the other the crosshead is scribed, the wheels being stopped for this purpose when a point near the end of the stroke is reached. The trammel is next used to mark the tyre also at this point, one end of it being placed in a pop on the under side of the frame, or other convenient adjacent point, and the tyre scribed with the other end; then, again turning the wheels, the dead point is passed, and as the mark upon the crosshead is reached, the compasses exactly touching it, the wheels are stopped, and the tyre again marked from the same point. The distance between the two points upon the tyre is equally divided, and a pop made, and the wheels revolved until the trammel exactly enters it; at this point the slide bar is marked to indicate the dead centre, the distance between this point and the extreme position of the piston being the clearance. The other dead centres are found in exactly the same way, and the clearance marked for each one.

Having indicated the dead points of the cranks, the lever is put over into full forward gear, and the wheels turned forwards, until one of the marks upon the tyre is reached by the point of the trammel entering the pop exactly; the wheels are then stopped, and the amount of port opening measured upon the valve spindle—this will be the lead for this port and gear. Turning the wheels again the next point is reached, and the lead taken in a similar way, and so on for the four centres.

Reversing the engine into full backward gear, the wheels being turned backwards, the lead is measured for the same points in back gear. The reason for taking the lead in full gear is that with the shifting and straight link motions the lead is here least, it is therefore certain to be sufficient in the running positions.

It is customary with some builders, instead of raising the driving wheels and turning them alone to set the valves, to place the engine upon a sufficiently long straight road over a pit and move it backwards and forwards so as to more exactly approximate the working conditions.

If it should be found necessary through any inaccuracy in setting the eccentric sheaves, or if by an altered condition of service it is desirable to adjust the lead, it can only be done by shifting the eccentric sheaf round upon the axle, increasing the angular advance if the lead is to be increased, or decreasing it if the opposite result is desired. New keys are required in the sheaf shifted, and, if much altered, new sheaves may be wanted. Some makers, to guard against errors, set the valves before the keys are fitted, holding the sheaves by set screws only, and then when all adjustment is complete fitting the keys to sheaves and axle.

It is always important to notice that all the parts of the motion that are to be coupled up to work together should be made to "lead" right for each other, and not be strained at

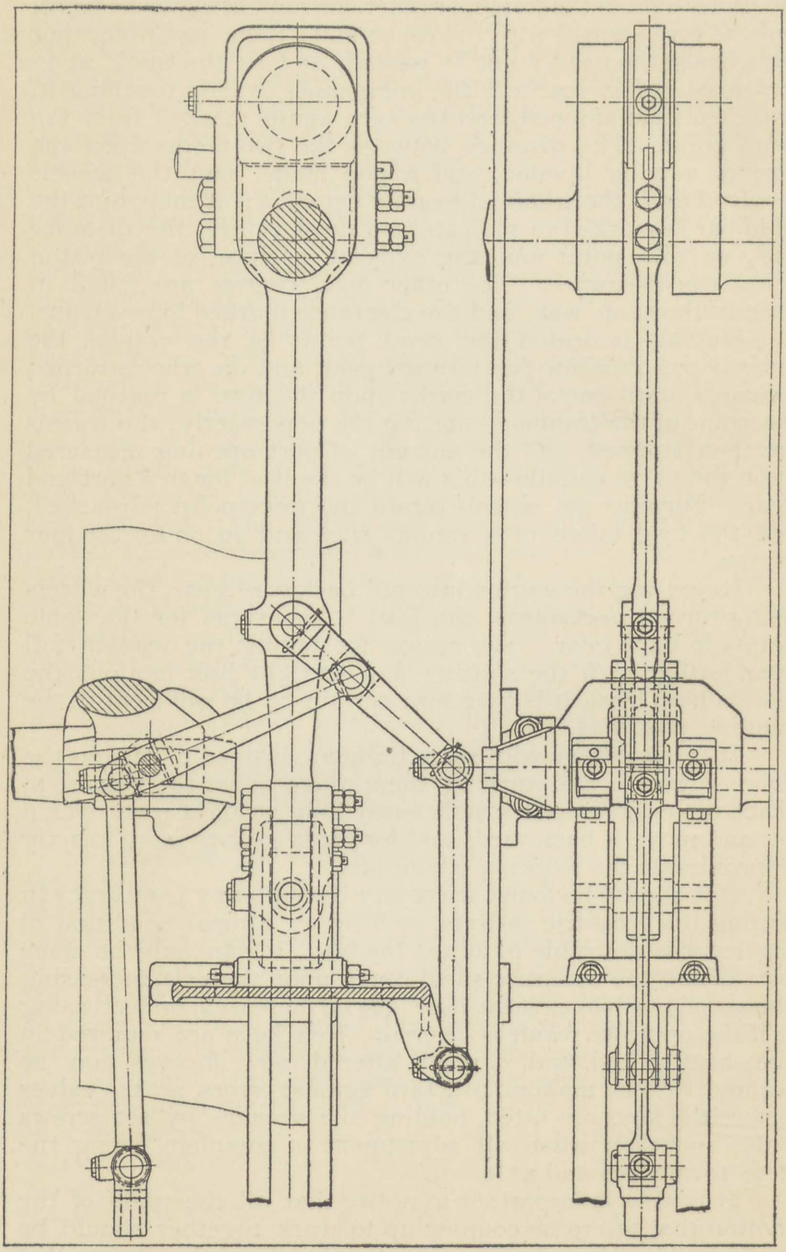


FIG. 21.—JOY'S VALVE GEAR.

all; for instance, the eccentric rods are coupled up to the butt or crutched ends, and the fork placed against the link and pressed over as far as it will go on either side, the amount that it passes the link being noted, and the rod set if necessary until it travels an equal distance each way. All the setting can usually be done without taking the rod down by forcing it over at the forked end, and hammering the rod at the root upon the side towards which it is desired to draw it. If any "twist" exists, it must be taken out, this usually being a smith's job, as the rod must be taken down, heated and set.

When all the adjustments are completed, the working pins are put in place, the taper pins inserted and driven smartly home, and the splits opened with a chisel; all check nuts are put on and tightened up, and split pins or cotters driven in and opened, this being done before the turning gear is removed, as it is often necessary to turn the wheels to get the several parts into more convenient positions; after this has been done, the jigger may be taken down and the spring gear coupled up.

Before the engine is run on the trial trip, it is usual to remove the pistons and valves, leaving off all the front covers, and close the piston and valve rod stuffing boxes; then steam is raised in the boiler, the regulator opened, and all dirt, etc., blown out of the ports and other inaccessible parts of the cylinders.

Coming now to those motions partly or wholly dispensing with eccentrics, and better known as radial gears, we will describe first Joy's motion, in which the valve movement is taken from the connecting rod through a system of levers, as being one of the most successful and most used of them. An arrangement of it applied to an inside cylinder engine is illustrated in Fig. 21.

The connecting rod has an enlarged boss formed in it at a suitable point, about one-third of the length of the rod measuring from the small end. This is bored out and fitted with a bush; through it a pin passes, projecting on either side to carry the forked ends of the "correcting link." This is coupled at its other end to the "anchor" link, which in turn is pinned and allowed to vibrate about a fixed point. In the illustration this point is upon a projecting lug upon the motion plate or slide bar bracket. Examples may, however, be often met with in which it is on either a frame stay or a shaft fixed across the frames, as found most suitable in the particular design of engine. The correcting link has a bearing in its central portion, to which are connected the "valve levers," these being further provided with two other bearings—one at the top end for the attachment of the valve rod end, and the other close to it for the pin, which carries upon its ends the "quadrant blocks," which are fitted to sliding curved guides fixed to the reversing shaft.

It will be seen that the vibration of the connecting rod when the engine is running moves the quadrant blocks up and down in the curved guides, compelling the valve rod to take a course dependent upon the position of the guides; thus, in the sketch the guides being vertical, the valve rod, and with it the valve, will have least movement horizontally, and the engine is in "mid-gear." When it is desired to run forward, the reversing shaft has a partial revolution given to it, tilting the top of the guides over towards the cylinders; this causes the block to move in the required direction and gear. When the engine is reversed to full back gear, the shaft is partially turned, so that the tops of the guides lay over towards the firebox; the points of cut-off between mid-gear and full gear are settled by giving the guides more or less inclination as required.

To determine the several dimensions and positions of attachment of the various rods, etc., it is necessary to take into account all the arrangements of the engine. The position of the pin hole in the connecting rod for attachment of the correcting link is found by drawing lines from the points in the crank circle which the centre of the crank pin occupies when the piston is at half stroke to the centre of the small end pin, and taking a point in the length of the connecting rod which has a vertical vibration equal to at least twice the full stroke of the valve, so as to avoid too great an inclination upon the guides when the engine is put over into full forward or backward gear.

This point being fixed, mark off upon the centre line of the rod the position it will occupy when the crank is upon its front and back centres respectively, and draw a vertical line —vertical to the centre line of the motion—through a point exactly central between them. The length of the correcting link can now be found; its end, which is attached to the anchor link, must be sufficiently far away to allow of the angle between its two extreme positions being less than a right angle.

The anchor link should be made as long as convenient, so as to allow the end of the correcting link to rise and fall as nearly as possible in a vertical line, it will not affect the distribution of steam which end of the engine its end is fixed, but it is usually found more convenient in locomotives to fix it forward of the crank.

Next, upon the centre line of the valve spindle, which must be in the plane of vibration of the connecting rod, upon each side of the vertical line above mentioned, mark off the amount required for lap and lead, that for the front port being drawn upon the crank side of the vertical line, and that for the back port upon the cylinder side of it. Now, assuming the crank to be upon its front dead centre, and the correcting link coupled to the anchor link, choose a point in the length of the correcting link, which has to be assumed, and draw a line through it to the lap and lead mark for the front centre, the crank being upon that centre; the point where this line crosses the vertical line will be the centre line of the reversing shaft, and the centre of oscillation of the curved guides, which must be concentric at each end of the stroke of the piston. The exact point in the correcting link for the attachment of the valve levers must be found so that the quadrant blocks vibrate equally on each side of the centre of the quadrant block guides. It will now be seen that as the centre of oscillation of the quadrant block, and the centre of the reversing shaft exactly coincide with each other when the piston is at each end of its stroke, it will be possible to reverse the motion from full forward to full backward gear without communicating any movement to the valve rod, the reversing shaft simply making a partial revolution, the lead being constant in all gears. This point is important, and is made use of when the valves are being set in the shop.

The valve spindle may be of any convenient length, and is coupled up to the top of the valve levers at one end, and to a crosshead upon the valve buckle spindle at the other. Whatever length is chosen for the valve spindle must be also the length of the radius of the quadrant block guides.

It will be noticed that the lap and lead are entirely dependent upon the distance apart of the two centres of the valve levers, which are connected to the valve spindle and the quadrant blocks respectively, and can only be altered by varying this length.

The path described by the point in the connecting rod where the correcting link is connected is a horizontal ellipse when the engine is running, and the end of the valve lever to which the valve spindle is coupled describes a vertical ellipse at the same time; therefore, this particular style of motion is known as "elliptical" gear. It would be possible to couple the end of the valve levers direct to the connecting rods, and dispense with the correcting link altogether, but this would give an irregular motion to the valve, and give a different distribution of steam in the front and back strokes.

In some small locomotives with outside cylinders, where it would not be possible to find room for the anchor link in the position shown in the illustration, the correcting links are cut off at the point of attachment of the valve levers, and the anchor link, coupled to them there, and at its other end to small return cranks upon the crank pin—the stroke of which must, of course, equal the distance travelled by the other end of the anchor link.

Deviations from the above positions and proportions may be made without materially altering the correctness of the results.

The metals employed are usually wrought iron for the links, rods, pins, etc., the wearing portions being well case-hardened. The quadrant block guides too are of wrought iron, being usually turned up and cut from a large ring of the necessary radius and case-hardened. The quadrant blocks are of bronze or cast iron, if of the latter, to prevent wear they are cast in chills and ground up to shape. The reversing shaft is of cast steel, and the bushes in the connecting rods of phosphor bronze.

For the "Joy" gear many advantages are claimed—it is simple in construction and maintenance, the dead weight of the whole is less, and it is generally more correct in working, as, if the centre lines of the various levers, etc., are properly set out, a valve path diagram is given, in which the lead and cut-off are exactly equal for both ends of the cylinders, and they remain so for all grades of expansion to mid gear.

The valve opens more rapidly than when actuated by link motions, the cut-off being prompt and the release of the exhaust quick, whilst it moves slowly during the expanding and exhausting periods. These qualities are very desirable for a locomotive slide valve, when obtained without any undue lead, compression, or too early exhaust.

The cut-off point is not limited by the throw of eccentrics, etc., but the reversing depends upon the angle to which the quadrant block guides are inclined, so that it would be only necessary to allow these to be carried over past the point usual for a full gear cut-off of, say, 75 per cent. to obtain a cut-off of 80 or 90 per cent.; thus the starting power of the engine can be greatly increased, and the trouble sometimes necessary of reversing to get it into a more favourable position dispensed with.

To set the valves in the shop, the four dead centres of the crank are found in the same way as for link motions, as also are the cut-off points for each port. Then setting the engine upon one dead centre, the rods being coupled up, the motion is reversed from one full gear to the other, if the valve spindle moves, the reversing shaft has to be raised or lowered until this ceases. This having been done, the other dead centre upon that side is tried in the same way, and the lead equalised for both ends by moving the shaft backwards, or forwards as found necessary. All dead centres are treated in the same way, and the valves are then set; the process is much simpler than that required for link motions.

Among other radial gears is Hackworth's, where the valve motion is taken from one eccentric, which is fixed upon the axle exactly opposite the crank, and has its rod working vertically, with the end attached to a block moving in a pair of curved guides; the amount of cut-off given to the slide valve depends upon the inclination given to these guides; in this respect the gear is similar to that last described. It is not largely used, however, on locomotives.

In Walschaert's motion, which is not, correctly speaking, a radial gear, as no ellipses are described by it, the valve has its travel controlled from two perfectly distinct movements, one that of the crosshead, the other that of an eccentric fixed upon the crank axle, these being combined by a system of levers, so that the motion of the slide valve is the same as that derived from the stationary link. A slot link is used for enabling the motion to be reversed from fore to back gear as required.

An example of this motion applied to an inside cylindered engine is shown in Fig. 22, The crosshead has a prolongation upon it, carried down to a convenient point for connection to a union bar, which at its other extremity, is attached to the end of a combination lever, this latter has two holes for the attachment of the valve rod and radius rod respectively, the former at the end, and the latter just below it. At the far end of the radius rod is fixed the quadrant block which moves in a slot link, pivotted, and allowed to oscillate about its trunnions, working in carriers projecting from the slide bar bracket. To the lower extremity of the slot link the end of the eccentric rod is attached, so that when the crank axle revolves the link vibrates backwards and forwards about its fixed centre.

The eccentric itself is keyed upon the axle, usually at right angles to the crank, though its position may be varied to suit special requirements, and thus, as far as it and the link are concerned, the valve may have no lead, but through the combination lever the eccentric and crosshead motions are so combined that the angular advance is in effect restored, and as a result the valve possesses a constant lead.

If the eccentric is fixed as in the illustration, in advance of the crank when moving forwards, the bottom of the slot link

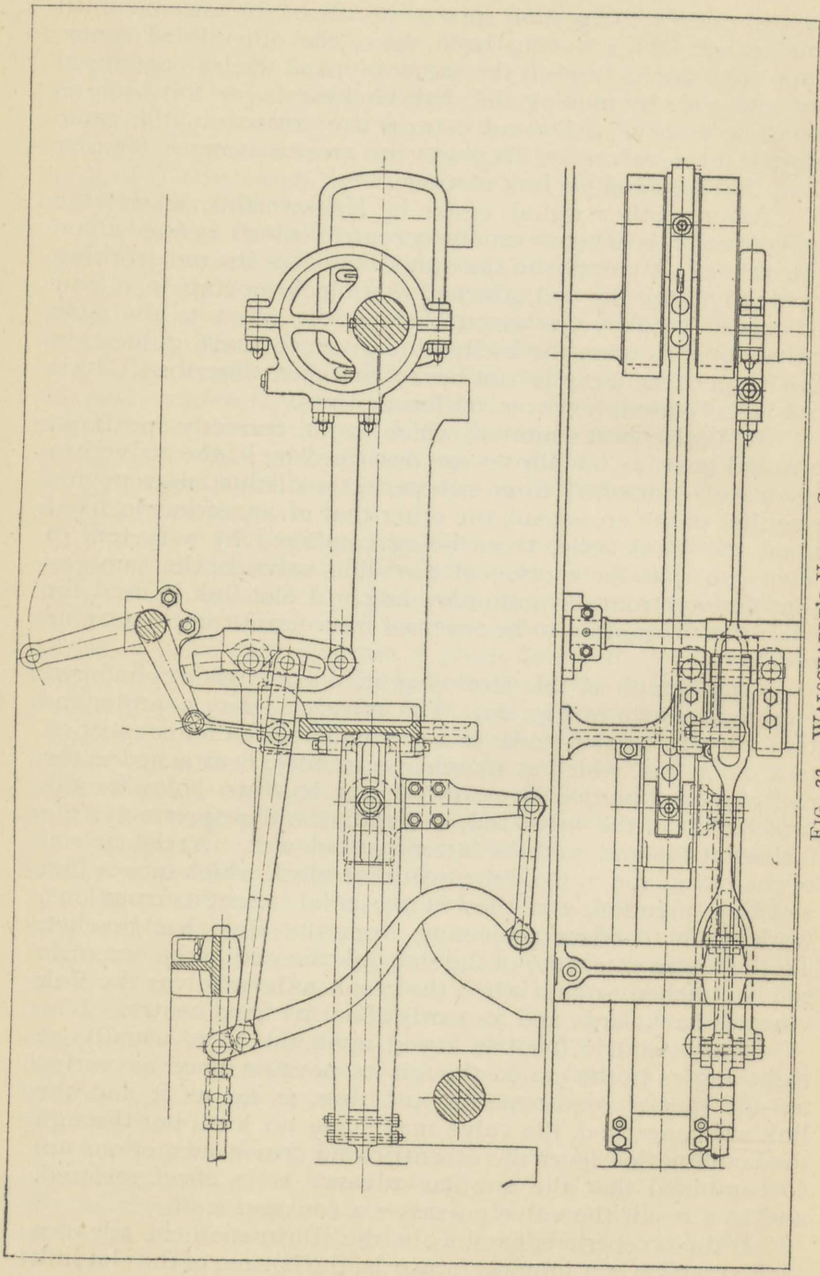


FIG. 22.—WALSCHAERT'S VALVE GEAR.

is directly operated by it, and therefore the radius rod must be at the bottom of the link when the engine is in tore gear; if, however, the eccentric is fixed at the opposite side of the axle and leads when the crank is turning backwards, the bottom of the link will be the "back gear" position. The opposite end of the slot link, will, ot course, have a motion exactly the reverse, therefore, moving the radius rod up will cause the engine to run in the other gear. In the illustration the engine is shown in full "fore gear."

The slotted link is shown of the open type, but the box link may be, and is, often used, the curvature of the slot being made equal to the length of the radius rod.

In the arrangement illustrated the combination lever is cranked, or set, this being done to clear the leading axle, but the action of the lever is exactly the same as it would be if a straight one were employed between the given centres.

It is less difficult to arrange the design of this motion for equal points of cut off at each end of the cylinder than it is with either the shifting or stationary link motions, owing to the very intimate relationship which exists between the piston and valve positions and movements through the combination lever.

The general accuracy of the movements of the valve when actuated by this gear, is not liable to be deranged by wear, owing largely to the reducing effect of the combination lever, slack at the bottom of it being lessened very much at the top, and its effect almost nullified.

This motion is not largely used in Britain, but is very extensively employed on the Continent owing to the ease with which it can be fitted to, and its suitability for, outside cylinder engines. When used on these it is usual to employ a return crank fixed to the crank pin instead of an eccentric, and in many engines, where there is a difficulty in putting the reversing shaft and its connections in the position shown, the radius rod is prolonged and carried beyond the quadrant link, for the reversing arm to be coupled to it.

There are many locomotives fitted with a modification of this gear, in which the distance between the centre of driving axle and valve is too small to allow of an arrangement as shown; in these, the quadrant link is hung up with its curvatures reversed, and the radius rod laid between the link and driving axle, the valve rod being lengthened to suit, and connected as before by means of the combination lever to a projection below the crosshead; this arrangement gives equally good results as that shown.

In Morton's gear the motion is taken from the connecting rod and crosshead, no eccentrics being used. The connecting

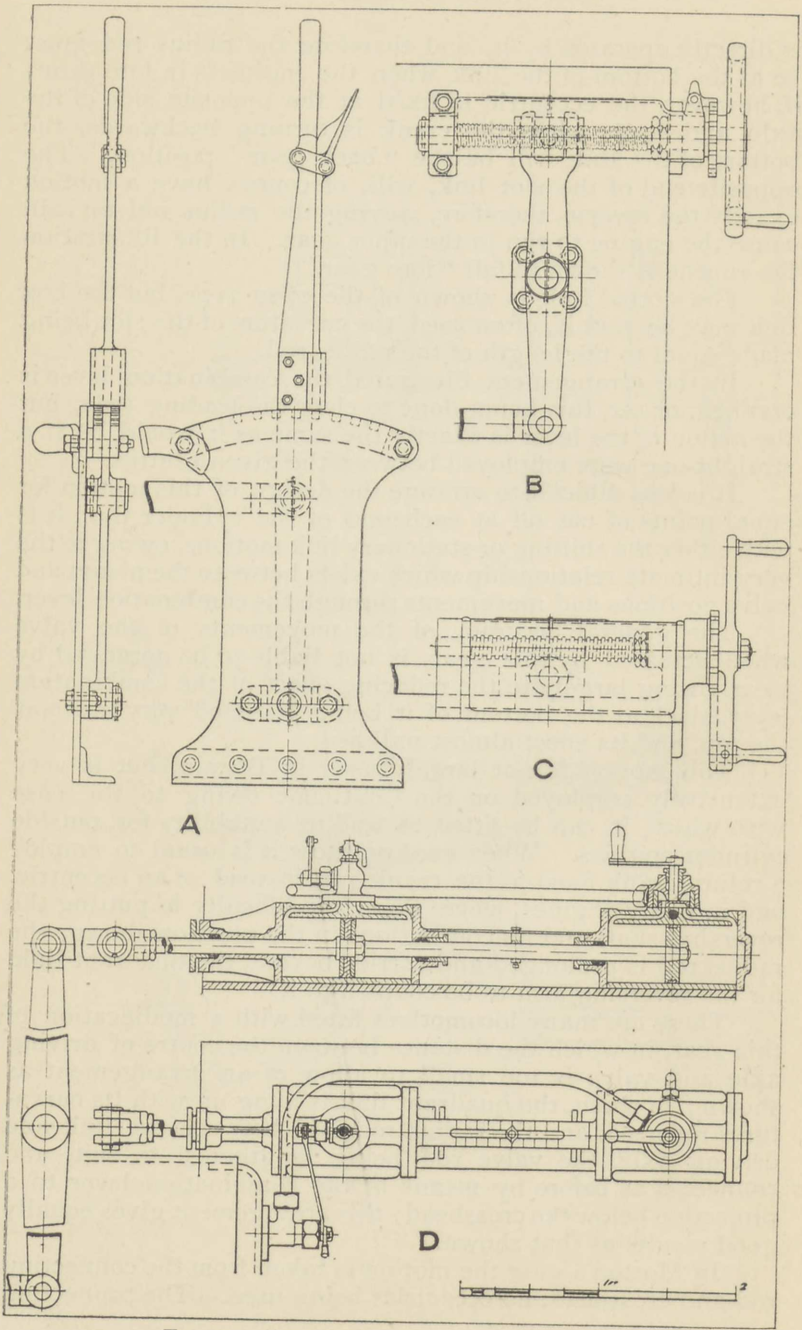


FIG. 23.—REVERSING GEAR ARRANGEMENTS.

rod has a boss formed on it about the middle of its length which carries a small crank with cheeks on either side; from these bearings project for the attachment of a floating lever, which has three other bearings upon it, for taking the radius rod at the top, anchor links just below, and a combination link which connects it to a projecting arm from the crosshead, at the bottom.

The slide bar bracket has bearings in projecting carriers, to take the ends of the anchor links, thus compelling the floating lever to move at the point where the other ends of the anchor links are attached with this fixed centre as a pivot. The intermediate valve spindles are continued through their guides upon the slide bar bracket, and upon the crank axle side of the bracket they are formed into quadrant links, having the curvature struck from a top pin-hole of the floating lever, the radius of the quadrant link being made equal to the length of the radius rod, which is coupled at one end to the floating lever, and embraces by a fork the block in the slot link; at the other end this block is also coupled by links to the arms of the reversing shaft, which, when given a partial revolution moves the block from top to bottom of the quadrant as required and reverses the engine from one gear to another, being in "mid gear" when in a central position.

The valve motions described are provided with means for operation from the footplate, so that the driver can, at will, not only reverse the engine, but regulate the expansion of the steam admitted to the cylinders by adjusting the cut-off to any point of the stroke as the work to be done may require. The details of the appliances adopted for this purpose vary considerably, but it is uniformly situated upon the same side of the cab as it is customary to place the driver, and arranged for easy manipulation by him. Fig. 23 illustrates several arrangements.

At A is shown a reversing lever, having a handle and trigger at one end and working on a pin passing through a plate and bracket at the other, the trigger is coupled to a rod passing down the lever to a catch sliding in a guide; when down this engages in slots or notches at the top of the plate, which is cut to a radius equal to the distance from the pivot of the lever; the notches are cut in separate sector plates set on each side of the lever, the catch being broad enough to engage both sectors, thus holding the lever firmly. When the catch is in the central notch the engine is out of gear, raising the catch by the trigger and pushing the lever over towards the front puts the motion into fore gear and pulling it back the reverse, the intermediate notches giving different grades of expansion. The trigger may be as shown, on the back of the lever, or it may be placed upon the front, a spring being provided to keep the catch down in its notch, as otherwise it would be liable to work up when the engine is running and allow the lever to be thrown violently to the front or back of its travel, according to the position of the valve gear, which might have unpleasant results. The spring may be flat, situated between the trigger and handle as shown, or it may be coiled and attached to the bottom of the catch rod, with one end secured to a hook in the lever; another mode of attachment is by a bracket fitted above the catch, the catch rod passing through it, and the coiled spring being on the rod between the catch and bracket. A boss is provided at a point in the length of the lever and having a pinhole for the attachment of the forked end of the reversing rod, which at its other end is coupled to the arm of the reversing shaft. A bracket is fixed to the side of the plate for the driver to place his foot upon and so increase his power to pull the lever over.

In the above lever the reversing rod is coupled to an arm projecting up from the reversing shaft, but in cases where these arms are carried downwards, the lever is then made much longer and pivotted at or near its centre, the lower half being carried down below the footplate and the rod coupled to it there.

A modification of the lever, fitted with a screw at the top instead of the handle is shown at B. The lever has a forked end at the top and is fitted with a pair of sliding blocks, which work upon projecting pins upon the nut through which the screw revolves; it is pivotted at its centre, and being usually coupled to an arm projecting up from the reversing shaft, the top of the lever stands over to the back when the engine is in forward, and to the front in backward gear. The pivot may be, as shown, fixed to the side of the tank, or in the case of tender engines, which have no tanks, it is fixed to a separate plate attached to the frame beneath it. The screw is cut with a treble thread so that the movement of the nut, and with it the lever, may be as quick as possible; it is carried in brackets at each end, and fitted with a wheel by which the driver may operate it. The wheel has attached to it a circular notched plate and, upon the bracket carrying the bearing for the screw, a catch is provided which can be dropped into the corresponding notch of the plate, thus securing the screw in any required position, as the thrust upon the nut when the engine is running is liable to cause the screw to revolve and put the motion into full gear. Above the screw and nut a guard or cover is fixed, having at its top a slot of a length equal to the travel of the nut, from which a pointer projects up and indicates upon a scale marked upon the face of the guard, the point of cut-off the gear is in.

Another method of applying the screw is represented at C, in which the lever is dispensed with altogether, and the reversing rod coupled directly to the nut upon the screw. The screw is cut with a coarse thread, as before, and carried in a pair of brackets, but instead of a wheel a pair of arms with handles set opposite to each other are employed. The handle at the top, in the illustration, is fixed to its arm and used to turn the screw, but that shown at the bottom is hinged and attached to a catch which it raises or lowers into notches in a ring fixed to the screw bracket casting, to enable the gear to be secured in any position. A cover and index is fitted as in the last case.

Many engines have an arrangement exactly the reverse of the above, the screw being attached directly to the reversing rod, whilst the nut, forming one with the boss of the wheel and being revolved with it, pulls or pushes the screw and reverses the motion from one gear to another.

The lever has the advantage of being quickly moved from one full gear to the other, and, therefore, is especially suitable for shunting engines; its disadvantage is that the notches, which have to be spaced widely for strength, frequently cause too great a difference in the rate of expansion when the catch is moved from one notch to the next, so that expedients are often resorted to by drivers to give a less difference, a common one being that of placing a piece of metal across the notches so that the catch will bear against it and hold the lever in a mid-way position. In the Norris lever, much used in the U.S.A., two catches are employed, one on either side of the lever, spaced to half a notch, and the catches being made with tapered ends, one or the other will always engage in the sector plate at half the travel of the plain lever. The advantages of the screw are the ease with which the engine can be reversed with steam on, and the great range of positions which it has.

In order to quickly and easily reverse the valve motion many arrangements of reversing gears, working by steam or compressed air, have been devised. One of these, operated by steam, is shown at D. Upon the top of the trailing splasher, inside the cab, two cylinders, each about 5-in. diameter by 9-in. stroke are fixed, with pistons both secured to the same rod, so that they move together. The cylinder shown on the right is for steam, and has the usual ports, one to each end of the cylinder and one to exhaust between them. Upon the port face is a flat bottom disc valve, revolved by means of a handle above, which has a cavity below wide enough and sufficiently upon one side of the vertical centre to cover one steam and the exhaust port, putting them into free communication with each other; upon the side of the disc opposite to the cavity is a hole through the valve itself, through which steam is admitted from above to the port below the disc, so that when the disc is turned, as shown, steam is admitted to the left port and the right port is open to the exhaust. When turned through half a revolution steam is admitted at the other port, and when turned a quarter of a revolution both ports are closed.

The cylinder on the left is filled with oil or water, and instead of the disc valve has a bye pass cock, and no exhaust port; opening the bye pass, which is done by giving the handle a partial revolution, allows the liquid to flow from one end of the cylinder to the other, as the steam pressure in the other cylinder may force it. Closing the valve separates the liquid in each end and locks the piston in its position. The steam cock upon the cylinder is coupled to the bye pass cock and opens and closes with it. The piston in the steam cylinder is fitted with the ordinary spring ring, but that in the other cylinder is fitted with two cup leathers, as shown; a cup is also provided upon the bye pass cock, so that any loss, due to leakage, etc., may be made up and all slack kept properly taken up.

The movement of the piston rod is transmitted to the reversing shaft through a long lever, shown broken at the left of the sketch, and is coupled to a rod which connects it to the arm projecting down from the shaft. This gear is also fitted in other positions upon engines, often being arranged vertically as at the front end of the side tanks of tank engines.

The marks upon the scale indicating the gear and point of cut-off are found on the engine after it has been coupled up and had the valves set. Thus the cut-off points for the ports upon one side of the engine are determined as has been before described, and marks made upon the valve spindle, the crank is then set at the point in its stroke at which it is required to cut-off, this point being found on the slide bar, and the reversing gear moved until the valve exactly closes the front port, the point upon the scale that the pointer indicates is marked, and the wheels turned, with the reversing gear still in this position, until the back port closes and the position of the crosshead noted. The crank is then set at the next position for which the cut-off point is required, and the lever moved as before and the scale marked, and so on for all points in the forward gear, then the engine is reversed and similar points found for the backward gear. It is usual to mark the ends of the indicator with the words "fore" and "back" to show the gear the motion is in.

Clearance has been described as the distance between the piston and the covers of the cylinders, but when referring to the steam, its action within the cylinders, and its effect upon the working of the engine, as shown by the indicator, the term includes the ports and, in fact, all the spaces filled with steam between the valve face and the piston when at its extreme position. It is not possible in practice to do without clearance as it allows for wear, etc.; but the losses due to it may be decreased by closing the port to exhaust, and compressing a portion of the enclosed steam before the piston has reached the end of its stroke. The steam so compressed into the clearance spaces by the advancing piston forms a cushion useful in bringing it to rest without shock. The amount that can be allowed depends upon the speed of the engine, and can be very much more when running fast than when moving slowly, and if carried sufficiently far permits of the pressure of the steam in the clearance spaces being raised to that of the boiler; then all losses due to clearance are avoided, as the space is full of steam at maximum pressure when the piston commences its return stroke; but cushioning to this extent would entail a loss in another direction by greatly increasing the back pressure, and reducing the mean effective pressure upon the piston. Compression also, incidentally, has the advantage of raising the temperature of the cylinder and port, which had been cooled down to the heat of the expanded steam, and the entering boiler steam is thereby saved from condensation with consequent loss of pressure.

If all the working joints of the engine affected by the reciprocating motion of the piston, particularly the small and big ends of the connecting rods and driving axle-boxes, could be made a perfect fit, so that when the crank passed the dead centres no slackness was observable, it would not be altogether necessary to open the port to live steam before the piston reached its extreme point, or allow lead; but inasmuch as it is impossible to do this with large and heavy mechanism, such as that of locomotives, there will always be a certain amount of slack; in fact, it is purposely provided in the first instance, and this increases as wear takes place, until a considerable "thump" or "knock" is given as the cranks pass their dead centres, due to the momentum of the connecting rod, piston rod, etc., being suddenly arrested when these are checked preparatory to commencing the return stroke. By admitting steam to the end of the cylinder towards which the piston is travelling before it reaches its extreme position, its velocity is arrested, for the steam forms a cushion, for it to strike upon, thus relieving the axle, etc. The closing of the port to exhaust, as above described, before all the steam has escaped in front of the advancing piston, and consequent compression of the imprisoned steam, also assists in cushioning; but it has been proved that the compression alone, without assistance from live steam, admitted by prematurely opening the port by lead, is not sufficient to entirely eliminate "knock." The exact amount of lead necessary is determined by practice, and will vary from $\frac{1}{32}$ of an inch in most favourable cases to $\frac{1}{4}$ of an inch in others; when not otherwise specified, this figure being taken when the motion is in full gear.

Another reason for allowing lead is that it causes the ports to be opened for the admission of steam well before the piston commences its stroke; it is thus enabled to enter at greater pressure and fill the cylinder better than would be the case if the valve only opened just as the piston reached the dead centre and commenced to return, this benefit being specially felt in fast running.

Besides allowing live steam to enter the cylinder before the return stroke of the piston commences, it is also necessary to release the steam upon the other side of the piston as much as possible. The cavity of the valve, therefore, opens to exhaust upon the steam side of the piston before the completion of the stroke, so that the port openings, small at the commencement of the valve strokes, shall provide an outlet large enough for the free escape of the steam when the piston commences to return, and thus help to reduce back pressure, which is the name given to the retarding pressure upon the piston, and has to be overcome by the steam upon its other side. The size of the blast pipe opening is an important consideration, as if contracted the back pressure is greatly increased, but as the forcing of the fire depends very much upon it, it cannot be very large. The resistance also increases very much when the engine "primes" or "lifts water," as then the back pressure may be increased as much as 70 per cent. more than would be the case with dry steam.

If obliged to pass through passages too contracted for it, the steam will be reduced in pressure or be wiredrawn. The most common causes of this are small ports, insufficient port openings, especially when the engine is notched up close and cutting off early, or throttling, either in the steam pipes or by having the regulator partially closed. With the ordinary slide valve actuated by link motion there will always be a certain amount of wiredrawing, owing to the slowness with which the valve closes the port as the point of cut-off is approached.

It is not, as a rule, advantageous to cut off steam at less than 20 to 25 per cent. of the stroke of the piston, owing to the fact that the steam is wire-drawn by being forced into the cylinder through so small a port opening, also the cushioning becomes very great at this travel of the valve, and if the latter is arranged so that the cushioning is lessened, the comparative coolness of the exhaust steam would lower the temperature of the ports, etc., so that the entering steam for the next stroke would be further reduced in pressure by coming in contact with them. These various effects depend upon the correctness with which the valve motion has been designed and constructed, and the exact amount of influence which each has upon the engine, can only be determined from the engine itself by the use of the steam indicator.

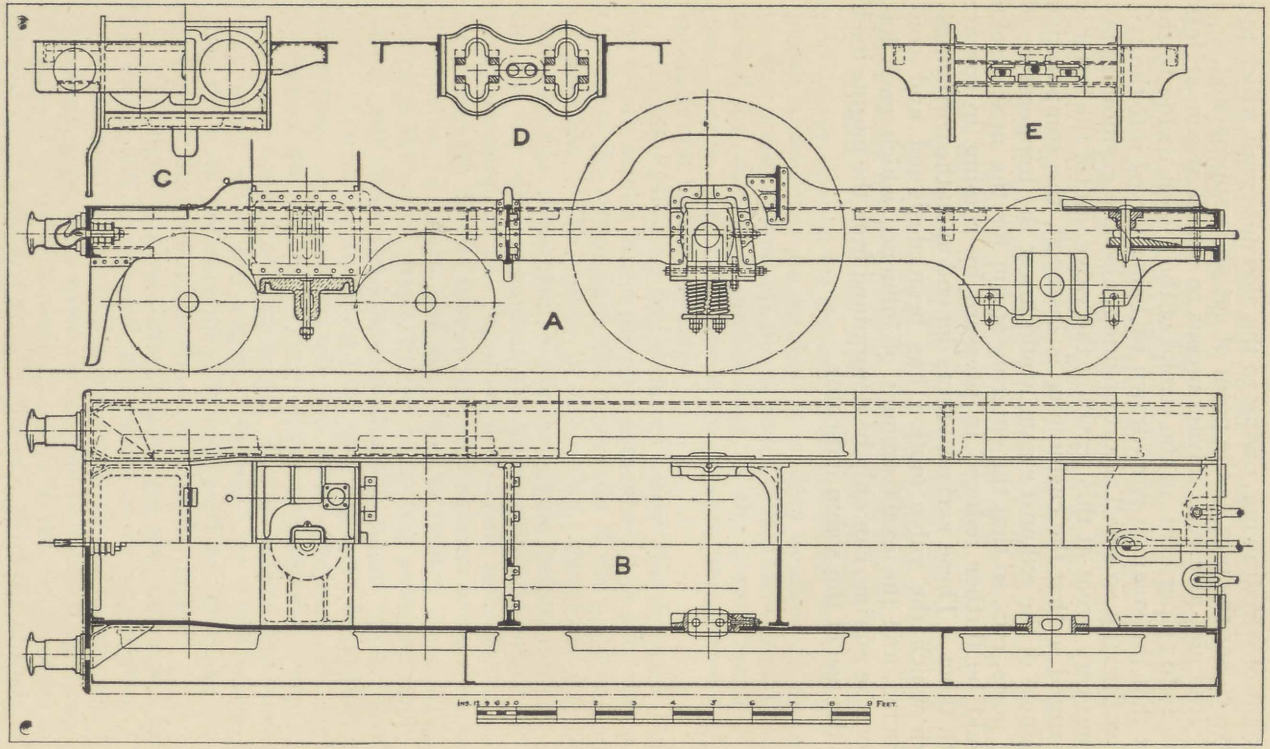


FIG. 24.—FRAMING FOR SINGLE BOGIE ENGINE.

SECTION III.—THE FRAMING, WHEELS, ETC.

HAVING described the engine itself, we have next to consider the carriage and running gear. The engine and boiler are arranged and carried on a framing supported by the wheels and axles. The frames are in Europe invariably built up of plates, usually four in number, the two inner being the main frames, whilst the two outer are for supporting the footplates, splashers, etc., and in addition take the bearings in cases where they are outside. The main frames are inside the wheels, and extend the whole length of the engine—from the back of the front buffer plate to the back plate in tender engines, or to the trailing buffer plate in tank engines. They are strongly stayed across from one to the other at suitable positions in their length, the contour depending upon the class of engine, arrangement of wheels, etc.

The outside frames are usually thinner, and when not used for carrying bearings are frequently of angle iron some 6-in deep by 3-in. on top flange to support the footplatings.

It was formerly the custom to make "sandwich" frames, which were built up of two thin plates of iron bolted on either side of a plank of oak; this practice has now become obsolete and plate frames are general. In America the practice has always been to build up the framing of bars some 3 or 4 inches square in section.

The main frame plates being arranged vertically and inside the wheels, the space to be obtained between them is limited, for as the distance between the tyres (upon the standard 4-ft. 8½-in. gauge) is 4-ft. 5½-in., the greatest width over the frames must not exceed 4-ft. 4-in. outside, this giving ¾-in. between the frames and tyres, less than which it is not advisable to allow. The frames are now invariably of steel plate, rolled to the thickness required, from 1-in. to 1⅛-in.

Fig. 24 shows a set of frames suitable for an express engine having a leading bogie, single driving wheels, and trailing carrying wheels, with inside cylinders and inside bearings only to all the wheels. The depth varies to suit the different attachments, at the leading end it is equal to that of the front buffer plate, then opens out to take the cylinder, and below it the bogie centre pin casting, then is reduced, again swelling to take the driving axle box guides or hornblock, being stayed across the bottom of the gap so made by the hornstays. Then for some distance at the top it is horizontal; upon this portion the expansion brackets of the boiler slide. Below the frames are shaped out to take the trailing axle box guides, being stayed as before by the hornstays, the end being of a depth suitable for taking the footplate and trailing buffer plate.

The plates after marking are roughly punched out to shape, and are afterwards slotted or otherwise machined to the exact dimensions, then levelled by hammering or rolling, and finally drilled, the holes which are to have cold rivets inserted being made $\frac{1}{16}$-in. less than the finished size.

The hornblocks, spring brackets, etc., are carefully fitted in their appointed places by chipping and filing, and the holes are reamered out to exact size, the bolts or rivets being turned a tight driving fit in them. If the latter are hammered down cold the holes are better filled then than would be the case with hot rivets. The hornstays are fitted and secured across the openings cut to receive the axle box guides.

The frames are next placed upright at the proper distance apart; the cylinders, bogie casting, motion plate and frame stays are put between and temporarily held by bolts, and the frames squared by having lines of fine twine stretched on each side outside them, and set equally distant. Two other lines are passed through the cylinders from a straight-edge fixed across the front of the frames, at the proper height, to another straight-edge placed across through the driving hornblocks, and fixed so that the centre line of the driving axle may be represented by its edge. The centre line of the cylinders, shown by the twine, will now intersect the centre line of the axle when the cylinders are set.

To be more nearly correct this imaginary centre of the driving axle is assumed by some builders to be from one to two inches above the actual centre, to allow for the depression of the springs due to the weight of the engine.

The lines are all pulled as tightly as possible, and the distances between them taken carefully in all ways, so that the frames may be free from all cross-windings or other inaccuracies.

All the holes are next opened out to finished sizes in the cylinders, bogie centre, frame stays, etc., and the rivets or bolts turned to fit tightly in them and secured.

In the plan at B the various stays, etc., are shown in position. The frames are set in at the leading end in order to increase the side play of the bogie wheels, and are supported by a strong stay of angle iron rivetted to them and the buffer plate. Next there are the cylinders, then the slide bar bracket and the frame stay fixed just behind the driving wheels and arranged to clear the cranks. This latter is shown of cast steel, but very frequently it is built up of plate, with double angles holding it to the frames at each end. Between this and the footplate is the space for the firebox. The footplate may be either built up, or be in the form of a cast iron box, made heavy in order to balance the weight of the engine. In some engines this box is made to form the compressed air reservoirs for the Westinghouse brake, thus saving the room which these require when built up of plates. It is in either case usual to make arrangements in this footplate for the attachment of the tender in various ways. In that illustrated, three bars with eyes at each end reach between engine and tender, and pins pass through the holes holding them securely together. The centre bar is the larger, and the side ones act as safeguards in case of breakage of it or its pins. Side chains are often used in place of the side bars. The tender has short buffers which press against the plates shown on the back plate on each side of the central hole for drawbars. These are seen in the view of the back end shown at E.

The outside frames, as seen in the plan and cross sections, are of angles, and are mainly for taking the footplating, splashers, cab, etc., being supported at intervals by gusset stays from the main frames to prevent them from sagging or dropping. An angle iron is also fixed to the main frames to take the other edge of the footplating. In the plan the outline of the footplate is drawn. The overall width of it depends upon the construction gauge, but in this country it may not exceed 9-ft., and is usually arranged about 4-ft. 2-in. above rail level.

The buffer plate or beam is either as shown, of a single steel plate, somewhat thicker than the main frames, or built up of two thinner plates, one on each side of a beam of oak, this being favoured by some makers to reduce the shock upon the frames when the buffers strike. The buffers are bolted to the plate at a distance apart of about 5-ft. 8-in., the draw bar hook being passed through the centre of the plate and having a spring either of steel or indiarubber upon it inside.

In front of the engine attached to the frames on each side or in some cases to the buffer plate, are guard irons, which reach down to about 3 inches above the top of the rails, to remove any obstruction from them that would, if left there, be liable to derail the engine.

On some narrow gauge engines, and also on many old ones for the ordinary 4-ft. 8½-in. gauge, the inner frames do not extend the whole length of the engine, but only from the front buffer plate to the front of the firebox, to which they are

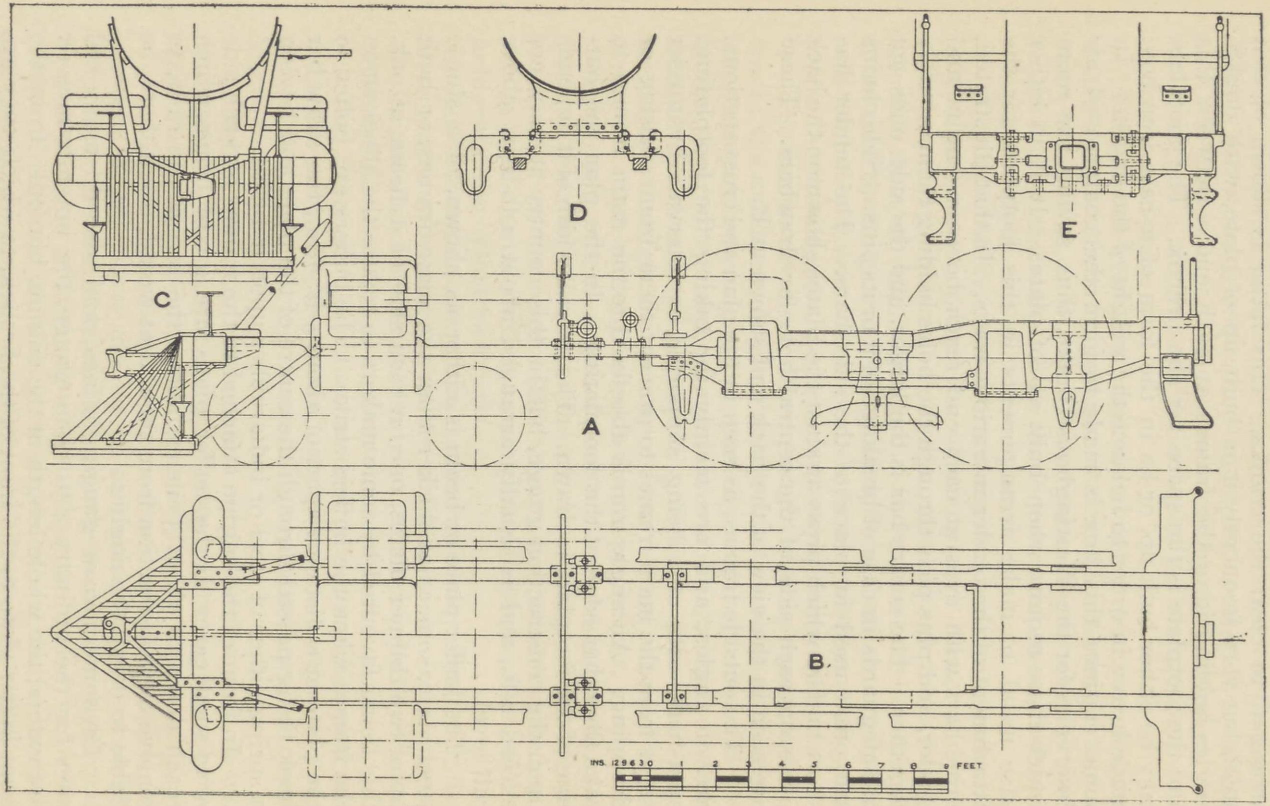


FIG. 25.—BAR FRAMING FOR AMERICAN ENGINE.

attached by angle irons, so that the firebox itself becomes the frame for the remaining length of the engine. This is done in order to get in as wide a firebox as possible.

Fig. 25 gives an arrangement of bar framing as employed in America, it is shown for an engine with a leading bogie, four-coupled driving wheels, and outside cylinders with the steam chests on top, and the valves actuated by rockers.

A is a side elevation, at the front end the leading bumper is fixed, and to this the pilot, or cowcatcher is securely fastened; two lugs are formed upon the upper sides of the bar frames for the reception of the cylinder castings, which are carried across from side to side and form a frame stay there; the guide yoke, or slide bar bracket also reaches across and carries the slide bars on the outside of the frames and a plate between, which forms a support for the boiler. Another stay and boiler support is placed just behind this, in front of the driving axle. Close to the trailing axle is a fourth cross-stay, and the trailing end is closed in by a casting which connects the end portions of the frames together, and takes the tender draw gear and buffing attachments.

The frames are each in two portions, the front carrying the cylinders, rockers, and reversing shaft brackets and the main portion carrying the axle box guides, or as they are called the "pedestals"; these are formed of the same bars, but spread out a little wider than the other parts to form a better wearing face for the axle boxes; gibs or liners, usually made vertical, are fixed to the face nearest the cylinders, the other face being inclined and fitted with a wedge for adjustment; the bottom of the gap is closed and held from spreading by means of a clamp or hornstay. Two arms project forward from the driving pedestal, and between them the front frame is placed and held by wedges and bolts, a foot upon it also being butted up to the pedestal and fixed there.

In many engines, especially those having more than two pairs of coupled wheels, the main frames are built up and bolted together, instead of being welded as in the example, so that in case of failure or collision the damaged portions may be the more easily taken out and replaced than would be possible with whole frames. The front end is especially liable to accident, by head end collisions, and is therefore made so as to be detached without disturbing the main frames.

From the driving to the trailing pedestals, the frames are doubled, the upper bar being called the top rail and the lower one the bottom rail; they are stayed together vertically by blocks placed between them and fastened to each; these form convenient means for the attachment of the brake hangers, etc., and also act as expansion clamp bearers, for, as in the design illustrated, the boiler is entirely above the frames, the firebox bottom being made of a shape similiar in outline to the top of the frame, as represented by a dotted line; large plates are fixed to the sides and carried on either side of the frames for securing the boiler from side movement, but they permit of its sliding along when expansion from heat takes place.

As the frame bars are about 4-in. square in section, the distance they are apart transversely would permit of only a very narrow firebox, if it were placed between them, therefore in many recent American designs, the boiler is placed as represented.

The "pilot" is strongly built up and well stayed and supported by struts to the front bumper, which is usually of wood, it is also strutted from the bottom of the cylinder casting between the frames. The bumper is further supported by stays from the sides of the smokebox, these being shown at the front ends of views A and B, and upon the front elevation at C. The pilot is provided for removing any obstacles from the track, in the form of stray animals, etc., as many of the American roads pass through wild and unsettled country, with little protection from fences.

The cylinders are placed in position between the two lugs or projections forged upon the top of the front rail, they are firmly wedged between these and held by several bolts passed through the casting, which forms a frame stay as well as a support for the boiler and smokebox.

There are no outside frames provided as in European engines, the footplates or running boards being carried upon brackets projecting from the boiler at a considerable height, a step upon the side of the pilot enables a man to mount to the bumper, another step upon a support up from the bumper allows him to reach the running board, headlights, etc. These steps are seen in views A B and C.

D is a section taken just behind the cylinders, and shows the guide yoke and boiler support; the rocker shaft bearings are fixed to the frames and the guide yoke to them.

The back view of the end casting of the engine is shown at E, from it the method of securing the ends together and the large proportions of the cab will be seen; this latter in America is much larger than here, as the loading gauge of the railways allows a height of 15-ft. 6-in. to the top of the chimney, as against 13-ft. here, and some 10-ft. in width, as contrasted with about 9-ft. here, it is therefore possible to pitch the centre line of the boiler higher, and consequently have one of a larger diameter; then to secure a good view of the road for the driver, he can be accommodated with a seat in a wide cab, built practically over the rear of the firebox.

Returning to the engine plate frames, these are cut out to receive the hornblocks or axlebox guides, which are bedded down to them and secured as already mentioned. There are many patterns of such hornblocks, those now generally used being of cast steel in preference to cast iron, but as the firmness and rigidity with which these are held to the frame is mainly dependent upon the bolts or rivets, it has been the practice with some makers to form them of wrought iron and weld them to the frames. With the separate castings it is customary to secure them with turned bolts or rivets, the latter hammered down cold. If bolts are employed it is best to rivet the threads at the outside of the nut, after the nut has been tightened up to prevent it from slackening back.

A pattern suitable for coupled wheels is shown at A, Fig. 26. It has a flange surrounding the ledge which fits in the gap of the frame, and holes are drilled for the reception of the holding bolts or rivets. On the side nearest the front of the engine a face is formed from 5-in. to 6-in. in width at right angles to the frames and vertical. This face is carried up and over the top of the axlebox gap and down the other side, where it has an inclination of about 1 in 10 to the vertical with a wide groove cut in it for the reception of a similar projection upon a block or wedge, which has its other face vertical, and of an equal width to the fixed face opposite. These two upright faces enclose between them the axlebox, and any adjustment due to wear, etc., may be made by raising or lowering the wedge by means of the bolt shown carried down through the hornstay. This bolt is screwed into the wedge and turned by the square at the bottom. When the required position is found the screw is secured by the nut below the stay being locked. The wedge is prevented from leaving its place when being fitted or when the box is out of place by the stud or sunk headed bolt which passes through a slotted hole in the hornblock and has a nut upon its outer end.

Oil holes are provided at the bridge across the top for supplying lubricant to the faces, and also to the axlebox bearing, pipes being often led from some handy place on the footplate.

The hornstay passes across from one face to the other to stiffen the frame. In the particular example shown it also forms a bearing for the coiled springs to press against, these latter being placed upon long bolts reaching down from the axlebox. When so employed, one bolt upon either side is

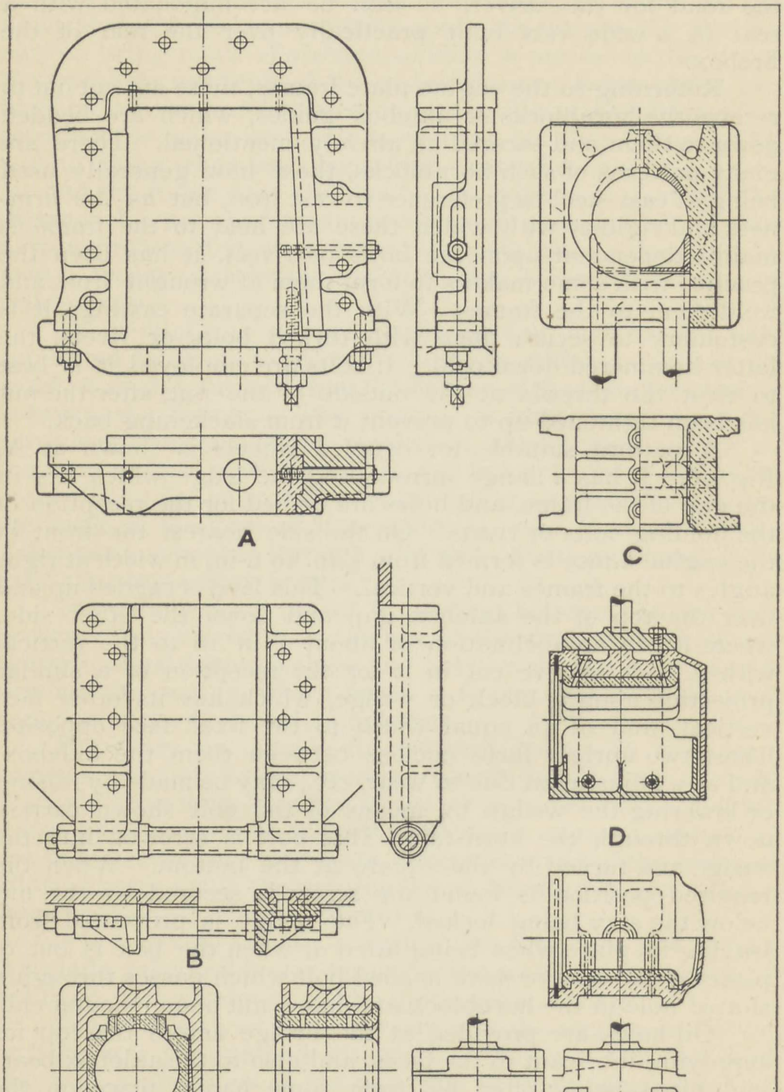


FIG. 26.—HORNBLOCKS, AXLEBOXES, ETC

sufficient to hold the stay up, lugs upon each side of the jaws also keeping them from opening; but when laminated springs are used, and are not in any way fixed to the hornstay, it is usual to have three or four bolts on each side, with split pins to secure the nuts upon them. Webs are carried from one flange to the other at right angles to strengthen them.

The frames have been found by experience to be weakest at the corners of the gap cut out for the guides, especially when fitted with hornblocks with no wedges, so that the corners of the castings are well thickened up, and no bolt holes are located on this line of weakness.

Instead of being cast in one piece, the hornblocks are often cast in pairs, one piece being fixed on each side of the gap in the frame, there being no connection between them at the top, except by the frame itself. This method is only used in places where the wheels are simply carrying wheels, as in single leading and trailing wheels and bogies. They are cheaper to make and machine, but do not support the frames at the corners, and are therefore unsuitable for the coupled wheels. An arrangement is shown at B adaptable for outside leading or trailing bearings with overhung springs, the hornstay not being suitable for underhung springs, as it simply consists of a long bolt passing through a hollow distance piece of the proper length to fit between the jaws.

It is most important that the faces of the hornblocks on each side of the engine shall be accurately in line, this can be proved by means of a long steel straight-edge held to the faces after they are filed up or otherwise finished; to ascertain that they are square with the frames, a long square is held upon this straight-edge and tried with the lines stretched parallel with the frames on either side. If they should happen to be out of winding they must be adjusted by removing metal from one or other face as required and refacing them. A plumb line and square held to the face proves its perpendicularity.

Axleboxes are made of gunmetal throughout, or of cast iron or steel with gunmetal bearings fitted to take the journal, the shapes being very varied. At C a gunmetal box, suitable for driving or coupled axles, with a hornblock as at A, is illustrated in section and elevation. The sliding faces on each side are of the same width apart as the jaws of the guides, and have flanges upon each side to guide the box sideways. It is turned out at the crown to take the axle journal, and closed in at the bottom by a cast iron or steel keep or oil cellar. A stout pin is passed through holes in the legs of the axlebox, and upon it are placed two eyebolts which project down through the hornstay for carrying the coiled springs. In some cases two smaller pins on either side parallel with the large one also pass through to secure the keep.

The keep acts as a reservoir for the lubricant retained in it, the latter being kept up to the under side of the bearing by means of pieces of sponge or horsehair preparations, worsted pads with springs being also used for this purpose.

The top of the box is cored out, both to lighten it and to form an oil receiver for supplying the journal. Holes are drilled through to a long channel, cut deep and broad along the top of the crown, so that the oil may be well distributed along the entire length of the bearing. Worsted syphons lift the oil out of the recesses at the top of the box and supply the channel. Strips of white metal are also let into the face of the bearing on each side of the centre line of the crown, both to reduce friction and act as a safeguard if the bearing should heat, as the softer metal melts and forms a lubricant itself which often saves the bearing from being cut. The white metal is run in and turned with the gunmetal.

When the boxes have been fitted to the guides all the centres are correctly set out, and the boxes are bored out and then fitted to the journals by chipping, filing and scraping. There is a difference of opinion as to how far the bearing should fit the journal, but it should not be allowed to touch quite down to the centre line, or there will be a tendency to bind here, and heated bearings will be the result. The oil recess along the crown and white metal strips have been found to prevent slackness and knock to a great extent, as they allow of most wear taking place in the crown. A thin cover plate of metal, with a strip of leather below it, is put on top, and prevents access of dirt, etc.

The amount of side play allowed both in guides and bearing is very small; in fact, in most cases, with coupled wheels especially, there is none recognised, the working fit providing quite sufficient for all practical purposes.

A box suitable for outside bearings and overhung springs is illustrated at D. The box is of cast iron, and is fitted with brasses which have the usual white metal strips along each side of the crown, but as the pressure is directly applied to the top of the box by the spring pin, the centre of the crown has not got the wide oil groove provided in the previously mentioned example. The keep below is also of cast iron, and held in place by two pins passed through. These are prevented from coming out when the box is in position by the fact of the box sliding in the guides.

To prevent dust, etc., from getting into the end of the box nearest the wheel where it is open, a flat piece of vulcanite or other suitable material, with a hole cut through it for the axle, is fitted into grooves formed in the box and keep.

In order to get over knock due to side wear a box with side adjusting bearings is used on some French railways. It is illustrated in section at E. The box is similar in shape to the last example, but is fitted with a crown brass and a fixed side brass on one side, that upon the other being adjustable to the journal by means of a wedge, which is held by a bolt passing through a lug cast upon the bottom of the casing, and having check nuts upon each side of it. A keep, supported by two pins as before, contains the padding, etc., which is held up against the lower part of the journal by wings projecting into the oil space. The spring pin takes a bearing in the cup-shaped recess at the top of the box.

To gain flexibility in the wheel base of an engine not fitted with a bogie and having single leading wheels, it is a common expedient to make the box a loose fit in the guides, so that the wheels may move sideways to an extent when the engine takes a curve, but as the spring pin is above, and must not be moved sideways, it is placed in a recess in a cover plate, which has no side play allowed, the box sliding under it when it moves. This arrangement is on the box shown at D, but it is not satisfactory on an engine with a long wheel base, as the side play must be large to gain sufficient lateral movement, and the engine has a tendency to a "nosing" action on a straight road. Therefore, some form of controlling gear is necessary; some makers use springs and some swing links for this purpose, but the most common method is to form the top of the box into inclined planes, and have the bottom of the cover plate of a similar shape to suit, as shown at F; if the engine with box so fitted has to take a curve the axle slides along, raising the spring with the cover plates, and when the straight road is again reached the influence of the planes causes the axle to resume its central position; this ensures a steadiness in running not obtainable in plain axleboxes.

The wheels are made of wrought iron, cast iron or cast steel. The first-named metal, however, has now been replaced to a large extent by the second for goods and shunting engines, and the third for passenger and express engines. A cast steel wheel suitable for a small inside cylindered coupled engine is illustrated at A, Fig. 27, in which the boss is made large enough to safely take the strain due to the axle being forced in and held, and also to take the crank pin for attach-

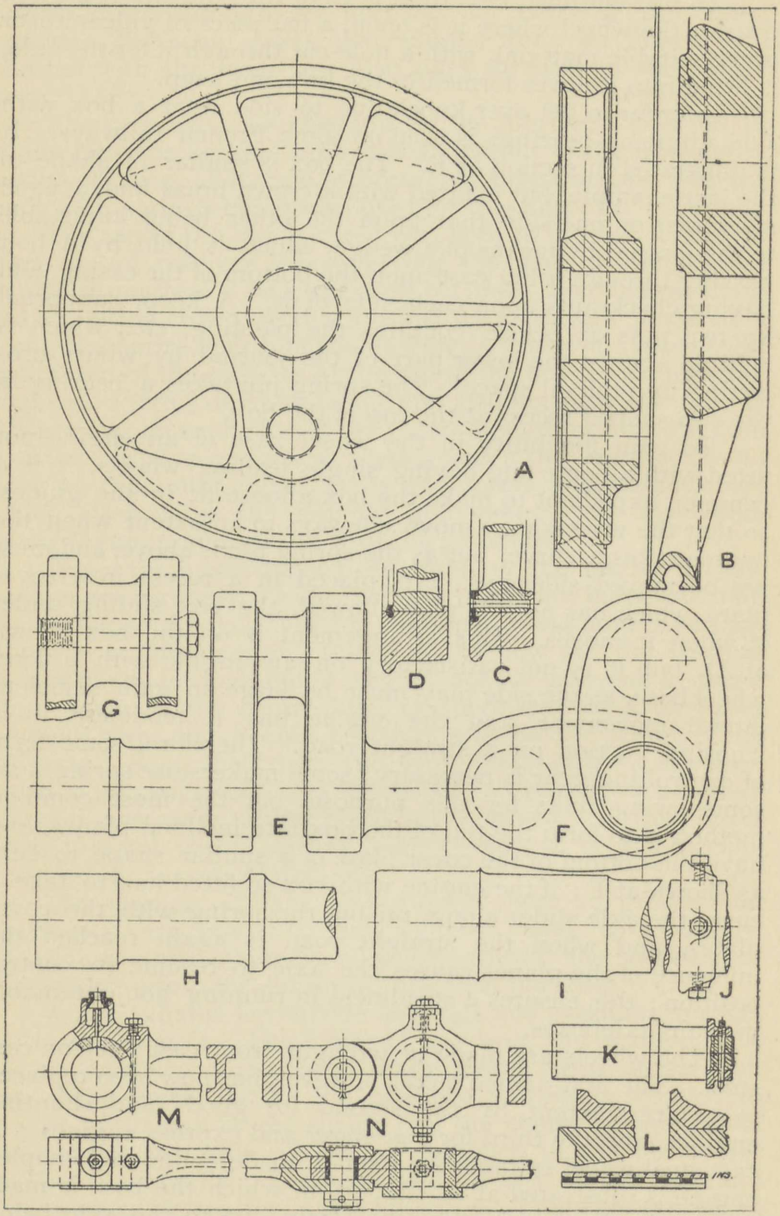


FIG. 27.—WHEELS, AXLES, ETC.

ment of the coupling rod. The number of spokes or arms radiating from the boss to the rim or frame depends upon the size of the wheel, they being usually spaced about 10 or 11 inches apart at the rim. The cross section varies from an ellipse to an oblong with rounded corners, according to the fancy of the designer; but in the cast iron variety, channel or H section is frequently adopted.

To ensure smooth running and even wear of tyres and the engine generally, it is necessary to balance the reciprocating and revolving weights of the motion, and with cast iron wheels as shown it is usual to cast the weights in place. In inside cylindered engines, the driving wheels on the crank axle have the balance weights placed on one side of the centre line of the axle and crank pin, the reason for this being that the power is applied to a point somewhat removed from the plane of the wheel. If the weight was exactly opposite it would not correctly balance, as the other crank which is at right angles has an influence upon it. The exact amount of offset is ascertained when the wheel is designed. It is usual to completely balance the whole of the revolving and two-thirds of the reciprocating weights. In the leading and trailing coupled wheels the weight is placed exactly opposite the crank pin, and is much smaller, being only sufficient to balance the coupling pin and boss, and half the side rod. In the sketch the full lines represent the outline of a driving wheel, and the dotted lines that of a leading or trailing coupled wheel.

In outside cylindered engines the balance weights are placed exactly opposite the crank pin, as the power is here applied approximately in the plane of the wheel, and the influence of the other crank is not felt.

With wrought iron wheels the weights may be forged in place, but it is more usual to fit them in afterwards and fasten by rivets passing through them and plates on the outside and inside of the spokes.

The hole for the reception of the axle is bored out, and in some cases has a recess about $\frac{3}{4}$ of an inch deep and $\frac{1}{2}$ an inch larger than the hole for the reception of a collar turned on the axle, this being done to prevent the axle from being forced on too far. Most makers also fit the driving wheels with a steel key, about 1 inch by $1\frac{1}{2}$ inches in section, in a keyway formed half in the wheel and half in the axle to prevent the wheel from turning upon the axle when working; but it is not customary to provide keys in the uncoupled or carrying wheels as they are an unnecessary precaution. The axles are forced in cold by a hydraulic pressure of from 45 to 50 tons in in cast iron wheels, and from 80 to 120 tons in those of cast steel.

The section of the rim depends upon the tyre fastening employed.

In American practice cast iron has until recently been generally used for all wheels, but now steel is being largely employed for the larger ones. When of cast iron they are often lightened by having the spokes and rim cast hollow, a form of which made with a very deep dish is shown in cross section at B. This setting out of the boss is done in order to secure a very long journal on the axle. The rim is hollowed out as seen at the bottom of the sketch. This, in many examples, is cast in segments to prevent the contraction, when cooling, from straining the periphery.

Tyres are of open hearth, crucible or Bessemer steel, one-third of the length of the ingot from the top being cut off, and the tyre blank made from the remainder under a heavy hammer, the centre is punched out in the direction of the length of the ingot, and the ring thus formed is rolled to the required section. They are then bored out in a lathe to the proper size and shape to suit the style of securing adopted. A small amount of shrinkage is allowed for, this being generally about one hundredth of an inch per foot diameter of tyre. The tyre is now heated to a black heat, placed upon the wheel and allowed to cool but not quenched in water, as this might make it brittle and liable to crack.

A variety of methods of securing the tyres on the wheels, in addition to the shrinkage, have been adopted, but we confine our remarks to three types. First, that of studding or bolting them on, in which case holes are drilled through the rim of the wheel into the tyre and tapped; set bolts are then screwed in. Secondly, the method shown at D, which is formed of a ring, turned, cut, and then sprung into a groove provided in the tyre and held by hammering the tyre down to it at intervals. Thirdly, by Mansell rings or a modification in which one ring only is used as shown at C, where the tyre has a lip sufficiently deep to take the side of the wheel rim and a groove upon its inside in which the ring fits, this is carried down exactly like the lip of the tyre upon the other side of the rim; rivets are then put in holes drilled through the ring, wheel rim and tyre lip, securing the whole together, so that when tyres are held by this method they may even be broken into small pieces and yet not fly from the wheel.

The outside diameter of the tyre is made up of the flange upon the inner side and the tread which bears upon the rail. The usual British form is shown at C, the flange projects down a little more than one inch, and is of the shape shown.

The tread is turned off to an inclination of 1 in 20 to the horizontal thus coning the wheels, this being done so that the face of the tread may be at right angles to the rail centre, as these are usually set at an inclination of about 1 in 20 to the vertical. It has been supposed, too, that coning the wheels assists them on curves as the engine flies outwards when passing round, and therefore the larger diameter is on the outer rail and the smaller upon the inner, as it should be; experiments have proved, however, that it is of little if any use for this purpose, but by coning them they always have a tendency to centre themselves on the rails. The driving tyres of six coupled and single express engines are generally made with flanges of reduced thickness, in order to allow a certain amount of flexibility to the engine, and save the crank axle from some of the side shocks received from striking the rails. For the same reason in engines with long wheel bases some of the tyres are made "blind," that is with no flanges at all. They are then about 6½ inches wide, so that freedom to pass curves is obtained, and yet the wheels do not lose their alignment with the other wheels to which they are coupled.

The American shape shown at D for the outside of the tyre differs by having a slightly deeper flange, and is wider overall.

Usually tyres when new are from 3 to 4 inches thick at centre, and are allowed to be turned up when worn until they are reduced to 1½ inches at the last turning. They are then allowed to wear ⅛ inch below that, but must then be removed, as with such thin metal the application of the brake blocks and consequent generation of heat would expand the tyre and loosen it.

Axles are also of open hearth or Bessemer steel, and are subject to severe tests before being accepted from the contractors, the ultimate tensile strength to be 32 tons per sq. in. A piece is taken from the forging and machined to 1¼-in. square and bent double whilst cold without sign of fracture. With crank axles one is often taken from the parcel and tested to destruction by spreading the webs by forcing wedges between them, and they are usually taken on the condition that the makers replace, at their own cost, any that may fail before they complete 200,000 miles.

At E half a crank axle is drawn, the wheel seat being at the left, next the journal, then the outside web or cheek, the crank pin, inside web and central portion. The other half is similar, but with the crank turned at right angles to the one shown at E, as will be seen on the end elevation at F.

It is difficult, especially when the steam chest is between the cylinders, to get the webs sufficiently strong, as the cylinders must be some distance apart, and the outer web is liable to be too thin, the crank having not only to turn the wheels but also support part of the weight of the engine. The inside web being further from the wheel is found to be more likely to break, and therefore it is often made thicker than the outer one, as the breakage of a crank axle is one of the most serious mishaps that can occur to a locomotive, especially if broken through the web. It is now customary to strengthen the webs with weldless bands of steel rolled and blocked to the required shape, and shrunk on after heating when the webs have been machined. A common shape for these is an ellipse as shown, but they are to be seen oval, almost rectangular and circular. In the latter case bands are not used, as the webs are of ample strength at the most usual place of breakage—midway between the axle and crank-pin.

To support the pin, which is the next most vulnerable part, some designers have a hole drilled through it and both webs, and a bolt put through with its ends either rivetted over, held by a head on one side and a nut the other, or as shown at G, screwed into a tapped hole in one web by a head outside the other.

Crank axles have been built up of separate pieces which are screwed together instead of being in one forging. In order to relieve the cranks of racking strain four bearings are often provided, one on each side of each wheel. The weight is then transmitted directly, and the bending of the axle by it avoided.

Straight axles are simple in shape, being round pieces of metal of suitable diameters. A common form is shown at H, the wheel seat in this case is plain having no collar upon the inside; then the journal being smaller, with a collar at its other end, the central portion is again reduced in diameter. It is most important that all the various diameters should not abruptly change one to another, as by doing this fractures are very liable to occur at these points; radii of ample sizes are therefore strongly recommended. Carrying this idea still further, some designers take one long sweep or double cone having no portion parallel. They have the disadvantage, however, of being somewhat more difficult to accurately fit the bearings to.

Axles for American engines are usually even simpler in shape, being either parallel throughout or as shown at I, in which the wheel seat and journal are of the same diameter, being separated only by a small fillet, against which the wheel bears when forced home, the central portion being reduced to a less diameter; no collar is formed at the end of the journal.

In parallel axles, or in those which are larger in the centre than at the wheel seat and journal, a separate collar is often located at the inside of the journal and held by four set bolts as shown at J. On driving axles the eccentrics fulfil a similar function, and form the ends of the journal.

If the size of the journals is to be increased for more bearing area it is best to increase the length rather than diameter, as speed is an important factor in friction, and this is added to if the diameter is increased. It is not good practice to place more than 8 to 9 tons as a maximum upon one bearing; if more weight than this is to be carried bearings should be added at the other side of the wheel. In a few instances a bearing is provided in the centre of the axle.

In some cases, especially with single leading or trailing wheels, outside bearings only are provided, as they are more accessible, and allow more room between the frames for the cylinders, fireboxes, etc.

Owing to weaknesses of the road, etc., it is not always possible to put all the weight necessary for adhesion on one pair of driving wheels, consequently two or more pairs are connected together by means of coupling rods working upon crank pins projecting from the wheel bosses of inside framed engines, or from outside cranks of those with outside frames. The holes for the reception of these pins are bored out after the wheels are fixed upon the axle, in a quartering machine provided with two heads having boring tools arranged at right angles to each other, with a sliding adjustment to suit different throws as required. The holes are bored out parallel, or with only a slight taper, and usually countersunk on the inner side. The crank pin is turned to fit with a projecting lip at the end, which can be hammered down into the countersink after the pin has been forced in with hydraulic pressure of about 45 tons. At K, a crank pin is shown with the part forced into the wheel boss on the left, then a collar against which the pin is pressed home and which also forms a distance piece to keep the coupling rod away from the wheel, next the journal, and lastly a smaller part on which a loose collar is fitted, secured by a taper screwed pin; this holds the rod upon the crank pin.

At L a larger section of a portion of the lip and boss is shown, the view on the left being that of the end of the crank pin as it appears when forced into position, that on the right showing it when the lip has been hammered into the countersink. These pins are either of steel, or of wroght iron well case-hardened on the journal and ground up true.

The coupling rods are either of iron or steel, being usually made in one piece without welds. The cross section varies from a plain rectangle to different H sections, and is sometimes parallel throughout, but perhaps more frequently thicker about the centre of the rod's length. In some of the H section rods the grooves are deepened as they near the ends, thus leaving more metal in the middle, and strengthening the rod there, where experience has shown it is most liable to failure in service.

The ends vary somewhat in shape, but the solid eye illustrated at M, with a bush inserted in it to take the wear upon the crank pin, is very largely used. The bush is, in some cases, of cast iron with a thin layer of white metal immediately round the pin, in others, of plain white metal or gun metal throughout, and sometimes in the latter metal with grooves of white metal inserted similar to those in the axle-boxes, etc. It is prevented from turning in the rod by means of a taper pin, as shown, which passes through a hole half in the rod and half in the bush, or by a bolt which is screwed up through a boss formed at the bottom of the rod, and enters a hole in the bush, as shown at N ; a nut upon the thread of the bolt locks it in position. In other cases the oil cup is separate from the rod, and is screwed into a hole at the top, the shank upon it being long enough to project into a hole in the top of the bush. A simple key answers the same purpose in other rods.

In engines with more than four wheels coupled it is necessary that there should be freedom allowed for the rods to give vertically in their length, as the different pairs of wheels are moving over varying levels in running, and if they were in one rigid length they would be liable to be broken. A joint to allow of this movement is shown at N, where the prolongation of one rod has an eye for the reception of a pin which also passes through a fork upon the other length, the hole in the first mentioned rod is often bushed with a steel bush, and the pin made a tight fit and held in the fork by a feather, so that all the wear is taken up in the bush, which can be easily renewed.

Another method is to fork one rod and form the other with a large eye to go between the jaws of this fork. These take a gun metal bush large enough to form a seat for the crank pin. The fork is made a working fit upon the outside of the bush, and so the rods get the required hinge action. A longer crank pin is necessary in this case. Entirely separate rods are also to be seen, one of which will be near the wheels and the other on journals provided upon the pins, which in this case will project out a much greater distance, as the rods work in entirely different planes.

In the case of outside cylindered engines the coupling rods necessarily have the same stroke as the connecting rods, as they are upon the same crank pins; but in inside cylindered engines the coupling rods are placed opposite the cranks, and are allowed a reduced throw, usually one to two inches less than the cranks. At times they are both upon one side, and the outer cranks are then provided with an even less throw. A reason for placing them so is that the wear upon the axle boxes is reduced, as the pull upon the coupling rod is taken direct by the connecting rod, instead of being reversed through the axlebox.

The wheels and axles are connected to the frames of the engine through the medium of springs, so that any shocks received by the wheels in running may be reduced and their effect lessened, and the liability of damage to the mechanism of the engine and to the road bed reduced; further, the engine has not the tendency to mount the rails that it would have if the wheels and frames were rigidly fastened together.

The springs are of various designs, those built up of long flat plates one upon the other being known as "laminated," whilst two of such springs placed one on top of the other, but with their curvatures reversed, are termed "elliptical"; those coiled out of flat section steel, with different diameters at top and bottom to accommodate the one coil inside the preceding one, "volute"; or of round bar or "Timmis" section, of equal diameter throughout, "helical" springs.

Steel of the very best quality is invariably used for this purpose, and the completed springs are well tested in a scragging machine before they are put under an engine to work.

A common form of laminated spring is illustrated at A, Fig. 28, in elevation and plan. Thirteen plates, 5-in. wide by $\frac{1}{2}$-in. thick, of varying lengths, are placed one on top of the other, the top one or master plate being the longest, and provided with eyes at each end through which pins pass to couple the springs to the frames. The plates are all held together at the centre by means of a buckle of wrought iron, which is shrunk on to them, with a long rivet passing through the plates and buckle and rivetted over at top and bottom. To keep the plates from moving sideways nibs and slots are provided in all except the bottom one.

Another shape for the eye at the end of the master plate is sketched at B, and is used for underhung springs in which

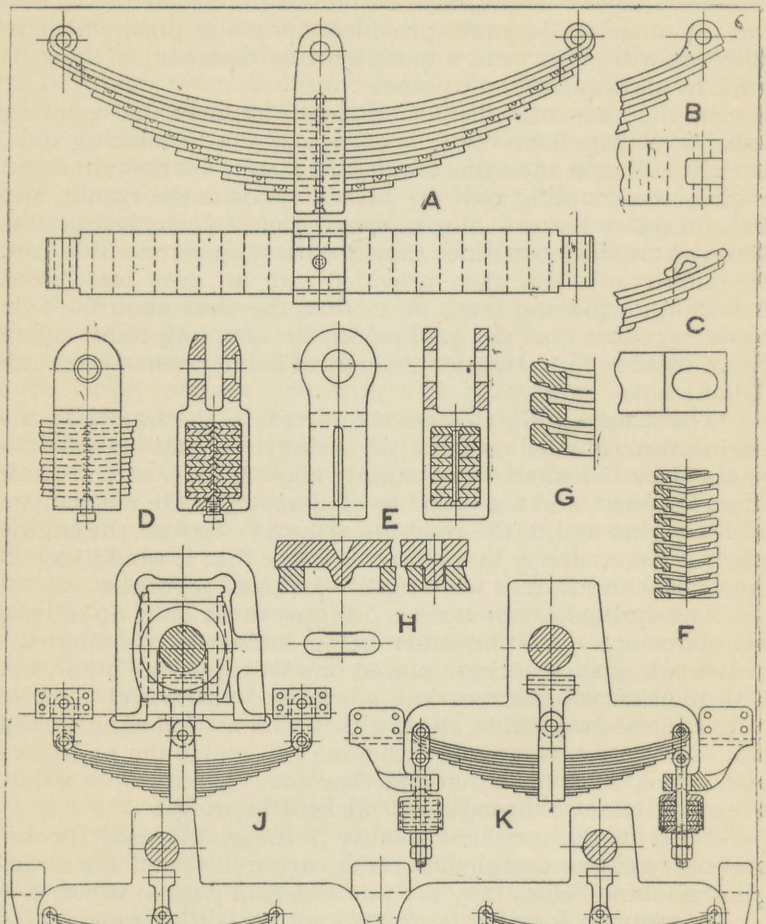


FIG. 28.—SPRINGS AND GEAR.

the brackets at the ends work upwards. At C a type much used on Continental engines is illustrated. In this the hanger is not attached by pins, but passes through a hole in the plates, and has blunt knife edges formed upon either side, which bear upon the spring in the hollow made by the top plate being turned back as shown.

At D a buckle is shown in which, instead of a rivet as at A to hold the plates, each has a depression upon its lower side and a corresponding projection upon the other, which engages in the depression of the next plate, and the bottom plate has the end of a set bolt screwed into it through the buckle, thus holding all the plates together.

At E the plates have the rivet passed through them only, and not through the buckle, being rivetted up before the buckle is placed in position. A long narrow slot is made in one or both sides of the buckle, so that any defective or broken plates may be easily detected. This form of buckle is common on the Continental railways and has advantages in facility for examination.

An enlarged sketch of the nib and slot is shown at H. The upper plate has a punch driven into its top side, pressing out a nib on the under side, which works in a long narrow slot punched out of the next plate; thus the plates have perfect freedom to slide along each other as the weight is applied, but cannot slide sideways.

The camber or amount of curvature allowed a spring is measured from a straight line through the centre of the end suspending pins, or from the point of support to the top of the top plate, and varies considerably. It should not be too much, as the more camber the less flexibility, and in theory the spring should be about straight when the maximum load is applied; however, in practice it is usual to allow them to have about 3 inches even then, as it is easier to get at the hornstays, pins, etc., and have shorter suspending links in many cases. On Continental engines the springs are often made straight, and when the load is applied they form a reverse curve.

A coiled spring of Timmis' section is shown at F. It is used under an axle box, as illustrated on the frame drawing, Fig. 24, two or even three of them being employed for one box, depending upon the weight to be supported. An enlarged section is shown at G, Fig. 28, in which it will be seen that the steel has two thick parts, one outside and one inside, with a web connecting them. These thick parts are in different planes to prevent the spring from taking a permanent set, and to give greater resiliency. The outer thick parts are deeper than the inner ones, and alone come in contact when the springs are driven home, this being found to reduce breakages and prolong the life of the springs.

An arrangement of underhung spring and gear suitable for a driving axle box is shown at J. The spring is similar to that at A, being coupled to the axle box by a link and pins. A large pin passes through the horns of the box and the top of the link; another one at right angles to it passes through the forks upon the buckle and the link, the spring having freedom to swing in either direction upon these pins. The ends of the spring are coupled to the frame by hangers and pins, which allow the spring freedom to lengthen when loaded. When springs are so fitted and hung, and the weight upon the wheels requires to be adjusted, it can only be done by changing the spring and substituting one with more or less camber, according to whether a greater or less weight is to be carried on the wheels.

At K is shown a somewhat similar arrangement, but instead of the springs being coupled direct to the frames, washers of india-rubber are inserted between to form a cushion for the springs and lessen the shocks upon them. Brackets are carried down from the frame, and through holes in them the bolt of the hanger passes; below, an inverted cup is placed on it and the rubber cushions put on, each being separated by a thin metal washer. A thicker washer is used for the last and then two nuts, one checking the other. The weight can here be adjusted by means of the nuts and screws without changing the springs.

As all the axle boxes fitted with independent springs are permanently loaded with the full weight to be carried by them it follows that, as the wheels pass over inequalities of the rails, this weight per axle may be largely increased for the time being; therefore many engines have two or more pairs of wheels fitted with compensating or equalising levers or beams, so that the rising and falling of the wheels mentioned may be accommodated without causing an undue load to be carried by any one box. With these beams every shock to one wheel and spring will be in part taken by the next to which they are coupled, thus lessening the injurious effects. This equalising is common in Britain and on the Continent, and is universal in America.

At L a form of compensating gear, connecting the driving wheels of a four wheels coupled engine is shown. The outside ends of each spring are hung to curved brackets attached to the frame, the inner ends being in a similar way attached to either extremity of a beam, which is pivotted at its centre to a carrier fixed to the frame between the coupled wheels. The ends of the spring are not provided with pins as in the last case, but the top plates are turned over to form solid pieces which fit into sockets in the hangers, These latter have the top forged in one with the sides, which are carried down on each side of an eye forming the top of the hanger bolt, and a pin passes through to make a hinge about which the spring may move when the load is applied. Nuts on the screws of the hanger bolts allow any necessary adjustment to be made.

It will be seen from this that in effect the weight of the engine is mainly carried at the pivots of the beams, and as the bogie carries its proportion of the weight at its centre, the engine is practically carried on three points, the most favourable method for obtaining stability in running.

In the case of engines with more than four wheels coupled it is not usual here, when equalisers are used, to provide all the wheels with them, but only two pairs, the remainder having independent springs. Sometimes, however, they are coupled across the engine by one transverse spring, with an end bearing upon each axle box. In America the whole of the wheels are invariably equalised, and in engines with many wheels this is often arranged for in groups; for instance, in "Consolidation" engines, which have four pairs of wheels coupled and a leading "pony truck," the truck and the leading coupled wheels are in one group and the remaining coupled wheels in another, coiled springs being often placed on the extreme hangers of each group, for the same reason that the rubber is used in the type shown at K in addition to the laminated springs.

The use of coiled springs is also common there, and at M is shown an example of equalising in which they alone are employed. The beams themselves rests on the axle boxes, and the springs are placed on the hangers, the pair being coupled together through the medium of bell cranks pivotted to brackets attached to the frames. Screws and nuts are provided on the hangers for giving the required tension to the several springs.

To obtain lateral flexibility in the wheel base various means are adopted. With coupled wheels which are necessarily rigid being all connected by rods, some are occasionally provided with blind tyres or reduced flanges, as has been already mentioned; but when the driving wheel base is not too long, as in four wheels coupled engines,, the remaining wheels are provided with one of several methods of allowing lateral play. Firstly by a four wheeled bogie or truck, secondly by a two wheeled bogie or pony truck, thirdly by radial or sliding axle boxes.

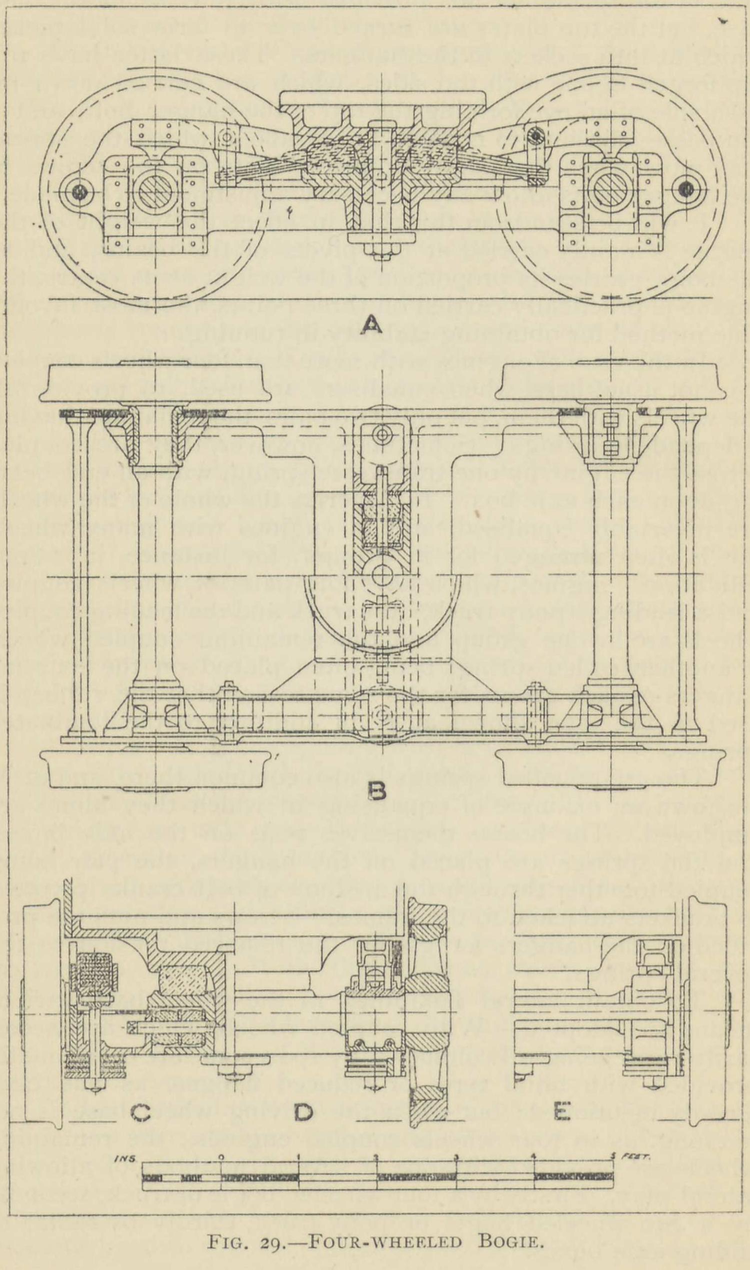


FIG. 29.—FOUR-WHEELED BOGIE.

In some cases, especially in engines fitted with a four wheeled bogie, all the flexibility is provided at one end; but when the other means are employed, they are often placed at each end of the engine with the rigid wheel base between them.

The four-wheeled bogie is made in various ways, the simplest being in the form of a frame having four axle boxes to take bearing on the axles, and a top with a large hole in the centre, through which a pin fixed to the main framing of the engine passes, and about which the bogie works. This arrangement has only freedom to move as a pivotted structure, for being unprovided with lateral displacement, the flexibility of the engine is entirely obtained by the bogie partially turning. It follows, therefore, that this form of bogie is best when the centre pin is not placed exactly in the centre of the distance between the two axles, but when nearer the trailing axle, as then the movement is mostly with the leading axle, and the centre line of the engine is less affected.

Fig. 29 illustrates the Adams type of bogie. Four wheels are placed with the axle boxes in guides in frames consisting of two flat plates held by a cross stay in the centre with a large transverse opening in it, exactly midway between the two axles. This has a faced horizontal surface on either upper side, with the ends closed in by cast iron boxes. Through holes in these, pins are passed having upon them the side controlling rubbers separated by thin metal plates. The transverse slide has projecting over upon each side of the part that fits the opening a ledge which engages upon the sliding faces on the cross stay, and the side rubbers are placed on each side between the slide and the distance pieces, an initial compression being given to the rubbers, the amount of which depends upon the average speed for which the engine is designed, being more for high speeds. The slide has an annular dish in its upper side and a hole through the centre for the centre pin. A large rubber pad is placed in the dish, and the bogie pin frame, which is fastened to the main engine frames, having a similar dish in its under surface, bears upon it. A long centre bolt passes through the whole, and a washer and nut is placed below. This pin, however, does not work, but is placed as a precaution against any parts leaving the engine in running.

On the top of the axle boxes the ends of two cradles are carried one on either side; the springs are held down by long bolts having eyes to take pins through the buckle. These pass through the distance pieces at each side, and have india-rubber washers upon them below to reduce the shocks to the springs. The ends of the springs are connected by suitable hangers to the cradles, so that as the engine is running the weight carried upon each axle box is equalised.

A is a longitudinal section of the bogie, with the slide and rubber pad shown at the centre, and the axle boxes, etc., at each end. B is a plan, the lower half in elevation showing the cradle which is built up of two plates, the ends of which are filled in with a suitable block for bearing upon the axle boxes, whilst the centre portion is swelled out to clear the spring buckle; hangers are provided with pins at the required distance from the centre. The top left hand box is in section, and the top right hand box in elevation showing the shape of the projections upon which the hollows in the cradle ends rest on the top of the boxes. C is a half transverse section through the centre of the bogie, D is a half transverse section through the axle box, etc., and E a half end elevation, showing the distance piece and stay between the frame plates of the bogie.

Bogies are often made with the frames much nearer together than that illustrated, with the springs, cradles, etc., outside them; the rubbers being dispensed with and the centre made metal to metal, with the side play controlling springs of plate or coiled steel springs. Also, instead of the cross slide travelling in a straight line the guides are sometimes made curved to a radius, but it is very doubtful if there is any corresponding advantage to compensate for the extra cost of making these radial guides.

In running, when an engine fitted with this bogie takes a curve, the frame partially revolves round the centre pin, and the slide moves over towards the side the curve leads, compressing the rubbers on one side, whilst those upon the other side assist the engine in smoothly following the bogie; on regaining the straight road, the rubbers return the frame to the centre line of the engine and retain it steadily there.

The weight carried upon the whole bogie usually corresponds to that carried upon the next pair of drivers, so that the load upon any one part of the rails is half that upon the drivers when the bogie leads, the rails being thus gradually forced down to a bed, ready for taking the heavy weight that follows.

The Stirling bogie has a different side controlling gear. The bogie frame stay is of hollow form with a pivot behind the transverse centre line, and on the longitudinal axis of the bogie; the bogie centre pin moves freely in a slot in the frame stay. On the opposite side of the bogie centre to the pivot are two sockets standing out at an angle to the centre pin, thus forming a Y with the bogie centre at the fork; the pivot at the bottom and the arms, which are carried through the sockets, have placed upon them rubber pads and nuts, so that as the bogie moves sideways for the passage of a curve the rubber pads upon one arm are compressed, and on returning to the straight both rubbers steady the engine. All the bearing springs in this type of bogie are made independent of each other and not connected by a cradle, the weight is carried as before on a cross frame, or upon slides at each side of the bogie.

The American type, or swing link bogie, differs from the last described, in that the controlling gear is vertical instead of horizontal. The framing, which is there usually of bars, is arranged in the form of a large square, with pedestals or guides for the axle boxes attached, transversely across the frame two other bars pass on each side of the centre and carry a casting, which is recessed at the top to receive the bogie pin fixed to the main frame of the engine, this centre is coupled to the crossbars by hanging links from projections upon the sides of the centre plate, reaching up and coupled at their top ends by pins passing through the crossbars, so that the bogie may turn about its centre, or swing towards either side without affecting the centre line of the engine, and the whole is centred by the weight carried upon the bogie. Side controlling springs are in some cases fitted to assist in keeping the engine steady on a straight road. A centre bolt passes through the whole structure as before, to prevent the engine from jumping up and allowing the centre pin to get out of the shallow hollow in the centre plate in which it bears, when running over an irregularity in the road. The axle boxes are coupled together by means of a cradle, and one spring acts for two boxes, as in the Adams' bogie. The swing links have great smoothness of action, and less friction than slides and springs, and are therefore very much easier, and lessen the strain upon the leading flanges when taking a curve. Although this type is called the American, a very large number of engines there are fitted with the rigid centre bogie, which has turning but not lateral motion.

When the weight carried by the leading end is not excessive, or for other reasons a bogie is not used, a single pair of wheels are employed, one method of providing such a single pair with a radial motion is as at A, Fig. 30, which is a side elevation of a Bissel truck. It is of a form usual in America for "Mogul" or "Consolidation" engines. A rectangular frame of iron about 4-in. deep by 1-in. wide has fixed to it guides or hornplates, which are carried down, and have the axle boxes sliding between them; projecting upwards on each

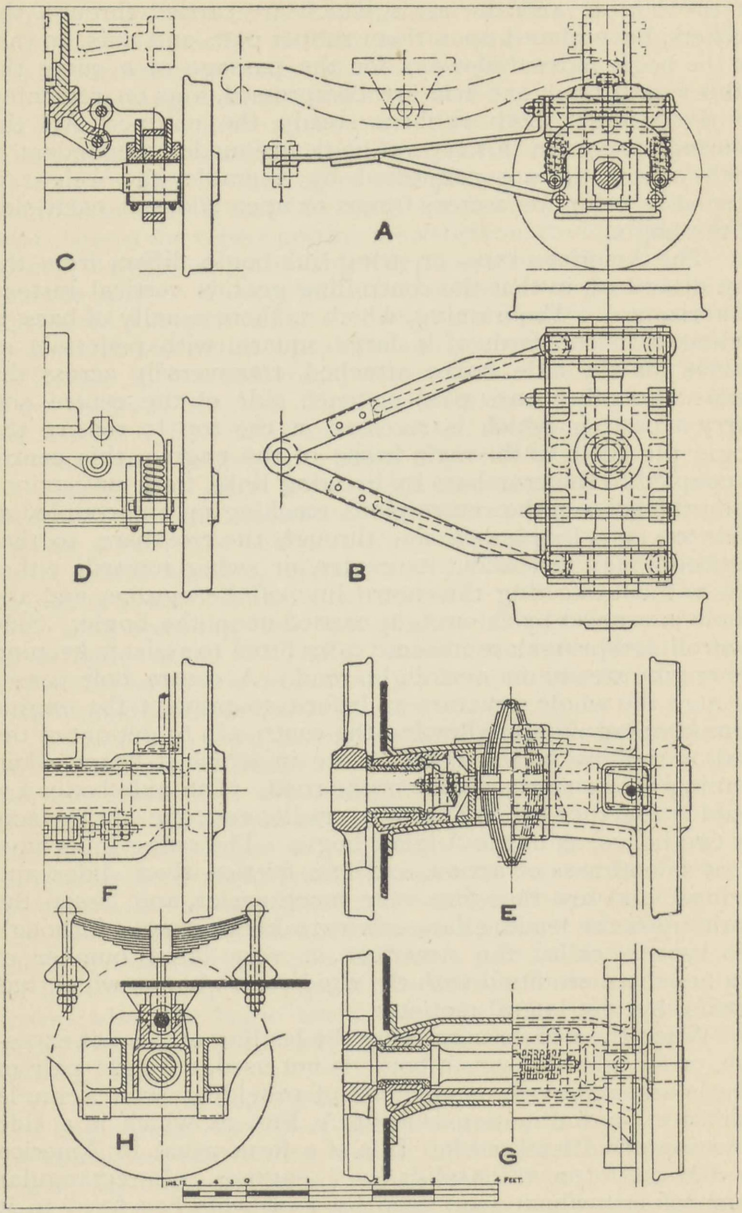


FIG. 30.—BISSEL TRUCK AND RADIAL AXLE BOXES.

side of the centre are lugs, through which pins pass, carrying the upper ends of the swing links, and a large centre casting is held in a socket fixed to the main engine frame, with projections to which the lower ends of the links are coupled, so that the frame can freely move laterally without affecting the centre line of the engine; the frame and with it the axles, etc., all swinging upon the links.

To the back of the above mentioned frame is fixed another one well stayed and V shaped, pivotted at its apex by a pin to a frame-stay between the main frames of the engine. This controls the movement of the truck, and prevents the wheels and frame from turning upon the centre piece, and taking up a position at right angles to their proper centre line, as they might do when the engine moved, and they were not held by the pivot.

The axle boxes slide in the pedestals, and upon the top and at each side of the boxes beams bear, which reach down and carry at their ends bearers for the springs, which are of the coiled type, and are compressed by the weight between the bearers and the bogie frame. The weight is transmitted through a compensating lever coupled at its one end to the leading coupled wheels of the engine, and bearing upon a point in the centre casting of the bogie at the other, being pivotted at, or near its centre to a frame stay. When more or less weight has to be carried upon these different pairs of wheels so connected, this pivot has, of course, to be nearest to that pair which carries most weight.

B is a plan of the arrangement, C is a half cross section through the centre, showing the swing links clearly, and D a half end elevation. The weight placed upon this bogie centres it as in the four wheels bogie with similar swing links.

When the swing links are arranged as shown, with their bottom pin-holes closer to the vertical centre of the engine than the top ones, they have the advantage over those placed exactly above each other, for when the engine goes round a curve it swings over and the outer wheels are made to take the greater weight, which allows the inner wheels greater freedom to do the inevitable slipping upon the shorter rail length inside the curve. Links arranged exactly vertically will simply swing over and approximately the same weight will still be carried upon each side of the bogie.

Another method of obtaining a flexible wheel-base is by means of a radial axle box, which allows a movement similar to the above, but in a different way. Instead of the movement being controlled by a centre pin about which the wheels radiate; the axles are fitted with boxes which are of a form such that they can slide in curved guides, attached to the engine-frames, and are thus prevented from partially revolving about the centre of the pair of wheels.

At E is shown one form of such a radial box, in plan, half section and half elevation. The curved guides are made of steel frame plate, and are bent to the required shape and radius, usually in a hydraulic press; they have sliding between them the axle box which is wide enough to reach across from one journal to the other, and has fitted in it gun-metal bearings for each journal.

As a pair of wheels such as shown at E, require a large amount of side play, about $1\frac{1}{4}$-in. upon each side of the centre is often allowed, and some form of controlling gear fitted to make them keep a steady central position when the engine is upon a straight road. In the type under notice this gear is in the form of an elliptical spring laid upon its side; the axle box having underneath at each side of the centre, lugs projecting down, carrying screwed pins which are adjusted by means of nuts upon each side of the lugs, so that any required initial load may be put upon the spring. The spring is kept in its place by being passed through a narrow slot, wide enough to take the buckle at one side of the guides, and through another sufficient in width for the plates at the other; the wider slot is then reduced to the width of the narrow one by a keep plate bolted on the guide, thus preventing the spring from rising up when the pressure comes upon it. The buckle slides in another slot at the centre as the curves are taken by the engine.

The weight is applied through the medium of independent springs placed above, the centre of which bear upon slippers which slide in curved guides upon the top of the box, and of the same curvature as the radius of the box, the axle box sliding under the shoes as it moves. F is a half cross elevation of this form of axle box.

G shows another radial axle box, which has a much less length of radius than the former one, and has a side controlling gear of coiled springs arranged above the axle. A projection above, in the centre of the axle box, which also takes both bearings, has a spring upon each side of it, and two lugs reach down from a frame-stay of the engine and hold the bolt upon which the springs are placed, and also take their thrust. The bearing springs are on top and the pins slide in shoes as before.

The advantage the Bissel bogie has over the radial axle box is easier action and less friction, as the swing links offer much less resistance than the curved guides and bearing spring shoes; a disadvantage is, the links have to be made a very slack fit upon the pins, as the twisting movement upon them has to be allowed for, the lower ends of the links being fixed to the engine swing in a direction at right angles to its length, but the upper ends have to travel in a radial line struck from the centre of the pivot.

The methods of obtaining flexibility by means of lateral movement, without any radial or revolving play, have been mentioned in the description of axle boxes.

We will now consider some of the miscellaneous fittings necessary for the running equipment ot the locomotive. The hauling power depends upon the tractive force, that is, the power exerted by the steam acting upon the pistons in the cylinders transmitted through the mechanism of the engine to the drivers operating in conjunction with the adhesion, the latter representing the frictional resistance due to the weight placed upon the driving wheels. This must always be greater than the former, or the wheels will be made to revolve upon the rails, and "slip" without moving the engine at all. With sufficient adhesion the wheels will revolve, and instead of slipping the whole engine and train to which it is attached will move along the rails in the direction desired.

The adhesion or resistance to slipping may, therefore, be said to be dependent upon the weight placed upon the drivers, but qualified by the condition of the rails. The friction between these two varies very considerably according as the latter are wet, dry or greasy. When dry and clean a tractive power exceeding one-fourth of the adhesive weight will cause slipping, when dry and sanded about one-third; in wet and frosty weather the friction is reduced to about one-sixth. Under ordinary working conditions—dry without sand, or wet with sanded rails, it is about one-fifth.

In order to be able to work under the most advantageous conditions and obtain as much adhesion as possible, it is the practice to fit sand boxes upon the engine in convenient places for allowing sand to run upon the rails when there is a tendency for the drivers to slip.

In Fig. 31 at A a sand box suitable for an engine with coupled wheels is shown. It is of cast iron, and is formed in one with the wheel splasher. The sand is filled in through the oval cover at the top, and is allowed to fall out by partially revolving a small "butterfly" valve at the bottom, which uncovers two holes over the sand pipe leading to the front of the wheels. The gear necessary for working the valve is worked from a lever in the cab, and the sand is allowed to run on both rails at the same time, the rod shown in plan passing

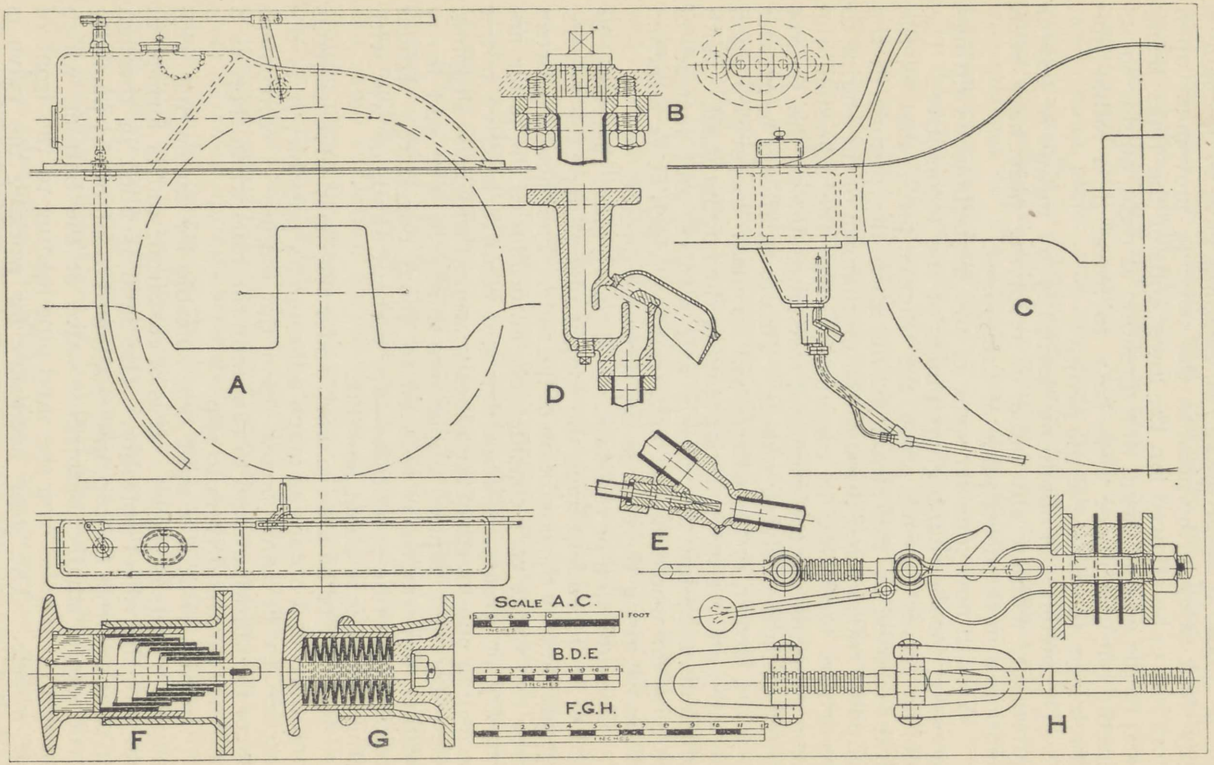


FIG. 31.—SANDING GEAR, BUFFERS, &c.

across between the sand boxes, under the boiler, and operating both sand valves simultaneously.

At B an enlarged section and plan of the outlet valve is shown. The valve of cast iron has a pin upon it below, fitting in a hole in the sand box, and a square above, upon which a socket on the spindle is placed; this spindle passes up through a guide nut, and carries a crank above for actuating it.

The sand is well dried by being baked in a kiln and sifted through a screen, the mesh of which is less than the hole in the sand box through which it must pass to the sand pipes.

When there is a strong side wind, or when the engine is running round a sharp curve, it often happens that the sand from pipes as shown at A falls clear of the rails; or if the engine slips and cannot be moved at all, the sand will not go under the wheel, and the fireman must get down and push it under with his shovel. To overcome these difficulties it is now usual to fit up a steam sanding gear, so that the sand may be driven under the wheel to the point of contact with the rail. Messrs. Gresham & Craven's steam sander is shown at C as fitted to the front of a large wheel. The sand box forms a frame stay between the inner and outer frames, and is carried down below them. To the bottom of it the "sand trap" is fixed; from this a pipe leads down to the sand "ejector," to which steam is also led, and carries the sand through a pipe directly under the wheel.

D gives an enlarged section of the trap. The sand enters above and fills the pocket, but is prevented from passing out by the lip projecting up above the level of that reaching down. When, however, steam is admitted to the ejector below, a partial vacuum is formed in the pipe, and air rushing up the bell mouth carries sand over the ledge with it down the pipe to the ejector. E is a section of the ejector: steam enters through a small pipe and issues from the nozzle, inducing a stream of sand as described. Any moisture that may be formed in the steam pipe can escape out of the small hole at the bottom of the ejector.

The steam valve on the boiler for operating this apparatus is specially arranged to prevent any leakage passing to the ejectors when not in use, and the pipes from it must not have any "pockets" to retain condensed water in, but must be led as straight down as possible, and the "tee" connecting the two ejectors, one on either side of the engine, must be placed as nearly midway between them as practicable, so that the quantity of sand delivered will be equal on each side.

Compressed air is also used for driving sand under the wheels, and sometimes the discharge from the driver's valve of the Westinghouse brake is carried up to the sand box to sand the rails when the brakes are applied. In Europe it is customary to place the sand boxes upon or below the level of the footplate, but in America they are almost universally placed upon the top of the boiler to give the sand a good fall; and this is made use of in some cases by causing the down pipes to have a "pocket" in them, or a slight rise in some part of their length. The sand is then retained in the boxes without valves, as it will not rise owing to the friction. Compressed air is admitted to the top of the sand box to overcome this and control the supply.

Different designers sand different wheels. In some six coupled engines the leading coupled wheels are sanded, in others the driving wheels only, the object being in this latter case to save the coupling rods from the great strain which must inevitably be thrown upon them when the sand gives the necessary grip between the wheels and rails.

As little sand as possible should be used, as sanded rails offer more resistance to the passage of the wheels of the train than clean ones do; and, further, sand should never be applied to the rails when the engine is slipping and the regulator open, as the sudden shock due to the stoppage of the wheels when the friction between the wheels and rails is increased is liable to cause a rupture of the working mechanism of the engine, bent coupling rods, broken crank pins, and even broken crank axles having been caused by this bad practice. The regulator should be closed and the slipping stopped before sand is applied, and then the regulator opened gradually, so that the power will be steadily developed to avoid jerks and snatches.

The buffers with which all engines on the standard gauge railways of this country are provided next claim our attention. They are attached to the buffer beam with their centres about 3-ft. 5-in. above the level of the rails and 5-ft. 8-in. apart, centre to centre, to meet those of the carriages and wagons forming the train. At F, a section through a common form of buffer is given. It consists of a hollow plunger fitting easily in a casing which has a bottom plate rivetted to it; this has a hole through which a centre pin passes. Within the plunger is a block of hard wood and a coiled steel spring; the centre pin passes through a countersunk hole in the head, and after the whole has received an initial compression it is secured by a cotter behind the back plate. This form of buffer requires a hole in the buffer beam to permit the centre pin to travel when the plunger is driven home.

A type of buffer used on the Continent is illustrated at G. In this the casing is similar to that last described, but the back plate is of cast iron formed to receive the nut on the centre bolt and allow of its travel when the buffer is compressed; the spring in this case is made up of a number of separate dished discs placed upon the centre pin with their curved faces arranged to meet alternately.

There are innumerable other designs of buffers, but the principles underlying all of them are the same as those illustrated. Many have indiarubber cushions instead of steel springs, this material being very suitable for withstanding the severe and sudden shocks to which the buffers are subjected in service, and which often prove fatal to steel springs.

A screw coupling is drawn at H. The draw hook has a shank which passes through the buffer beam at the centre of the engine, and has steel springs as shown or indiarubber cylinders held by a nut and split pin. Through a hole in the hook a link of the shackle is passed, a swivel being attached to the two ends of the shackle securing them and the screw together. The screw is revolved by means of the hanging arm, and turns in a nut fixed to the other link of the shackle; this second link is hooked upon the next vehicle, and as the screw is turned the necessary tension is secured, whilst the weight hanging down prevents the screw from slacking back in running.

On narrow gauge stock the side buffers are usually dispensed with, and the draw hook is made in the form of a combination of buffer and hook, the only point of contact being, therefore, on the centre line of the train. This is no doubt the most suitable place for this purpose, as the power required to compress the inside buffers of a long train when taking a curve is very great, and entails considerable work upon the engine.

In America the central combined method of attachment and buffing is universal both for goods and passenger service, the couplers of adjacent vehicles coupling on impact, and being uncoupled by means of a lever at the side. There is thus no necessity for anybody to go between for coupling or uncoupling. The extra flexibility obtained by the use of this method of attaching the several vehicles together, added to the flexible wheel base of all the stock, makes the American train, although heavier in build, comparatively easy to haul.

Having dealt now with practically all the working parts of the mechanism of the engine, reference must be made before concluding the section on the running gear, etc., to that necessary item, lubrication. The lubricating medium—oil,

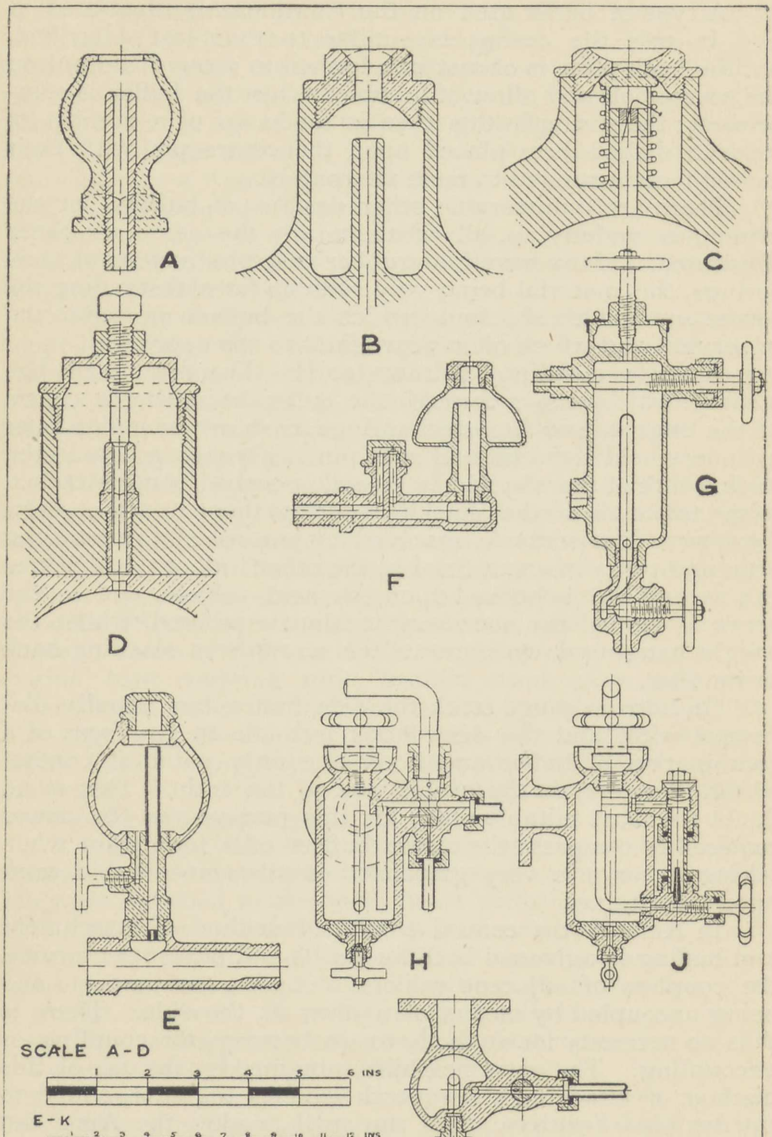


FIG. 32.—LUBRICATORS.

grease or tallow—has to be delivered to the exact part intended by means of one or other of various forms of lubricator. For oil the simplest is the oil cup, shown at A, Fig. 32 It is of cast iron or brass, and has a tube inside it reaching nearly to the top, and leading down to the bearing requiring the oil; the top of the cup is slightly reduced in size by having a lip cast round it to prevent the oil from splashing out when the engine is running. A wick trimming is placed in the tube, of such a fit that the oil may pass in the desired quantity to the bearing.

The trimmings are either of the "plug" or "tail" kind, according to the position of the part lubricated. Plug trimmings are fitted to oil cups, which are subject to violent movement, such as those on the big and small ends of connecting rods, eccentric straps, etc., and are made by taking a loop of copper wire and wrapping strands of worsted round it, then pushing the whole into the oil hole, leaving the top of the worsted about $\frac{1}{4}$ inch below the top of the pipe, and the bottom about 1 inch from the bearing. A loop formed of the copper wire prevents the trimming from being worked down the pipe. As the oil is thrown about by the movement of the part to which it is fixed some of the oil lodges in the recess above the plug, and slowly percolates through it to the bearing. When the part to be lubricated has no movement apart from that of the whole engine, as slide bars, axle boxes, etc., "tail trimmings" are used. They differ from the other form by having the ends of the worsted hanging over into the oil reservoir to lift or "syphon" the oil over to it by capillary attraction.

Plugs are more economical as they only supply oil when the engine is running and needed; therefore they are now used wherever possible, and often in places where "tails" were at one time employed.

On connecting and coupling rods the oil cup is usually forged on and machined up to the required shape. At B an oil well for a connecting rod big end is shown. The well is bored out and the internal pipe left standing up in the centre with a hole drilled down to the bearing. The top of the lubricator is closed by a screwed cap having a hole in the top for the admission of air. To prevent the oil from being thrown out as the rod revolves, it is usual to close this hole with a plug of cork or cane, which being porous admits sufficient air to allow the oil to pass out. A modification of this oil cup for a coupling rod end is represented at C, forged solid as before, but instead of the wick trimming and porous plug, a bent pin hangs over the oil pipe, with one end inside and the other out. As the rod end moves the oil splashes on to the pin and works over and down the pipe. The top is fitted with a spring button, held upright by having a hollow stem fitting over the outside of the oil pipe, a slot in it allowing the pin freedom to move; a spring holds it up to the top of the covering plug. To charge with oil the button can be pushed down with the point of the feeder, thus allowing the oil to run in. A further modification of this arrangement has the spring button and wick trimming instead of the bent pin. All of these forms may be used for either coupling or connecting rods.

An American big end oil cup is shown at D. No wick is used, but a long lift valve fits in the oil way, having a bevel seating at the top which prevents the passage of oil when the engine is standing; when the rod revolves the valve is lifted and oil reaches the bearing, the amount of lift being regulated by the screw at the top.

Oil grooves cut in the faces of the bearings form channels by which the oil is spread over the whole area of the journal, etc. The slot links, etc., have simply a hole with an enlargement at the top, no trimmings being required, as the movement is so slight that the necessary lubricant can be retained on the bearing surfaces. The internal moving parts exposed to steam pressure, such as the valves and pistons, have also to be lubricated, but require different appliances. E shows a simple oil cup for supplying oil to the air brake pump cylinder. It is fixed on the steam pipe, and is in the form of a globe having an inlet at the top, closed when the chamber is filled by a screwed plug, and an outlet pipe leading from the surface of the oil down to the steam pipe to which it is connected, the lower end of the hole being reduced in size to about $\frac{1}{32}$-inch diameter. When steam is admitted to the pipe, a small quantity passes through the little hole up the oil pipe and into the oil globe; here it is condensed, forming water which, being heavier than the oil, gravitates to the bottom and raises the level of the surface of the oil above the down pipe. Oil is thus slowly displaced and passes down to mingle with the steam below, lubricating all the wearing surfaces with which it comes in contact. When all the oil has been replaced by condensed water the latter must be run off by slackening the plug at the bottom and more oil introduced. From its action this is called a "displacement" lubricator.

The main engine cylinders are also sometimes fitted with a somewhat similar oiler; but more commonly two kinds are used here—one the "Furness," supplying oil when steam is shut off, and the other the "Roscoe," when steam is on. A section of the former is shown at F. It is fixed so that the supply pipe is in free communication with one end of the cylinder, a lubricator being fitted to each cylinder. When no steam is admitted to the cylinders there is a partial vacuum formed every time the piston travels from the covers, and on this fact the action of this lubricator depends. The globe is filled with oil and a small hole drilled in the cover plug allows air to enter, whilst a syphon of worsted lifts the oil over into a lower chamber leading to a valve box, which has two vertical holes in it, one fitted with a lift valve. When a partial vacuum is formed by the receding piston this valve is raised by the oil acted upon by atmospheric pressure, and a small quantity enters the cylinder. On the piston returning of course the valve is closed; oil thus enters only on the one stroke.

When steam is on, the pressure is naturally far in excess of that of the atmosphere, and the above described lubricator is inoperative; another system of lubrication must therefore be introduced, and the "Roscoe," which is a displacement lubricator, comes to the rescue. It is connected to the main steam pipe, and the slide valves as well as the pistons are oiled by it. At G will be seen one of this type, which is fixed to the side of the smokebox. The oil chamber has its outlet at or near the top, closed by a screw regulating plug, which regulates the required amount to be used, and also provides for a means of filling when empty if steam should be in the steam pipe. In this arrangement an internal pipe stands vertically in the centre of the oil space with its top closed, and having a hole at the bottom. The steam acting upon the surface of the oil presses it down, whilst the air imprisoned in this pipe is compressed somewhat; then when steam is shut off this pressure is made use of to feed a further quantity of oil. The filling hole at top and outlet at the bottom are plainly shown on the sketch.

Although the two lubricators last described are still in common use, locomotives of recent build are fitted with sight-feed lubricators fixed in the cab, where they are easily accessible to the driver. In these the oil is placed in a chamber to which steam is conducted and allowed to condense, the oil being thereby displaced, this then flows down a pipe where a small jet of steam meets it and carries it to the steam chest or cylinders. The displaced oil passing, drop by drop, up through a "sight tube" filled with the condensed water is visible, hence the name "sight feed" lubricator. The advantages of this method of oiling are, greater safety for the men, as there is no need to go round the platform when the engine is running to see if the lubricators are at work, as is sometimes necessary with the other kinds; economy of oil, as only the required quantity need be supplied; and further, the oil driven in in this way, finely mixed with the steam, is spread over the whole surface, and therefore lubricates better than when allowed to simply drip into the valve chests or cylinders.

One of the best known and most used is that made by the Vacuum Oil Co. H is a vertical section, showing on the left the oil and condensing chambers, and on the right the shut-off cock. This cock must be shut before the oil plug can be removed, therefore when open the handle is arranged to stand directly above the plug to prevent the latter being taken out when steam is on, for then injury might be caused to the operator by reason of the hot oil being blown out. Steam enters at the pipe on the right, passing through the cock, and down the condensing tube to the bottom of the oil, raising the surface of this above the central pipe, which is open at the top, and leads to the regulating valve at the bottom. In the shut-off plug a small port at an angle leads a jet of steam into the outlet pipe, which meets the drop of oil as it is passed up through the sight chamber to the surface of the water, and carries it away with it. J is another vertical section taken at right angles to H, and shows the sight chamber and regulating gear on the right. The former consists of a glass tube with a gland nut at each end to form a joint, and the latter has a screwed spindle which adjusts the supply to a small vertical nipple through which the oil passes in the form of globules. K is a sectional plan showing the relative positions of these various parts, the flange being provided as a convenient means of attachment to the cab side or bracket as required. The condensed water is drawn off as required from the outlet plug at the bottom.

SECTION IV.—THE TENDER, BRAKES, ETC.

ENGINES intended for suburban traffic and short runs are provided with tanks for water and bunkers for the coal upon their own frames, these tanks and bunkers being sufficiently large to carry water and coal for consumption between points where they can be replenished.

Sometimes the water tanks are placed on the footplate on each side of the boiler, and connected together by a large pipe passing under the latter, with the coal bunker also upon the footplate behind the boiler, the cab being between them. Where more water is required than can be conveniently got into two side tanks, a third is made below the coal bunker, but in all cases the tanks are in free communication with each other so that the same level is maintained in each as water is drawn off for use, and the equilibrium of the engine preserved. To prevent the water from washing from one end to the other, as it would when the brakes are applied or released when the engine is running, wash plates are fitted, reaching from side to side, to break and steady the bulk of water.

In smaller engines, and sometimes also in large ones, the tanks are made semi-circular in shape to fit on the top of the boiler, these are called "saddle" tanks; they make a compact and neat engine, but give a top-heavy appearance if too large.

Tank engines have the advantage of being able to run equally well in either direction, and do not therefore require turning after running into a terminal station, and for service where neither the speed is too high nor the runs too long, they are to be preferred. The tanks are made capable of carrying up to 2,000 gallons of water, and the bunker 3 tons of coal. When the quantity of water and fuel required exceeds these amounts it is usual to use an engine which has an independent tender attached.

Tenders are constructed to carry up to some 5,000 gallons of water and 6 or 7 tons of coal, but about 2,500 to 3,000 gallons is a more common figure. Tender engines should only be run at great speed in one direction, viz., engine first, the necessity arises therefore of turning at the end of each trip.

Fig. 33 shows a typical British tender capable of carrying about 2,500 gallons of water and 5 tons of coal, this being quite sufficient for all ordinary needs. It is carried upon six wheels, spaced an equal distance apart, the bearing upon the axles being outside the wheels as being more accessible than

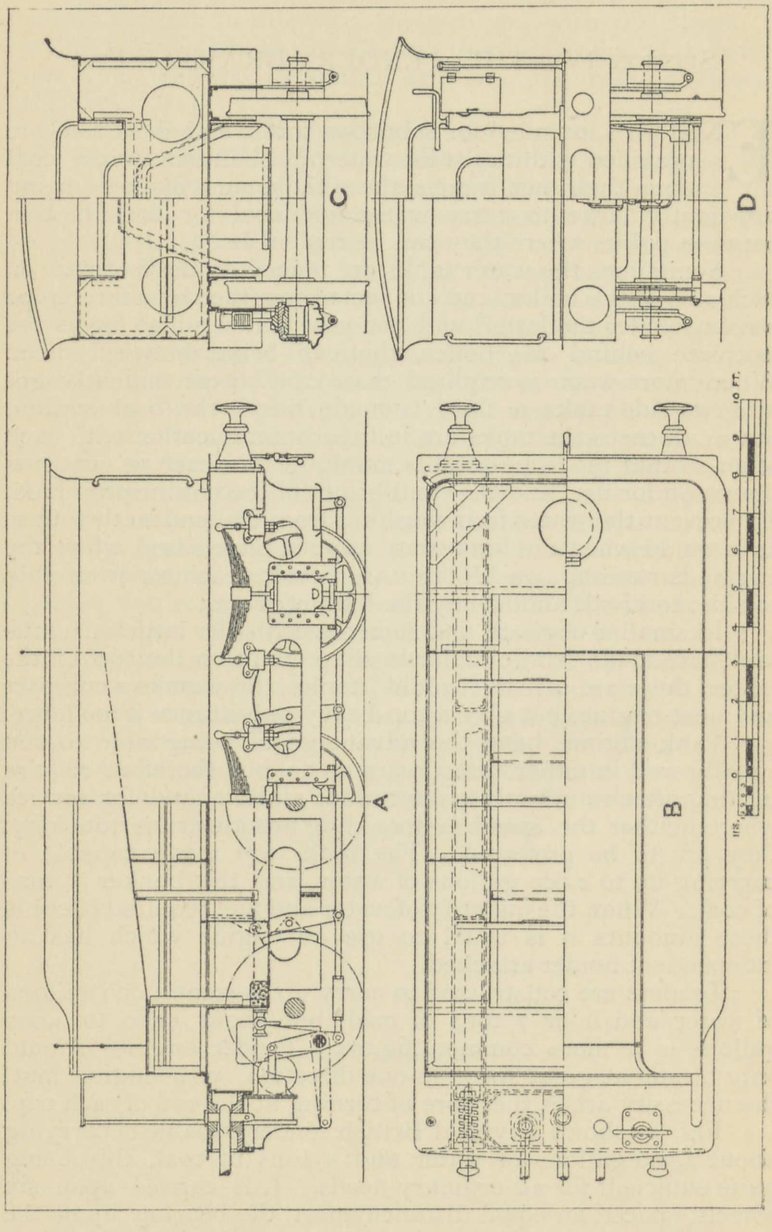


FIG. 33.—SIX-WHEELED TENDER.

they would be if between them and below the tanks. The frames are double, the outer ones carrying the axle box guides being the deepest, both frames run the entire length of the tender between buffer beams; stays between them strengthen the structure, as well as form convenient places for attachment of brake-hanger brackets, etc.

The springs are above the axle boxes, and are fitted at each end with rubber blocks or washers in cylindrical brackets cold rivetted to the outer frames, these rubbers greatly lengthen the life of the springs as they relieve them from the sudden shocks as the wheels pass crossings or points. As the wheel base is comparitively short no side play beyond a slack working fit of the axle boxes in the guides is allowed; the axle boxes are usually of cast iron with brasses fitted to take the bearings.

The method of coupling the tender to the engine varies. A common one has two buffers placed at the front end and bearing against the back plate of the engine when it is coupled, to steady both engine and tender in running. A large draw bar in the centre with an eye at each end for a pin, and two smaller bars for emergency, one at either side, form the attachment, an initial compression being given to the buffers in coupling up to the engine. More recent examples, however, depend solely on one strong central connection whereby it is contended the wear of the wheel flanges is diminished, and easier transit of curves secured.

The buffers at the rear end of the tender are similar to those upon the front of the engine, as are the draw hooks and couplings, which have been already described. Footsteps are provided at each end so that the men may mount to the cab at one end and to the trailing buffer beam footplate at the other to attend to the tail lamps or couplings as may be necessary.

The water tank is built up of $\frac{1}{4}$-in. plates well stiffened with angle irons rivetted to them, both at the corners for the attachment of the other plates and also at various parts of the structure. The sides are stayed together by plates which extend completely across and form washplates, large holes being cut through them of sufficient diameter to allow the water to circulate freely, and to permit of the men passing when making and repairing the tanks. Longitudinal washplates are also fitted in some cases, these are especially necessary when the tender is running upon lines which abound in sharp curves, as they help to keep the water from accumulating at the outer side of the curve by centrifugal force and from throwing an undue weight upon the springs and bearings at that side.

The inlet hole and strainer is fitted at the top towards the trailing end, the latter is for the purpose of preventing the entrance of pieces of wood or other foreign matters into the tank. The feed water is again passed through another strainer before it leaves for the injector or pump on the engine. The holes in this last strainer, which is fitted just over the outlet to the cock, are smaller than the smallest part of the injector, so that anything which passes them will not be likely to cause a failure by blocking up its cones or passages.

The coal space above is made with a sloping bottom, so that there may be a tendency for the coal to shake forward towards the door, through which the fireman takes it for the fire. A division plate extends up behind the coal preventing it from getting to the water inlet hole, and also partitioning off a convenient place in which to keep the fireirons and other large tools. The coping round the whole tender gives a finish and hides all the loose tools, further it enables more coal to be carried, and is a safeguard to the men if passing over the top. Where the coal space is insufficient it is usual to carry bars in the form of a fence above the coping to increase it, this, however, is hardly necessary when the tender is built as in our drawing. Tool cupboards are formed on each side of the tender, a portion of the water space being cut off for this purpose at the front.

A hand brake is fitted, and blocks bear upon each wheel, and for goods engines this is often the only brake provided, but with passenger engines the continuous brake adopted is also either coupled direct to the mechanism, or the steam brake of the engine applies the tender brake simultaneously with that of the train. In the drawing it is shown coupled to the air brake cylinder, but the principle adopted is similar for vacuum or steam brakes.

A, shows an elevation of the tender, the front half being in section showing the water and coal spaces, as well as the method of staying the front part of the frame, etc. The back half gives the outward appearance of the whole tender. B is the plan also in half elevation and half section. C is a cross section through the centre line of the middle axle, the left hand half looking towards the back of the tender, and the right hand half looking towards the front, both the washplates and stays will be plainly seen as well as the rests for the coal space, which are formed of stout angle irons carried down to the well of the water tank between the wheels, this well helps to keep the centre of gravity of the tank down, and, especially when the tanks are partly empty, prevents the swaying of the tender which might occur if all the water were carried higher up. D gives elevations of the two ends of the tender, the left hand being the back and the right hand the front view.

When the amount of water required for the trip is likely to exceed the quantity carried, it is customary now to fit the tender with a Ramsbottom scoop, which can be let down into water troughs laid between the rails to replenish the quantity carried without stopping. In cases where this arrangment is not adopted larger tenders, carrying 4,000 gallons and over are made, usually running upon two four-wheeled bogies, which are, however, unlike those of the engine as they are not fitted for side play but only move about the centre pin with circular motion. Bogie tenders are being largely built on the Continental railways, as the weight of trains and length of runs increase, and in America they have always been the standard type whether fitted with picking up scoops or not.

Various details of tenders are shown in Fig. 34. A represents an arrangement of axle box guides and horns of different design to those shown on the tender drawing, Fig. 33, which are similar to those described for the leading end of engines at B, Fig. 26. The frames are cut out and carried down below the guides, the hornstays being fitted to them, so that the frames and not the hornblocks are held. The blocks are fitted and bolted or rivetted to the frames similarly to those of the engine.

An axle box is drawn at B, in front elevation and in longitudinal section. The box is of cast iron, and has a gunmetal bearing fitted inside, with a sliding block above and a keep below the journal. The front can be detached by taking out the three bolts holding it, and then by simply raising the box the bearings can be removed and replaced without taking the wheels from under the tender. In the sliding block above, a socket is made to receive the end of the pin projecting down from the spring buckle, and outside this an oil box is formed with a lid to enable oil to be supplied to the bearing as well as the slide. In the keep below, a pad of sponge or horsehair is placed, and oil that is put into the oil cup at the front is retained in this and fed up to the under side of the bearing, thus continually lubricating it without any oil syphoning out. The keep can be detached by taking the nuts off the four bolts projecting down through it from the box.

A spring is shown at C, made in one of the various ways described when dealing with engine springs. The plates are held from slipping out of the buckle by a depression made in the top of each plate, forcing out a projection on the under side, which fits into the depression in the next lower plate,

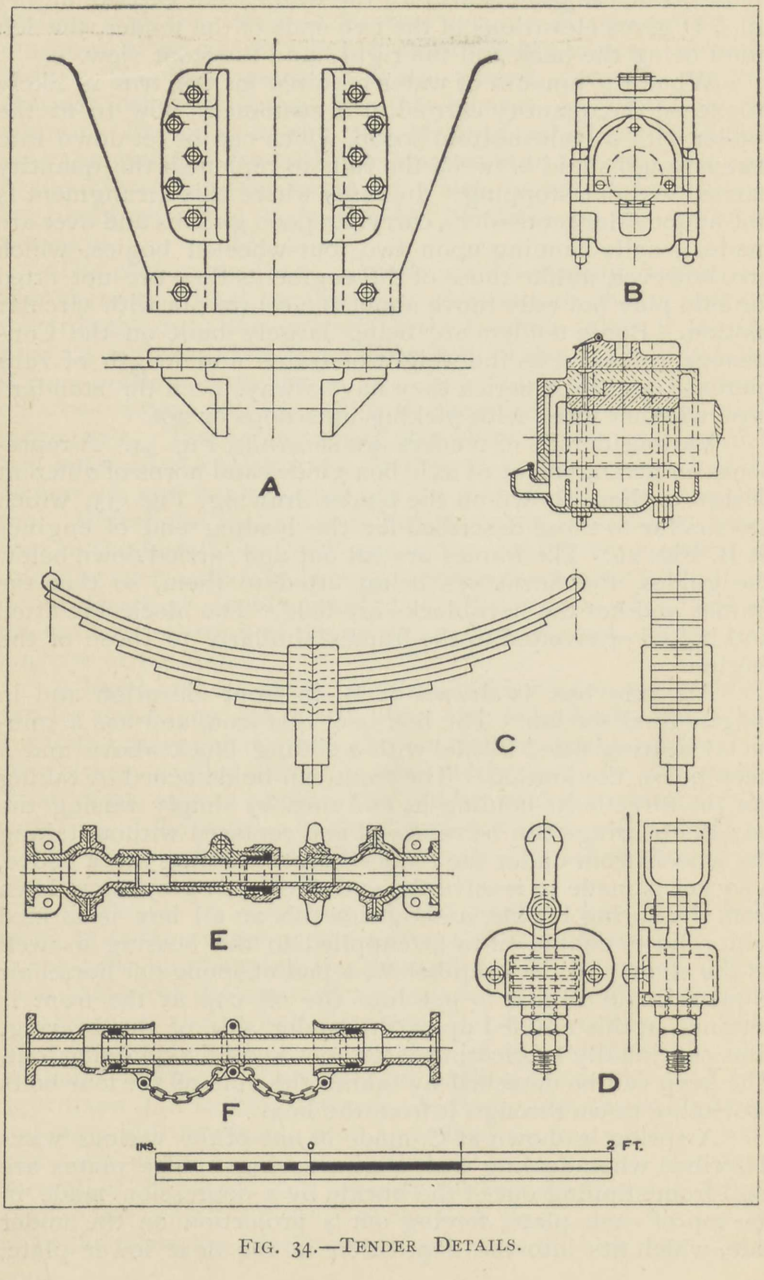


FIG. 34.—TENDER DETAILS.

the bottom one entering a similar recess in the buckle; into the top one the buckle is driven. Nibs and slots prevent side slip as in the engine springs. The ends of the top plates are turned over, and form a solid block upon which the hangers take a bearing. In some cases instead of this solid end a pin hole is made, and a pin is passed through it and the hanger.

An arrangement of hanger and bracket is drawn at D. It is fitted with the rubbers, as before mentioned, to relieve the spring plates of hard shocks. The steel casting at the top holds the end of the spring, and is connected to the suspension bolt by means of a pin, which also permits the spring to have freedom to elongate as the load is applied. The two nuts below are for giving the required tension to the spring, the lower one checking the upper. The rubbers are either, as shown, in several layers separated by metal discs, or in one block, as may be preferred. A bracket fixed to the frame has a cup-shaped recess below in which the rubbers are located. This forms a protection for the rubber from the action of the atmosphere, which would tend to harden it and spoil its elasticity, and also from oil which would probably be more or less destructive to it. Springs hung direct from the frame without the interposition of the rubber pads are, perhaps, more common, but the arrangement shown is growing in favour.

The pipes conveying the feed water from the tender to the engine are necessarily flexible to allow of movement when running; they are often made of indiarubber, canvas or other suitable material, but as it is customary to pass steam through them from the boiler when standing, or when it is desired to heat the feed water, this hose is not altogether satisfactory, therefore flexible metallic connections have been designed.

One example is shown at E. It has a ball and socket joint at each end, and a sliding joint at the centre, the former permitting of up and down and side motion as the engine is running and traversing curves, and the latter allowing for any difference in length caused by the tension and compression of the draw gear between engine and tender. A union nut at one end provides for it being separated when it is necessary to uncouple the engine from the tender. A gland and packing prevents the loss of water from the slide, and an eye is provided to which a chain can be attached for safety.

Another arrangement used on Continental engines is drawn at F. In this two bell mouthed castings are fixed, one to the engine and one to the tender opposite each other; a pipe reaches across and couples these together. The water flows through this pipe, and is prevented from escaping at the

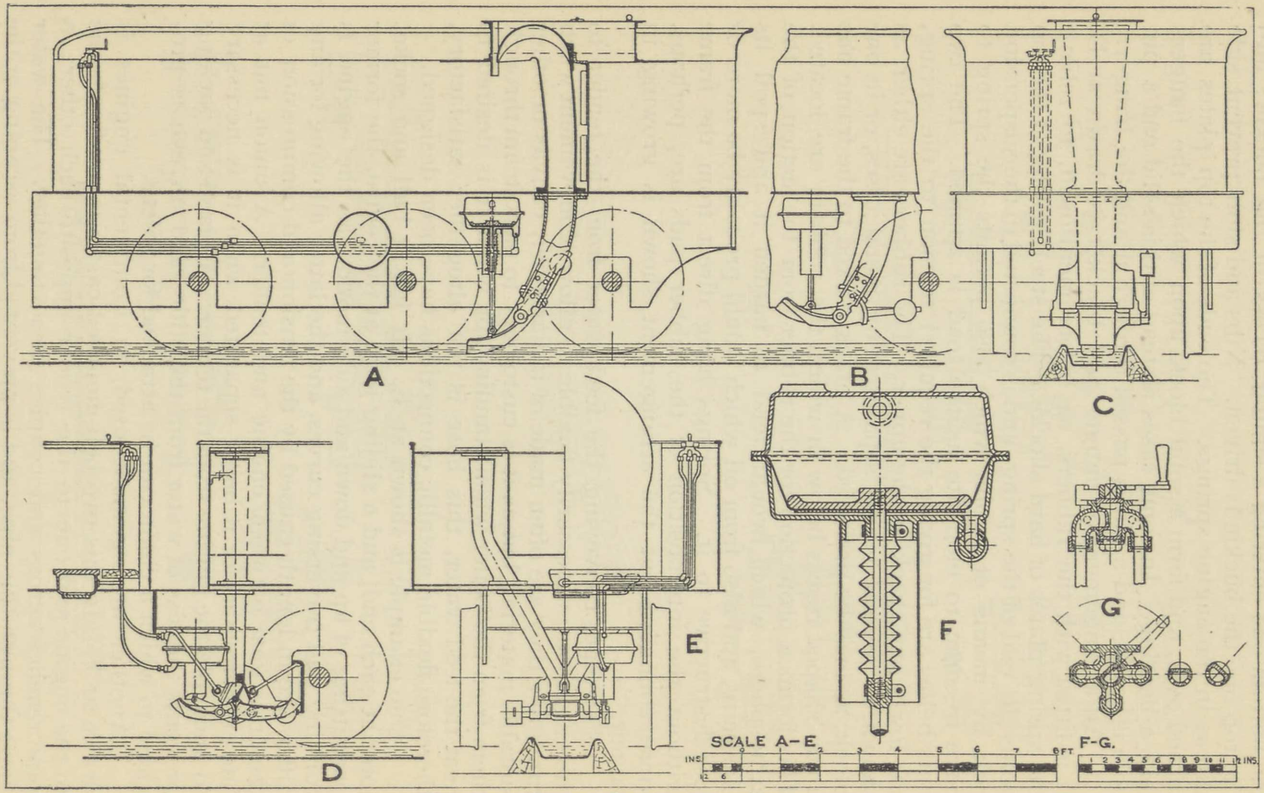


FIG. 35.—WATER PICK-UP AND DETAILS.

ends by means of idiarubber rings encircling it in suitable grooves and fitting into the bell mouths. To prevent the pipe from being drawn entirely from either of the sockets, as might be the case if one end was a tighter fit than the other, a clip with a double hook is fixed to the centre of the pipe, and has a chain attached to the sockets. Perfect freedom in movement is secured by this arrangement.

A long length of iron pipe, bent into a circle of large radius, has also been used for the same purpose, as well as many other devices.

Lamp irons or brackets are fitted to the backs of the tenders as well as to the front of the engine for the attachment of the lamps by night or disc boards by day, for guiding the signalmen and staff as to the destination of the train.

Fig. 35 gives some details of the water picking-up arrangements now so often fitted to tenders with limited water capacity and to which we have already made reference. A hinged scoop is provided, and fitted so that it can be lowered into, and raised from, a long, narrow trough, placed midway between the rails and filled with water. When passing over this at high speed the tender tank is filled by lowering the scoop into it, and when a sufficient quantity of water has been taken, the scoop may be lifted up clear of the trough and of any other obstructions.

At A in the Fig. a longitudinal section of a tender shows the scoop lowered into a trough with a free passage for the water, up through the internal pipe, into the tender tank. Three castings are here employed, viz., the scoop of gun-metal, the lower portion of the water-pipe with hinge, and the internal pipe, both of iron. A hinged lid above the box, covering the receiving pipe, opens freely when the tank is full and allows any superabundance of water to escape. Unless such a provision was made, there would be liability of damage to the tank, as the water enters at a high velocity and consequently considerable pressure.

All the water that so escapes, in the example shown, runs over the top of the tender and thence to the ground and is lost. Some tenders are therefore fitted with large branch pipes leading down from each side of the top of the internal pipe and meeting just below it, passing out of the tank bottom, immediately above the trough, so that instead of the water raising the lid, it escapes down the pipes back into the trough.

The shape of the internal pipe varies. In the form shown the top curves over towards the front of the tender, or direction in which it travels; in others, as at D, it simply rises vertically, or it may have a direction at the top, towards the back of the tender. This latter would seem to be the more correct shape, as there would be less friction for the water than in the first case, where the water has to have a greater velocity given to it than that of the tender as it approaches the top of the internal pipe. In all cases the area of the water channel increases towards the top of the pipe.

The scoop is provided with a shoe of thin steel at its base where it enters the water to form a cutting edge. This can be easily renewed when worn out and, if necessary, adjusted to the right level as the tyres get worn and springs vary.

At B a portion of the tender is drawn, showing the scoop in the position occupied when out of use.

C shows an end view of the tender with the scoop let into the trough; this latter is shown in section.

The raising and letting down of the scoop is performed by the aid of hand levers in the cab or on the tender front, within easy reach of the enginemen, but as the pulling of the scoop out of the water trough, especially when travelling fast, is by no means an easy task, means have been adopted by which steam, or the vacuum, or compressed air used for the brakes can be employed for the purpose. On Fig. 35 the gear patented by Mr. J. A. F. Aspinall, to whom we are indebted for most of the following particulars, is represented. To work on the vacuum system, a chamber is fixed below the tender, and has a pipe connecting it to the actuating cock fixed handily for the operator in the cab. Two other unions on this cock connect to the lower and upper sides of a vacuum cylinder, divided by a flexible diaphragm. The admitting of atmospheric air to one side of this diaphragm, and the putting of the other at the same time into communication with the vacuum chamber, causes the diaphragm to be raised or lowered at will; a rod fixed to the latter is moved with it and carries the scoop. The lifting of the scoop is by this method expeditiously performed by simply turning the handle of the actuating cock, whilst a balance weight assists in this and keeps the scoop up when out of use.

At D a side view of a tank engine is given with this water pick-up gear. As these engines have to run in either direction without being turned, it is convenient that water should also be taken when moving either way. This is accomplished by having two scoops, one facing in each direction, both being attached to a common discharging pipe and connected together by means of suitable levers, so that one or both may be lowered into the trough at will. In the drawing the arrangement is for both scoops to be operated at the same time; one of them, however—that facing the direction in which the engine is running—will only take water, the other simply follows in the wake of the first. A flap or hinged valve at the junction of the scoops with the casting closes the way by which the water could otherwise escape. When the engine runs in the reverse direction of course the other scoop will take water, and the flap will fall over to the opposite side.

. E is an end view of the same engine, showing the branch pipes up which the water passes and enters each side tank simultaneously and in equal quantities. In both these views the scoops are shown raised up in the carrying position; a balance weight is fitted, as before, to hold the scoops safely in this place.

An enlarged section of the cylinder and diaphragm is shown at F. The top and bottom of it are each made of a dished form, provided with flanges which face each other where they are bolted together; the diaphragm is of india-rubber, or other suitable material, stiffened at the centre by the piston head above and plate below. Bosses, for the connection of the pipes to top and bottom of the cylinder, are provided. The piston rod which reaches down to the scoop is not fitted with a stuffing box but a large flexible hose securely fastened at top and bottom covers it; this prevents the access of air to the bottom end when a vacuum is formed, but allows full freedom for the rod to rise and fall with the piston head.

At G the actuating cock is drawn to the same large scale as the cylinder. The cock casting has three unions to it, for the attachment of three pipes, one from the vacuum chamber and one from top and bottom of the cylinder respectively. The plug in the cock is chambered out, so that by giving it a partial revolution it is possible to put either end of the cylinder in communication with the vacuum chamber, the opposite end of the cylinder at the same time being opened to the atmosphere; when turned to a position midway between the extremes, the holes are all closed. The three positions of the plug are shown below and at the right of the figure.

The water troughs are usually made of steel plate bent to the required shape in lengths and rivetted together; they are about 18-ins. wide by 6-ins. deep placed upon the sleepers and supported at the sides upon baulks of timber. The level of the top of the trough is about 3-ins. above that of the top of the rail, and the water line 2-ins. above the rail. The scoop, when down, dips into the water about 2-ins., being then at the rail level.

The total length of the trough may vary, according to the quantity of water it is required to take, but it is usually about 500 yards long, with ends which gradually taper out.

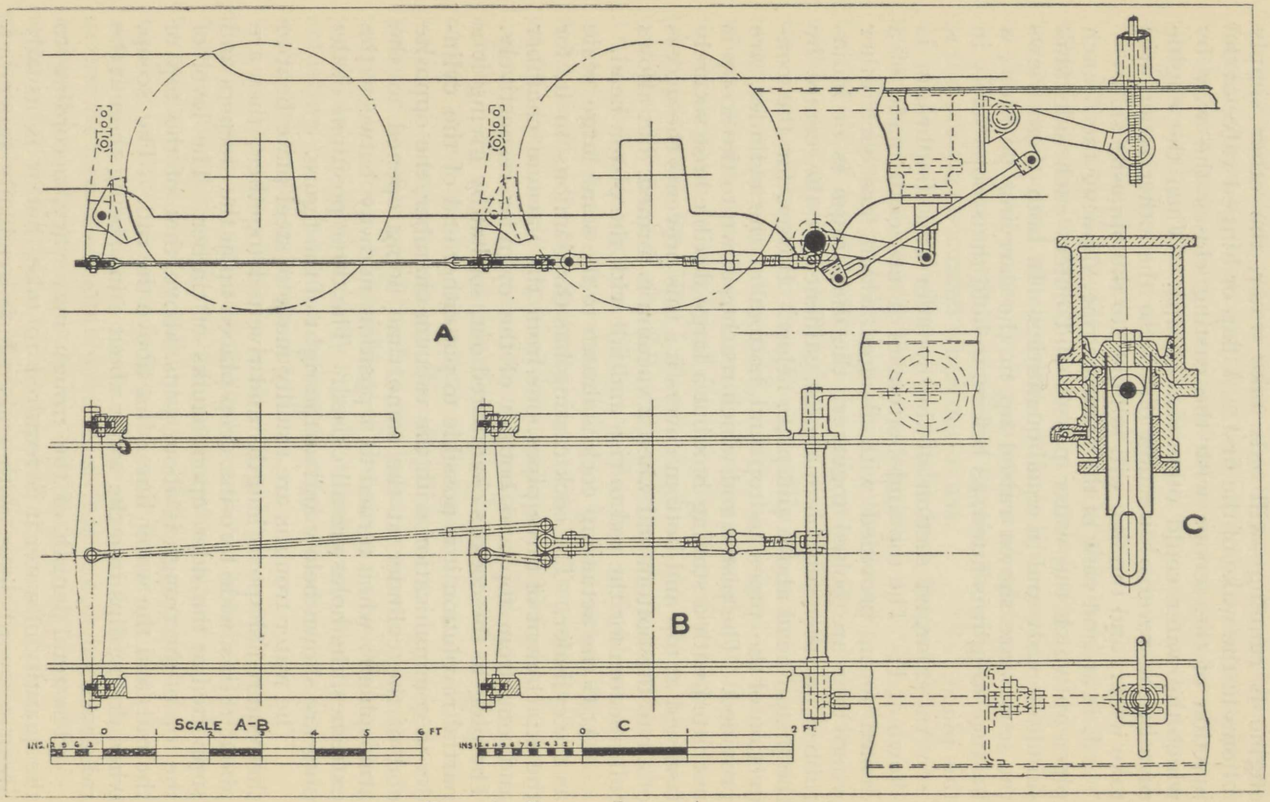


FIG. 36.—ENGINE BRAKE ARRANGEMENT.

The rails are kept parallel with the surface of the bottom of the trough, so that should the scoop not be lifted at all while travelling over the trough, it will be raised from the water as the shallow end of the trough is reached, and when raised completely out, the balance weight will lift it up to its running position.

It is necessary that the troughs should be occasionally cleaned out, as passing engines taking water will wash stones and ballast into them; further, they must be fitted with automatic gear for refilling as the water is taken out by the engines.

In order to retard the speed and assist in stopping, the wheels of both engine and tender are fitted with brake blocks which bear upon the periphery of the tyres. When pressure is applied to these the friction prevents the wheels from freely revolving and, if carried to excess, stops them completely. It is not always customary to brake the wheels of the engine, but when they are so treated the coupled wheels are chosen, and in the case of an engine having single drivers, the trailing carrying wheels in conjunction with the driving. On engines for heavy service it has become the custom to fit all the wheels of both engine and tender with brakes.

Fig. 36 shows an arrangement of brake work suitable for a 4-coupled engine having a trailing bogie. A stout shaft is carried across the engine in a suitable position and fitted with bearings in which it can revolve; arms are forged or fitted and keyed on this, one for the attachment of the pull rods (this in the figure is between the frames), another for the hand brake gear, usually upon the fireman's side, and a third for the connection of the cylinder operated by steam, air or vacuum, as the case may be.

In front of each wheel, hangers are suspended from the frames carrying brake blocks, these are connected to the ends of beams below, which reach across the engine; to these a pull is applied by the operating power, this, being taken at the centre, an equal pressure is transmitted to each wheel, so that it takes an equal share in the stopping of the engine. The pull rods are attached to the centres of the beams, but to allow of freedom in wearing they are each coupled at their other ends to a smaller beam, which has another pull rod attached at its centre; this is then coupled to the arm on the brake shaft. Between this shaft and the small beam an adjusting nut having a right and left handed screw thread at each end respectively is provided, so that as wear takes place the correct position of the arms of the shaft may be maintained. When the blocks are completely worn out new ones may be fitted and the nut slacked back to its original position.

At A and B the arrangement and positions of the various parts may be traced, being shown in elevation and plan. Owing to the fact of the firebox being directly above the shaft in this example, it is not possible to place the hand gear there, so an arrangement of bell cranks and levers is shown, by means of which it can be moved further back to a convenient position in the cab.

On some engines the shaft itself is carried well back, and the pull rods lengthened to suit; on others the brake blocks are made to bear upon the coupled wheels opposite each other —that is, the leading coupled wheels will have blocks upon their front, while those upon the next coupled wheels may be upon the back, or the hangers and blocks are in some cases both between the wheels, the blocks being pressed outwards away from each other. Neither of these methods are to be preferred to that shown as they both tend to throw stresses upon the coupling rods when applied, the former by compression, the latter by tension. In many other designs blocks bear upon both sides of the wheels at the same time, but this is not always necessary, as one block well applied is sufficient.

Slotted holes are provided in the pull rods from both the power cylinder and the hand gear, so that when one of these is used to apply the brake the pin of the other lever simply travels in the slot; all the wrought iron wearing surfaces are well case-hardened to reduce the wear as much as possible, and split pins or cotters are used to prevent the pins, etc., from slacking back.

Brake blocks are usually of cast iron and being of softer metal than the steel of the tyres, they therefore take most of the wear, being easier to replace when worn out. The proper length of block is between 1-ft. and 1-ft. 6-in.; if made less, it is liable to get very hot when applied hard. No advantage is secured by exceeding this length, as blocks which are too long and are applied at the centre have a tendency to bend, only bearing hard opposite the point where the pin is situated.

To use softer cast iron, which alone would not have sufficient cohesion to stand the rough wear for long, blocks are now extensively made of iron cast upon inserts formed of several layers of expanded steel closely packed and interlaced with each other. These hold the particles of iron up to their work, and greatly increase the life of the blocks as well as the friction and consequent retarding power. They are known as the Sargent patent diamond brake blocks.

Compositions of various kinds are also being tried, forced into recesses cast in the middle of the blocks, but it is questionable if the extra cost of such refinements is guaranteed by the results.

Nearly all the brake blocks upon British engines are made to bear upon the tread of the tyre or that part which runs upon the rails. Thus two wearing influences both tend to wear out the tyre at the same place, and cause a hollow section, consequently necessitating frequent re-turnings, hollow tyres being not safe for any great speeds owing to the liability of the flanges fouling any of the points, etc., and thus causing derailments. It might be good policy, therefore, to copy American practice in this particular, and provide blocks made approximately to the shape of the tyres, but hollow at the tread, so that the blocks wear away the portion of the tyre that the rails do not touch, that is outside of the tread and the flange itself. The tendency is then to keep the tyre to its original shape, and obviate re-turning for a time.

The brake, when operated by hand, is a slow method of stopping a train, and when important that the stop should be made quickly, a more rapid power appliance must be provided. It is, therefore, now compulsory to fit all passenger trains with a continuous brake, but, unfortunately, owing to the method of working our goods trains with slack couplings, etc., it is impossible at present to apply a continuous brake to them, and the hand brake has survived on the freight service, although goods engines are now being rapidly equipped with steam, air or vacuum brakes.

An arrangement suitable for either of the mechanical systems is drawn, but a steam cylinder is shown at one end of the shaft. This is coupled to one lever, and operates it by means of steam which is admitted to one end of the cylinder to drive forward the piston and apply the brakes. Two cylinders made smaller than that shown, and one placed at each end of the shaft, can be provided if desired; or in those engines which have the shaft situated below the cab, the steam cylinder can be placed in the centre of the engine and coupled to an arm on the shaft there.

The cylinder is drawn to a larger scale at C to illustrate the internal arrangement. It is formed by a casting bored out to take the piston which moves in it; a casting below forms a cylinder head and stuffing box for the piston rod, which is in this case in the form of a large hollow pipe coupled to the piston above, inside this is an eyebolt fixed to the head for the attachment of the pull rod, coupled at its lower end to the lever upon the brake shaft. Two brass or cast iron rings upon the piston ensure a steam tight joint, and a small leak-

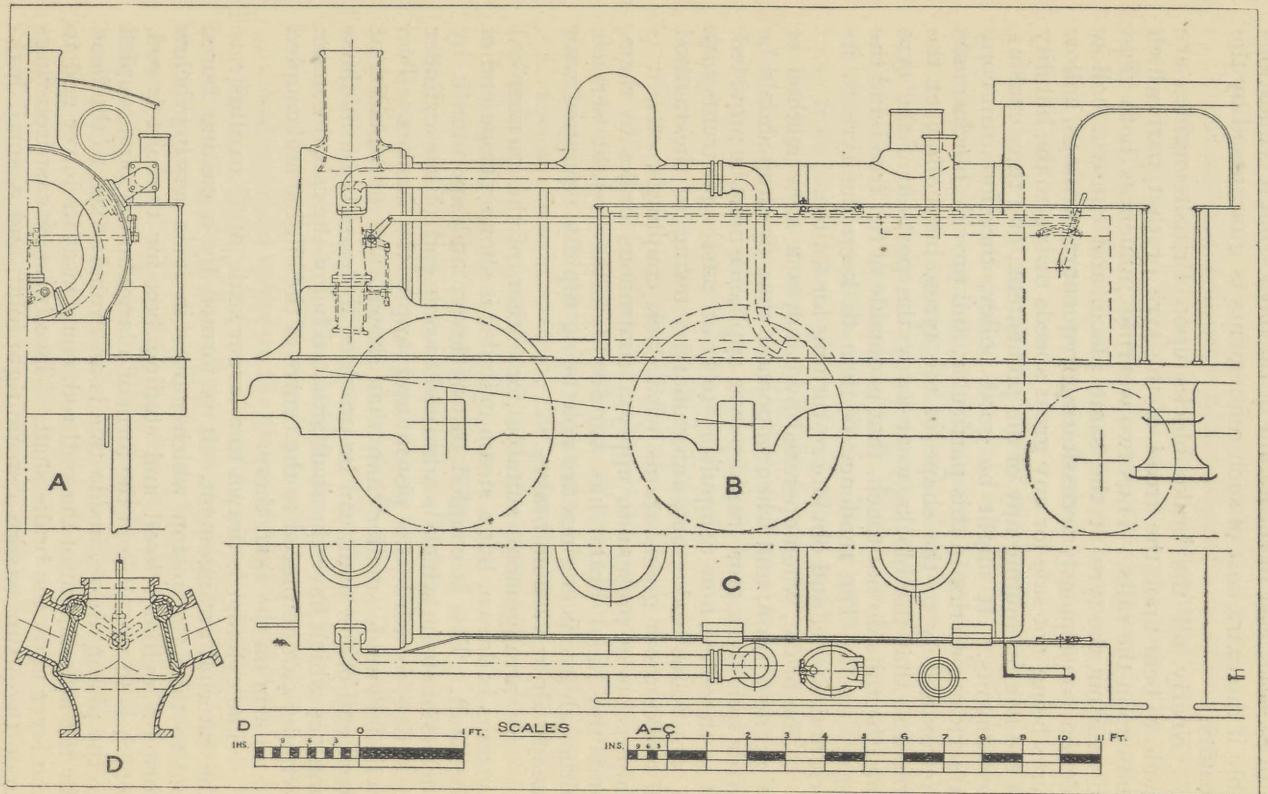


FIG. 37.—CONDENSING ARRANGEMENT FOR TANK ENGINE.

age groove is also provided at the bottom of the cylinder, so that any water that should collect in the cylinder above the piston may escape by it through the drain hole and escape valve. This latter is fitted with a ball valve which closes when steam is applied, but when the brake is released and steam allowed to pass up through the operating cock, the pressure is removed and the ball falls back, allowing the water to escape.

The operating cock on the firebox front has ports in it so that when the brake is to be applied steam enters the cylinder. For release the cock is given a partial turn, and the steam is shut off from the boiler, and that in the cylinder allowed to escape through the cock. It is thus impossible for the pressure to gradually accumulate in the cylinders and apply the brakes against the driver's wishes.

Under various conditions of service, locomotives of special types are employed, but in this book, so far, only ordinary classes have been dealt with. We may, however, briefly mention a few of the chief departures from the orthodox.

In tunnels and on underground lines the emission of steam from the chimney would be intolerable, therefore some means have to be adopted to obviate this. The engines on these services are usually of the tank variety, with the blast arrangements modified as under to suit the special requirements.

A pair of hinged flap valves are fitted in a chamber or valve box at the base of the blast pipe, between it and the exhaust opening from the cylinders, from this valve box two branch pipes lead on either side to the water tanks of the engine. The arrangement is such that when the flaps are moved outwards they close the outlet to the side pipes, and allow a free passage directly up the blast pipe and chimney when the engine is doing ordinary work in the open; when running in tunnels, etc., the flap valves are, by means of levers and rods from the cab, simultaneously moved inwards and brought together on their lower sides, meeting on the centre line and closing the exit up the blast pipe, but opening the passages for steam to pass to the two side branch pipes leading to the water tanks in which it is condensed.

Fig. 37 gives several views of an engine fitted with such an arrangement. At A a half front elevation with smokebox door removed, shows the blast pipe, valve box and side branch pipes leading up through the outside conducting pipes to the water tanks. B, which is a side elevation, shows all the pipes by which the condensation of the steam is performed. The large conducting pipe above the tank is fitted with an expansion joint at the elbow, which is fixed to the top of the tank to allow for the expansion of the pipe when it is heated by the exhaust steam. Inside the tank a pipe takes the steam down to the bottom of the water, where any not condensed escapes into the water and is finally disposed of. To allow for the escape of the air, etc., displaced by the entering steam, another pipe is fitted to the top of the tank, standing vertically just in front of the cab. Inside the tank, below this escape pipe, a box with large perforations in the bottom of it is fitted in the tank. This prevents the water being thrown out of the tank when the condenser is being employed. The escape pipe is placed at the side of the cab window so as not to obstruct the driver's view.

When most of the running is made with the ordinary blast pipe, and the condenser is only occasionally used, the water in the side tanks does not get too hot for the injector feed, but when running on services which require almost continual use of the condenser, as on underground lines, the water gets too hot and injectors would not take it. Pumps worked from the crosshead or other moving part of the engine are, therefore, fitted for maintaining the proper water level in the boiler. The water must, however, be frequently changed, or the steam will not be condensed, and a large valve is usually placed in the bottom of the tank, operated by means of levers in the cab, for emptying the water expeditiously ready for the tanks being refilled with cold water.

The lever in the cab for moving the flap valves in the blast chamber is provided with a binding screw so that the valves may be firmly held in the required position. When running and using the condensing apparatus, no effect from the blast being obtained on the fire it is necessary to keep the blower on in order that the steam pressure may be maintained. For fuel, smokeless Welsh steam coal, or a similar product must be used on underground service. Recently oil fuel has been burned with considerable success, and as it possesses many advantages in firing, it should be largely adopted.

At D a section of the valve chamber is drawn to a larger scale to show the arrangement of the flap valves, etc. The body, which is of gun-metal, has open sides, to which covers with flat faces are fitted; bosses upon these covers have holes through them for the rods upon which the flap valves inside the chamber and levers outside are fitted. The flap valves are also of gun-metal, and have grooves machined at each side, about $\frac{1}{2}$ an inch wide by $\frac{3}{4}$ of an inch deep, into which strips are fitted. These are forced outwards by flat springs to form a steam tight joint against the covers. The faces of the valves are also seated fairly upon the faces of the holes to the branch pipes on each side, but when the blast orifice is closed by the shutting together of the flaps, the bevelled edges of these latter meet and form a V by which the steam is deflected to either side branch pipe. In the drawing the valves are represented as covering the side outlets, and providing for a free opening up the blast pipe. The levers outside are shown in dotted lines; they are each provided with a long slotted pin hole and a forked end to the pull rod has a pin through it and both the levers, pulling this rod upwards brings the levers together, and consequently the valves. A spindle above reaches across from a guide on the smokebox wrapper to another upon the blast pipe, and has suitable levers upon it for attachment of the outside rod from the cab, and the inside pull rod to the valve levers. Balance weights are sometimes fitted to help in moving the valves, but are not always considered necessary.

When very severe gradients and sharp curves make it difficult to design a suitable engine owing to the inconvenient length that would be necessary to carry weight enough for adhesion, double engines have been employed. The best known of these, perhaps, is the "Fairlie" type, which has two groups of driving wheels arranged in swivelling frames or bogies, each group being coupled and provided with separate cylinders and crank axles. By these means very powerful engines can be made with the weight well distributed over a long and flexible wheel base. The boiler has one or two fireboxes at the centre and two barrels with tubes leading each way—to the front and the back. Two chimneys and domes are also provided. The firing is done through a side door or doors, and the fireman rides upon that side of the engine, the driver having all his levers, gear, etc., upon the opposite side.

For heavy mountain service many modifications of the ordinary adhesion locomotive are to be met with. One system provides an additional small pair of cylinders and drivers equipped with mechanism for raising and lowering, so that when ordinary roads are being negotiated the engine works as usual, but when steep banks, or exceptionally heavy loads are to be worked, the auxiliary wheels are pressed down to the rails and steam admitted to the extra cylinders, giving additional power to assist in overcoming the trouble. The raising and lowering is performed either by steam, air, or vacuum, and varying weights can be put upon the wheels. As one of the chief constituents of the power of a locomotive to haul a load is its boiler, and such arrangements as this make no extra provision there, these curiosities are not to be commended.

On steeper grades still, where adhesion alone would not be sufficient however applied, "rack" engines are used. The track for this type of locomotive is laid with ordinary rails for carrying the engines and cars, while another or third "rack rail" is placed between, having large teeth, or steps, in which a "cog" on the engine engages. The locomotive is provided with an engine similar in design to that ordinarily used but constructed to drive a shaft, which carries the "cog" wheels; these gear into the rack and enable the load to be hauled, and will hold the engine immovable in any position it may be stopped in, assisting in the safety of working up or down the steepest grades. Engines of this type used on mountain railways are not turned round at the end of a trip, but continually run with the chimney towards the top of the gradient, and as the inclination of the rails is great the water level in the boiler would be very low at the firebox end if the boiler was placed parallel with the rails. It is therefore set at an angle with them, the amount of inclination, of course, depending upon the gradients to be surmounted.

On engines operating entirely on rack rails, the smooth rails being required for carrying and guidance only, the wheels bearing upon these may be loose upon the axles, thus allowing great freedom for the engine upon curves; but when the ordinary rails and sharp grades alternate, a double set of engines are provided—one for working the rack wheels, and another for the adhesion wheels, which in this case are coupled together by side rods. These two engines are entirely independent of each other, and the driver can use either of them at will as the severity of the road demands.

SECTION V.

EXAMPLES FROM MODERN PRACTICE.

MODERN locomotives are of an almost indefinite variety of types, which are classified by the total number of wheels, the number of wheels coupled, and the position of the cylinders, inside or outside the frames, whilst they may be further subdivided according as they have inside or outside bearings, the description of valve gear, etc., further, they may have separate tenders, or they may be tank engines, in the latter case the tanks may be side, saddle, well or rear. In this country locomotives commonly have either single driving wheels or four, six or eight wheels coupled, whilst elsewhere ten and even twelve wheels coupled have been built. Examples of almost every possible combination are to be found, and it would take a volume to illustrate them all. The sixteen plates chosen to illustrate this book may, however, be taken as representing those which have been most generally constructed during the last two or three years, though it must not be supposed that the types which do not find a place are therefore necessarily obsolete.

A brief description is appended together with the leading dimensions of the engines shown in the plates, all of which are types designed for the standard 4-ft. $8\frac{1}{2}$-in. gauge :—

PLATE I. *(Frontispiece)*.—Four Wheels Coupled Leading Bogie Ten Wheeled Engine for the Lancashire & Yorkshire Ry. Built at the Company's Works, Horwich. Cylinders, 19-in. by 26-in.; diameter of driving wheels, 7-ft. 3-in.; heating surface—tubes, 1877 sq. ft., firebox, 175·8 sq. ft., total, 2052·8 sq. ft.; grate area, 26·05 sq. ft.; working pressure, 175 lbs. per sq. in.; weight in working order $58\frac{3}{4}$ tons.

PLATE II. *(Frontispiece)*.—Eight Wheels Coupled Three Cylinder Compound Engine for the London & North Western Ry. Built at the Company's Works, Crewe. Cylinders—(2) H.P., 15-in. by 24-in., (1) L.P., 30-in. by 24-in.; diameter of driving wheels, 4-ft. $5\frac{1}{2}$-in.; heating surface—tubes, 1374·3 sq. ft., firebox, 114·7 sq. ft., total, 1489·0 sq. ft.; grate area, 20·5 sq. ft.; working pressure, 175 lbs. per sq. in.; weight in working order, 49 tons 5 cwt.

PLATE III.—Single Driver Leading Bogie Engine for the Great Northern Railway. Built at the Company's works, Doncaster. Cylinders, 18-in. by 26-in.; diameter of driving wheels, 7-ft. 6-in.; heating surface—tubes 1143 sq. ft., firebox 125 sq. ft., total 1268 sq. ft.; grate area, 23 sq. ft.

PLATE IV.—Four Wheels Coupled Leading Bogie Outside Cylinder Engine for the Pennsylvania Railroad. Built at the Company's Works, Altoona. Cylinders, H.P., $19\frac{1}{2}$-in. by 28-in., L.P., 31-in. by 28-in.; diameter of driving wheels, 7-ft.; working pressure, 200 lbs. per sq. in.; weight in working order, 65 tons.

PLATE V.—Four Wheels Coupled Leading Bogie Engine for the Belgian State Rys. Built by Messrs. Neilson, Reid & Co., Glasgow. Cylinders, 19-in. by 26-in.; diameter of driving wheels, 6-ft. 6-in.; heating surface—tubes, 1381·22 sq. ft., firebox, 118·78 sq. ft., total, 1500 sq. ft.; grate area, 20·6 sq. ft.; working pressure, 175 lbs. per sq. in.; weight in working order, 52 tons $16\frac{1}{2}$ cwt.

PLATE VI.—Four Coupled Three Cylinder Compound Engine for the Midland Ry. Built at the Company's Works, Derby. Cylinders—H.P. (1), 19-in. by 26-in., L.P. (2), 21-in. by 26-in.; diameter of driving wheels, 7-ft.; heating surface—tubes, 1374 sq. ft., firebox, 145 sq. ft., total 1519 sq. ft.; grate area, 25 sq. ft.; working pressure, 180 lbs. per sq. in.; weight in working order, 51 tons 12 cwt.

PLATE VII.—Atlantic Type Four Coupled Bogie Express Engine for the Gt. Central Ry. Built by Messrs. Beyer, Peacock & Co., Ltd., Gorton. Cylinders, 19½-in. by 26-in.; diameter of driving wheels, 6-ft. 9-in.; heating surface—tubes, 1777·9 sq. ft., firebox, 133·1 sq. ft., total 1911 sq. ft.; grate area, 26 sq. ft.; working pressure, 180 lbs. per sq. in.; weight in working order, 63 tons 5 cwt.

PLATE VIII.—Six Wheels Coupled Engine for the Furness Ry. Built by Messrs. Nasmyth, Wilson & Co. Cylinders, 18-in. by 26-in.; diameter of driving wheels, 4-ft. 8-in.; heating surface—tubes, 1029 sq. ft., firebox, 106 sq. ft., total, 1135 sq. ft.; grate area, 20·5 sq. ft.; working pressure, 150 lbs. per sq. in.; weight in working order, 38¼ tons.

PLATE IX.—Six Coupled Leading Bogie Engine for the Great Western Ry. Built at the Company's Works, Swindon. Cylinders, 20-in. by 24-in.; diameter of driving wheels, 4-ft. 6-in.; heating surface, 1517·89 sq. ft.; grate area, 35 sq. ft.; working pressure, 165 lbs. per sq. in.; weight, 59½ tons.

PLATE X.—Consolidation Two Cylinder Compound (Golsdorf system) Engine for the Austrian Southern Ry. Built by the Weiner Neustadt Locomotive Works. Cylinders, H.P., 21¼-in. by 24⅞-in., L.P., 31½-in. by 24⅞-in.; diameter of driving wheels, 4-ft. 3⅜-in.; heating surface—tubes, 2551 sq. ft., firebox, 140 sq. ft., total, 2691 sq. ft.; grate area, 36·275 sq. ft.; working pressure, 190 lbs. per sq. in.; weight in working order, 68 tons.

PLATE XI.—Four Wheels Coupled Trailing Bogie Condensing Side Tank for the Great Eastern Ry. Built at the Company's Works, Stratford. Cylinders, 17-in. by 24-in.; diameter of driving wheels, 4-ft. 11-in.; heating surface—tubes, 986·5 sq. ft., firebox, 94·9 sq. ft., total, 1081·4 sq. ft.; grate area, 15·27 sq. ft.; working pressure, 160 lbs. per sq. in.; weight in working order, 52 tons.

PLATE XII.—Four Wheels Coupled Double End Side Tank Engine for the Barry Railway. Built by Messrs. Hudswell, Clarke & Co., Leeds. Cylinders, 18-in. by 26-in.; diameter of driving wheels, 5-ft. 7½-in.; heating surface—tubes 967·6 sq. ft., firebox 106 sq. ft., total 1073·6 sq. ft.; grate area, 20 sq. ft.; working pressure, 150 lbs. per sq. in.; weight in working order, 61 tons 10½ cwt.

PLATE XIII.—Four Wheels Coupled Leading Bogie Radial Side Tank Engine for the Great Northern Ry. Built at the Company's Works, Doncaster. Cylinders, 17½-in. by 26-in.; diameter of driving wheels, 5-ft. 7½-in.; heating surface—tubes 1020 sq. ft.; firebox 103 sq. ft., total 1123 sq. ft.; grate area, 17¾ sq. ft.; working pressure, 170 lbs. per sq. in.; weight in working order, 56 tons.

PLATE XIV.—Six Wheels Coupled Saddle Tank engine for the Metropolitan Ry. Built by Messrs. Peckett & Sons, Bristol. Cylinders, 16-in. by 22-in.; diameter of driving wheels, 3-ft. 10-in.; heating surface, 724 sq. ft.; grate area, 13·5 sq. ft.; working pressure, 140 lbs. per sq. in.; weight in working order, 39 tons.

PLATE XV.—Six Wheels Coupled Radial Side Tank Engine for the London and North Western Ry. Built at the Company's Works, Crewe. Cylinders, 18-in. by 24-in.; diameter of driving wheels, 5-ft. 2½-in.; heating surface—tubes 980 sq. ft., firebox 103·5 sq. ft., total 1083·5 sq. ft.; grate area, 17·1 sq. ft.; working pressure, 180 lbs. per sq. in.; weight in working order, 52 tons 6 cwt.

PLATE XVI.—Eight Wheels Coupled Radial Tank Engine for the Great Northern Ry. Built at the Company's Works, Doncaster. Cylinders, 20-in. by 26-in.; diameter of driving wheels, 4-ft. 7½-in.; heating surface—tubes, 1302·10 sq. ft., firebox, 136·74 sq. ft., total, 1438·84 sq. ft.; grate area, 24 sq. ft.; working pressure, 175 lbs. per sq. in.; weight in working order, 79 tons.

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Plate III.—Single Bogie Express Engine, Great Northern Railway.

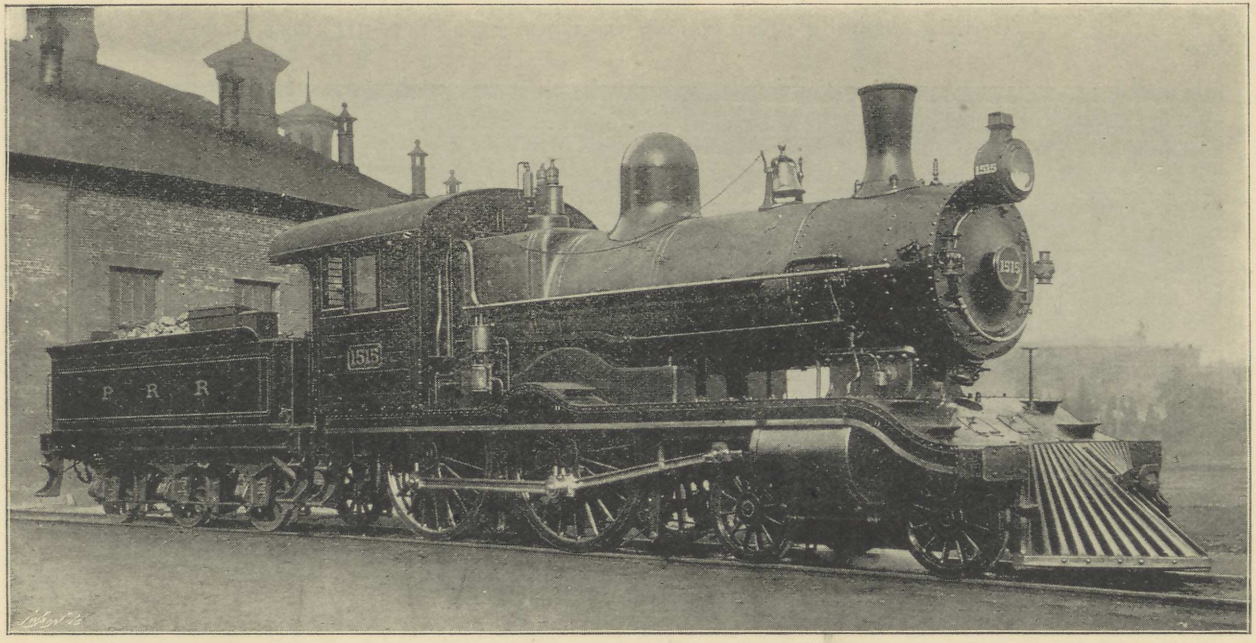

Photo by F. W. Blauvelt. *Pub. by F. Moore.*

PLATE IV.—FOUR-COUPLED BOGIE EXPRESS ENGINE, PENNSYLVANIA RAILROAD.

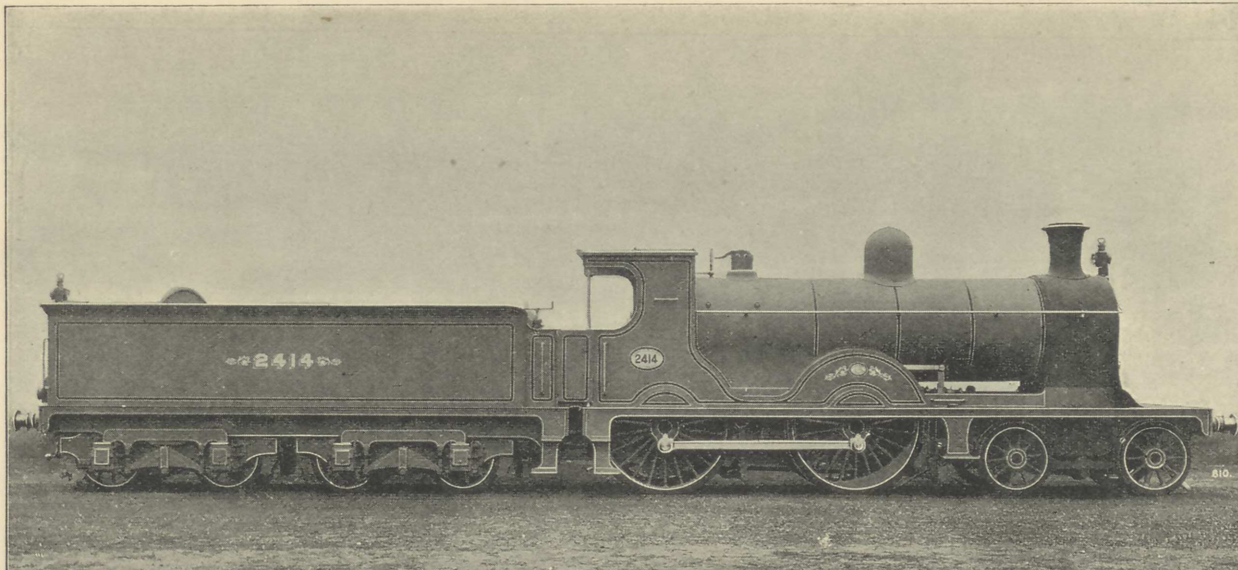

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PLATE V.—FOUR-COUPLED BOGIE EXPRESS ENGINE, BELGIAN STATE RAILWAYS.

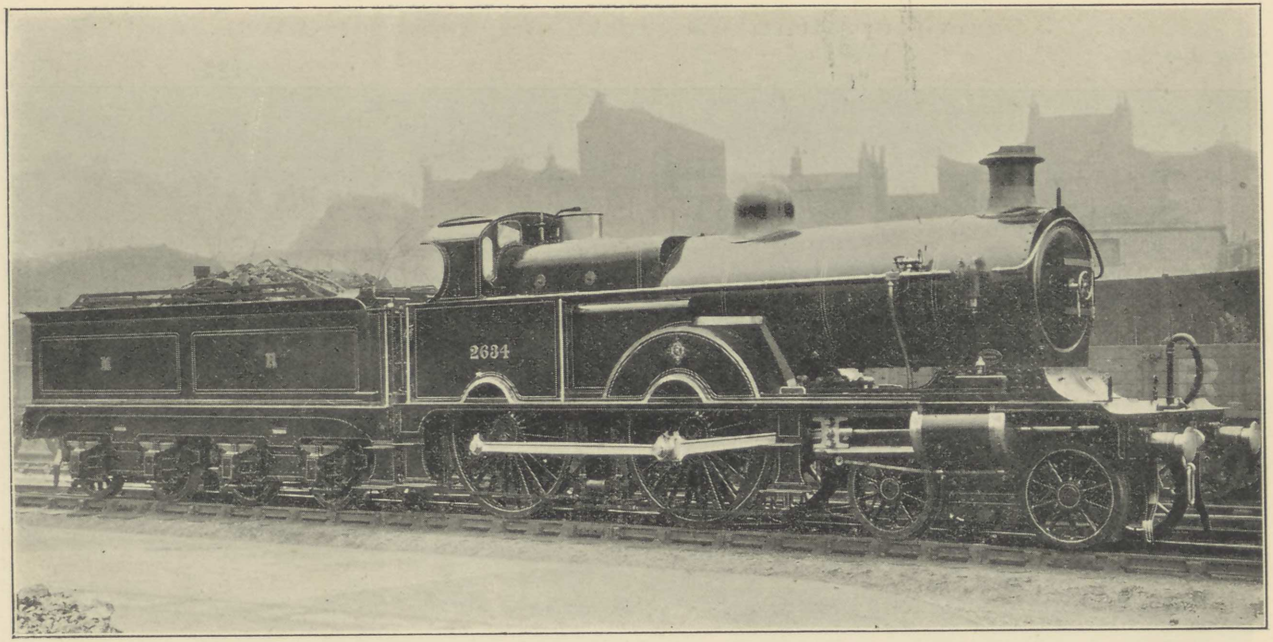

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PLATE VI.—FOUR-COUPLED THREE-CYLINDER COMPOUND ENGINE, MIDLAND RAILWAY.

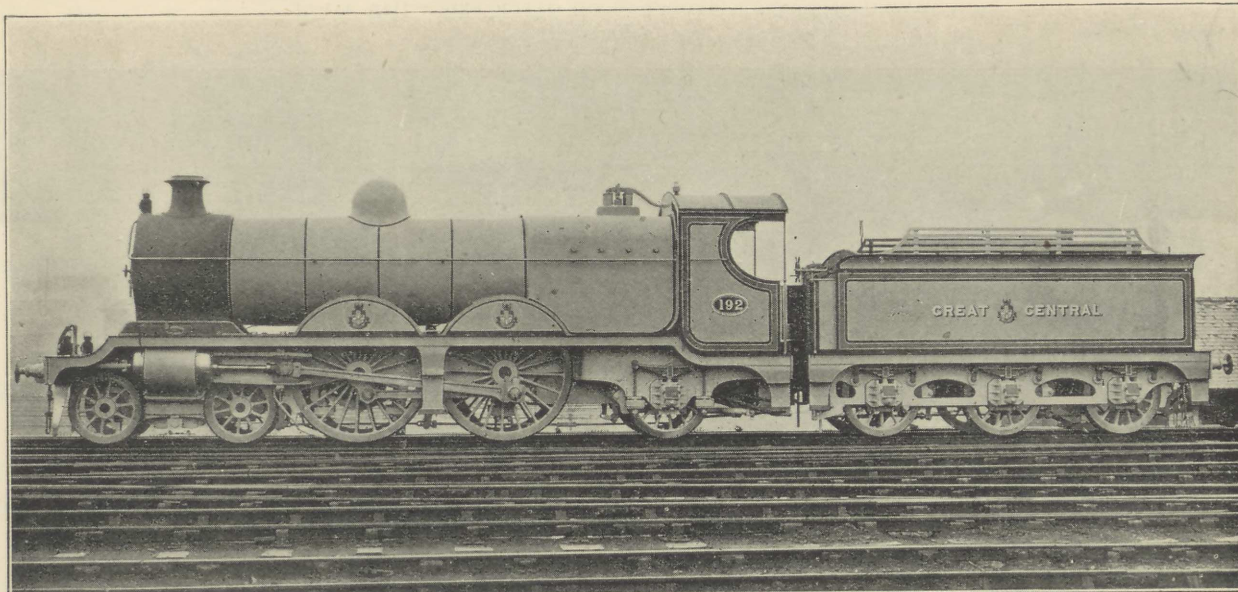

Plate VII.—Atlantic Type Four-coupled Bogie Express Engine, Great Central Railway.

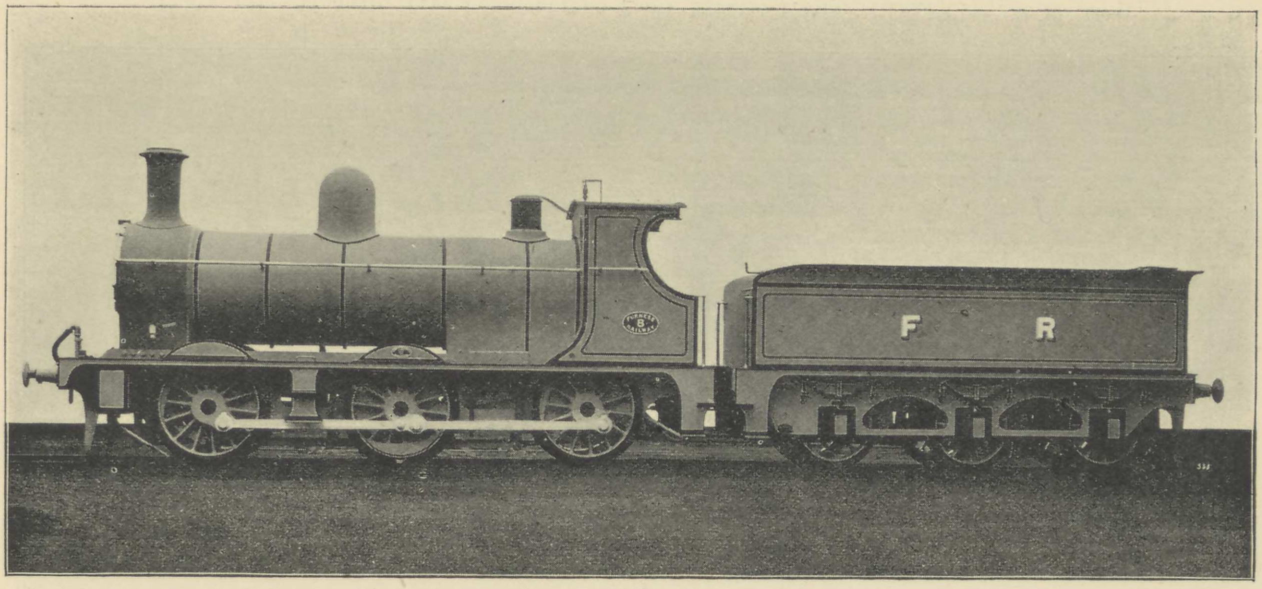

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PLATE VIII.—SIX-COUPLED GOODS ENGINE, FURNESS RAILWAY.

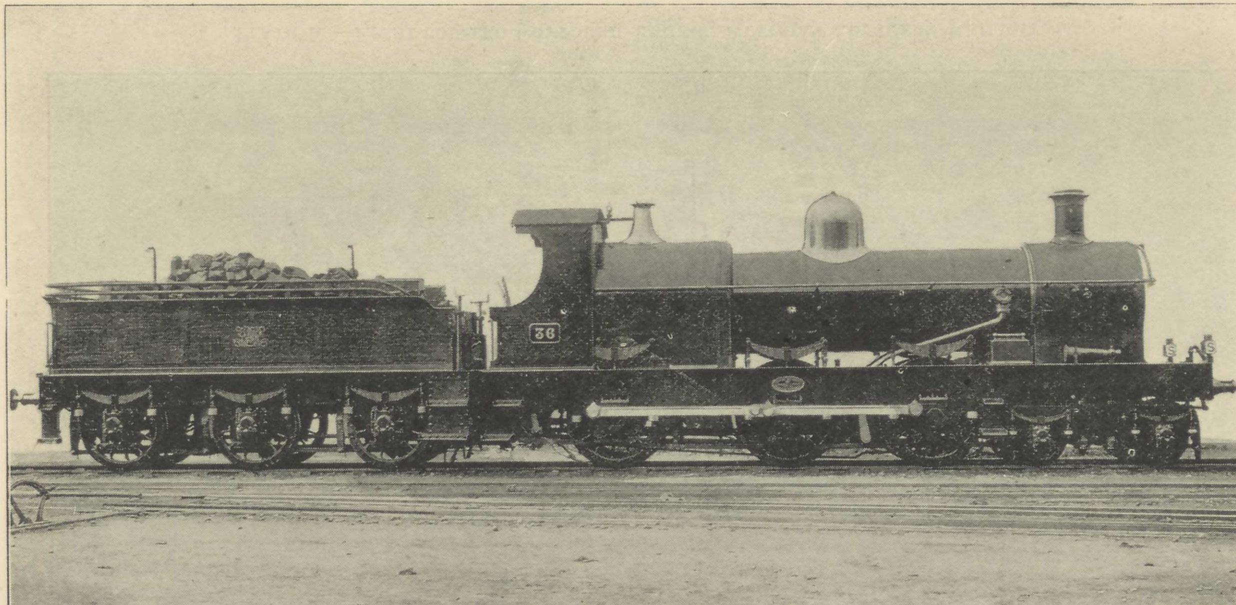

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PLATE IX.—SIX-COUPLED BOGIE GOODS ENGINE, GREAT WESTERN RAILWAY.

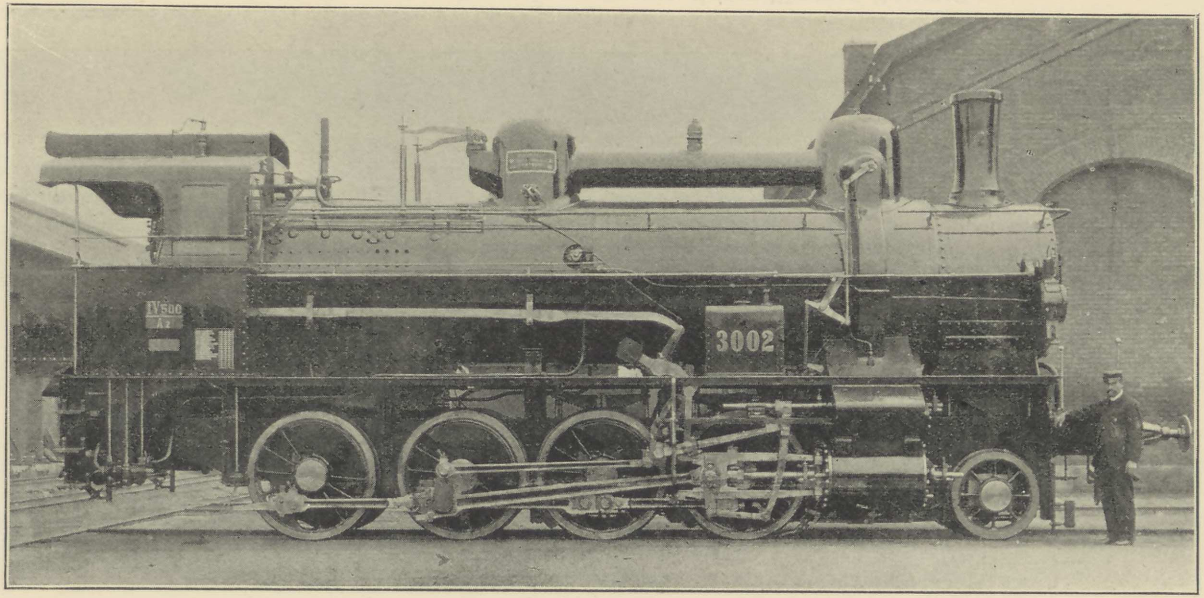

PLATE X.—EIGHT-COUPLED COMPOUND ENGINE, AUSTRIAN SOUTHERN RAILWAY.

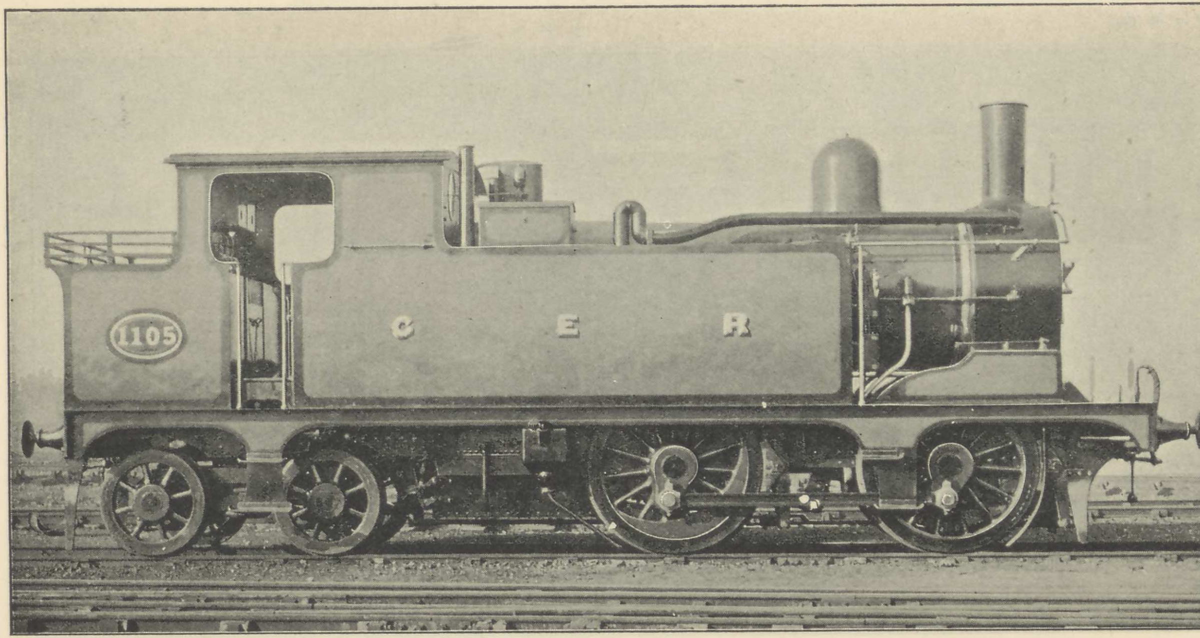

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PLATE XI.—FOUR-COUPLED BOGIE CONDENSING SIDE TANK, GREAT EASTERN RAILWAY.

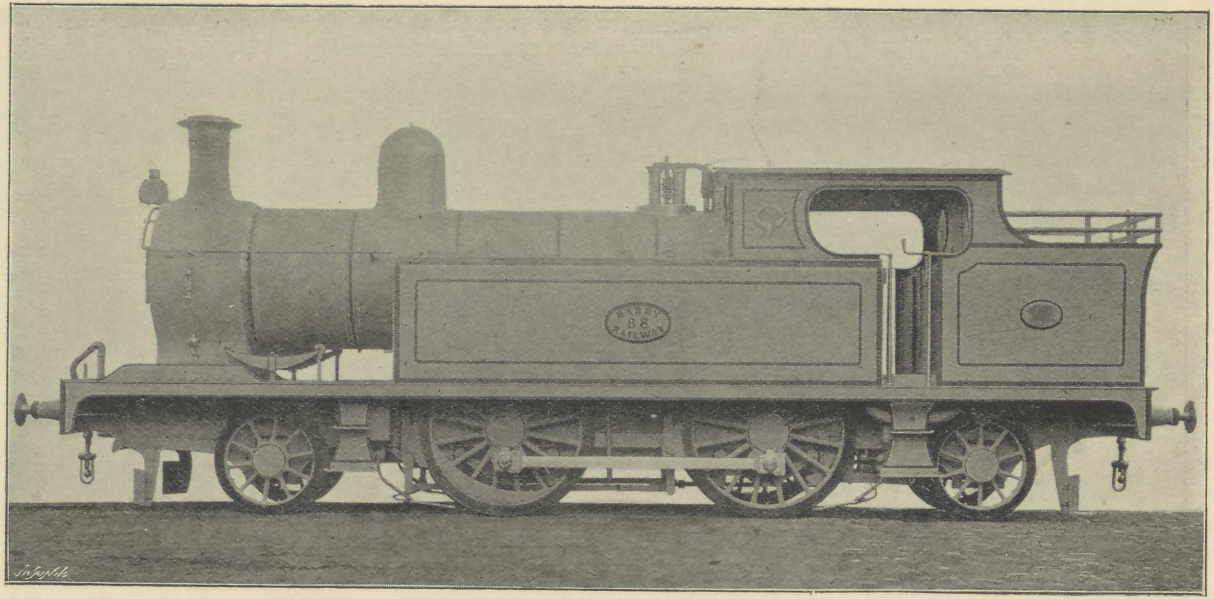

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PLATE XII.—FOUR-COUPLED SIDE TANK ENGINE, BARRY RAILWAY.

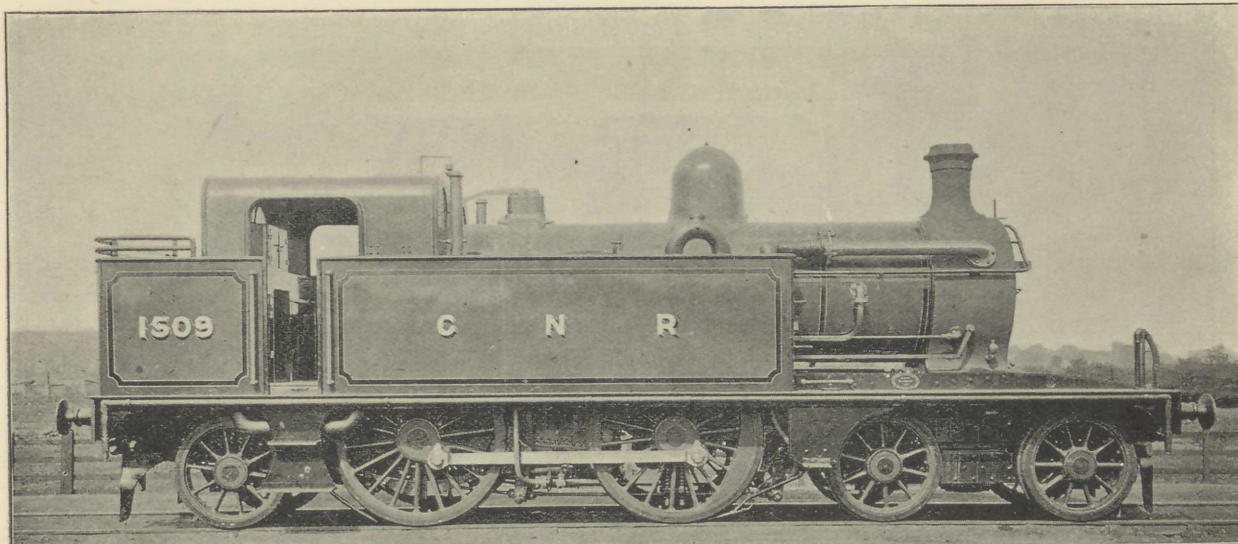

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PLATE XIII.—FOUR-COUPLED BOGIE SIDE TANK ENGINE, GREAT NORTHERN RAILWAY.

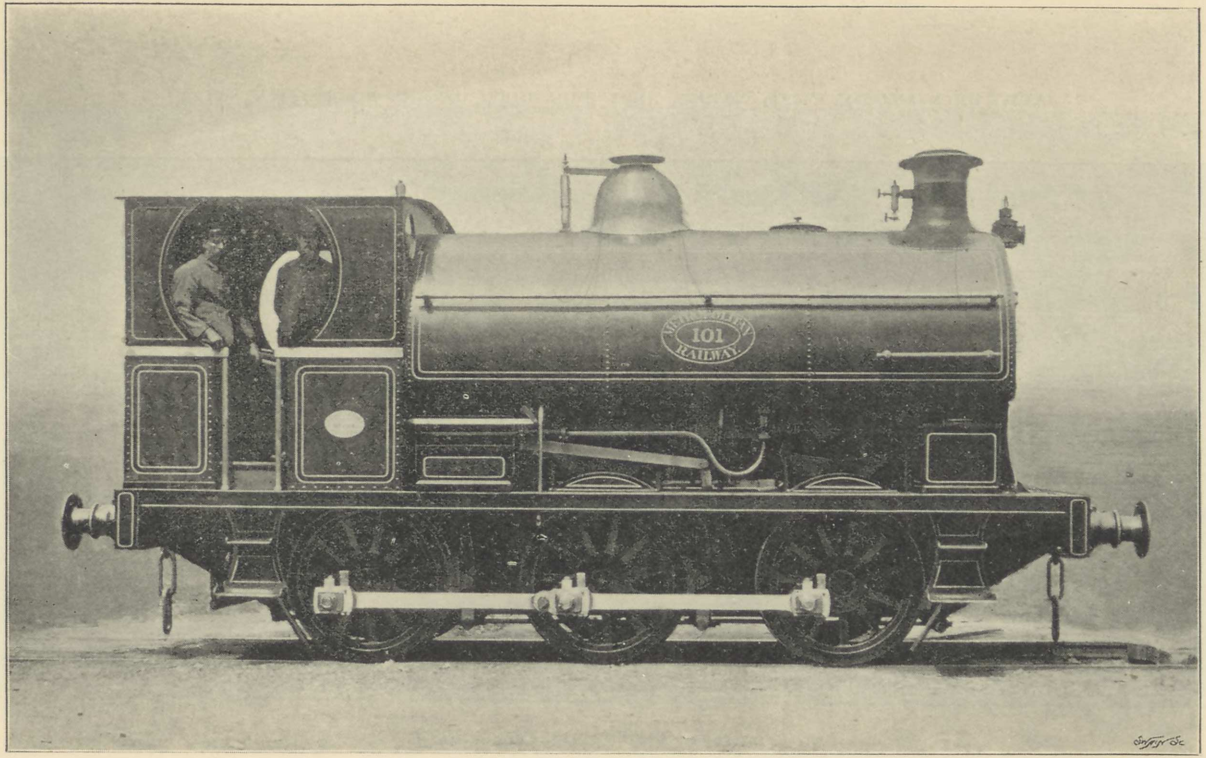

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PLATE XIV.—SIX-COUPLED SADDLE TANK ENGINE, METROPOLITAN RAILWAY.

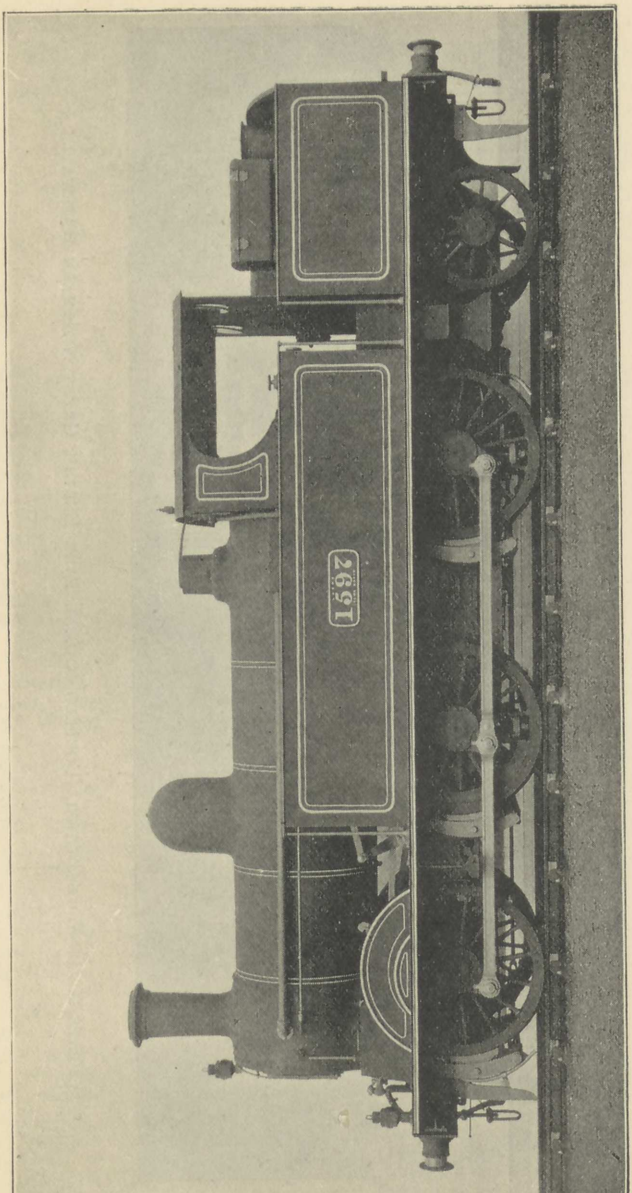

PLATE XV.—SIX-COUPLED SIDE TANK ENGINE, LONDON AND NORTH WESTERN RAILWAY.

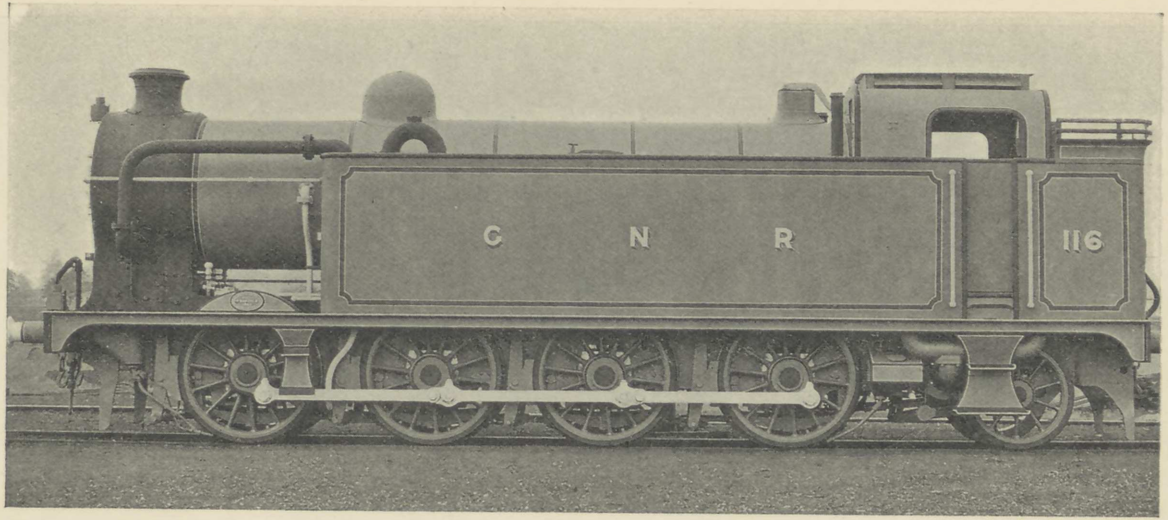

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PLATE XVI.—EIGHT-WHEELS COUPLED RADIAL TANK ENGINE, GREAT NORTHERN RAILWAY.

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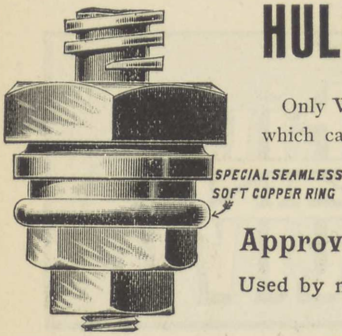

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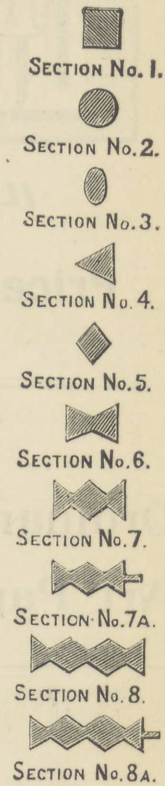

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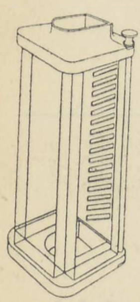

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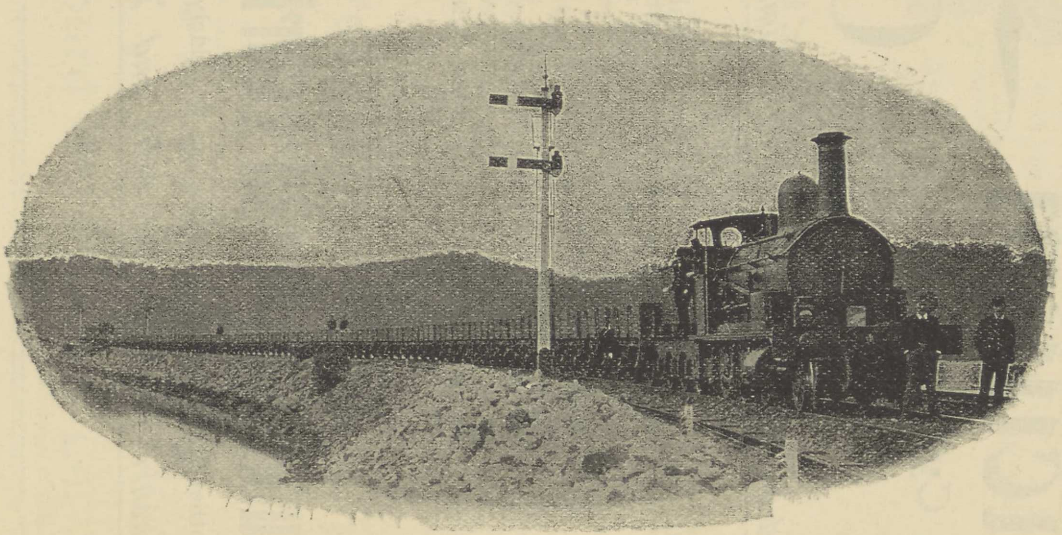

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