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Some Notes on the "Merchant Navy" Class Locomotives of the Southern Railway

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The operating requirements in respect of weights of trains and speeds determined the main dimensions of these new locomotives, and the paper refers to the limitations on the development of powerful locomotives imposed by the loading gauge and weight restrictions.

The *Merchant Navy* class locomotives embody many innovations in British locomotive practice, and the reasons for these changes from orthodox practice are fully explained, and the way in which the changes were carried out described.

Some difficulties were naturally experienced in service as a result of these departures, and they are fully related, together with the modifications which successfully overcame them. Some of the improved results obtained as a result of the innovations are reported.

Operating Requirements. When the design of these engines was first taken in hand it was required that they should be able to work trains of greater weights than the maximum then allowed and at higher average speeds. Passenger trains of 550 to 600 tons had to be regarded as probable in the near future. Average start-to-stop speeds of a mile a minute on short runs such as to Dover and of 70 m.p.h. on longer runs to Exeter, etc., had to be provided for, with a maximum limit of 90 to 95 m.p.h.

Express goods trains form an ever-increasing proportion of the train service and the tendency is to run them at the same speeds as passenger trains. This practice improves the operation

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of the line by avoiding shunting the slower trains on to slow lines or loops to let the faster trains pass; and this is especially so on the Southern Railway with its dense passenger services.

This results in a demand for mixed-traffic locomotives, or general-purpose machines. Provided the areas of the steam pipes and ports and the volume of the steam chests are such that the cylinders can be fed properly with steam with a minimum drop of pressure during admission, locomotives can do useful work at piston speeds as high as 2,000 ft. per min. A locomotive with a 6 ft. 2 in. wheel, therefore, will be able to operate trains at the highest speeds likely to be required in ordinary service.

Characteristics Required. Experience shows that to work heavy trains at high average speeds engines should have a tractive effort of 35,000 to 40,000 lb. and an adhesive weight of at least 63 tons, if the trains are to be accelerated quickly enough and are to be operated over severe gradients.

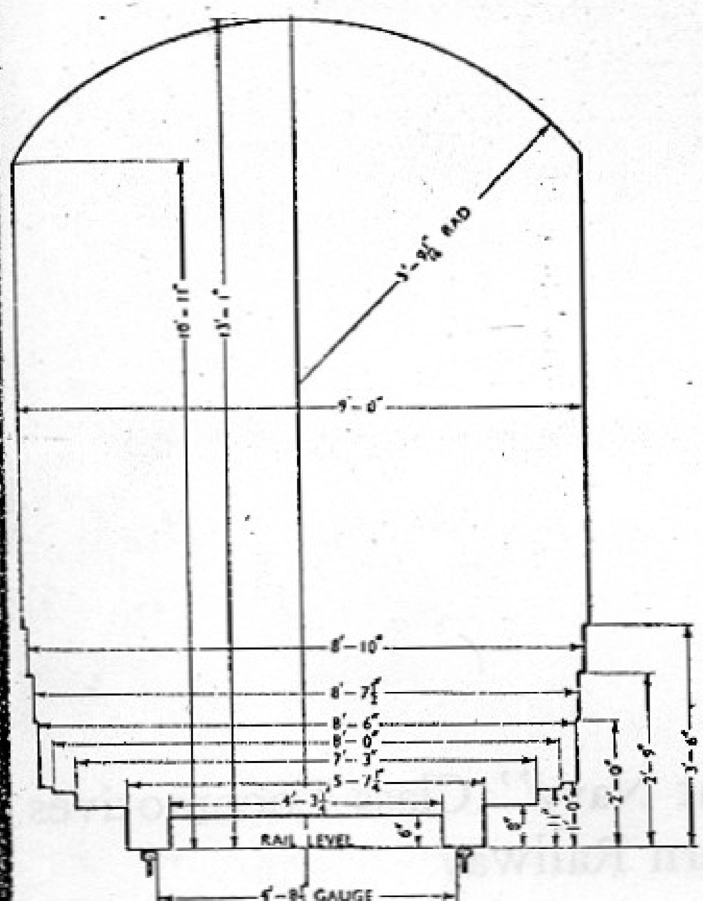


Fig. 1. Southern Railway Loading Gauge

Experience has also proved that a grate area approaching 50 sq. ft. is needed if sufficient water is to be evaporated to ensure the cylinders being supplied with all the steam they can use at the maximum rates of consumption. A grate area of this size means a large boiler with large firebox area and volume, adequate water capacity, and sufficient tubes to ensure that as much as possible of the heat generated but not absorbed in the firebox is transmitted to the water in the barrel before the gases reach the smokebox. Such a boiler must be of considerable weight.

Limitations on Dimensions. The designer, however, is severely restricted as regards the cross-sectional area of the locomotive by the loading gauge. The Southern Railway loading gauge is shown in Fig. 1 and shows that the height must not exceed 13 ft. 1 in., the width over cylinders 8 ft. 10 in. and the width over the cab at the cornice 9 ft. 0 in.

The overall wheelbase of the engine and tender is limited by the available turntables, which are 70 feet long.

The maximum weight allowed on any one pair of wheels is 21 tons. The total weight of the engine and tender is limited by the strength of the bridges.

Leading Dimensions. The following basic data were arrived at and the design has been based thereon:—

Adhesive weight	63 tons
Tractive effort	37,500 lb.
Driving wheel diameter	6 ft. 2 in.
Boiler pressure	280 lb. per sq. in.
Grate area	48½ sq. ft.
Total weight of engine	94 tons 15 cwt.
Total weight of engine and tender	145 tons
Cylinders: Number	3
Cylinders: Diameter	18 inches
Cylinders: Stroke	24 "
Wheel arrangement	4-6-2

Fig. 2 is the weight diagram of the engines as built and also gives the leading dimensions and ratios. To design and build an engine of the power required and with adequate boiler capacity within such a restricted weight necessitated particular attention to the reduction of weight wherever possible.

Innovations. The principal innovations in British practice introduced in these engines, and to which attention will mainly be devoted in this paper, are:—

(1) High-pressure boiler with welded steel fireboxes fitted with syphons.
(2) Enclosed motion with pump lubrication.
(3) New valve gear incorporating piston valves operated between the heads.
(4) New wheel centres with new tyre fastening.
(5) Reciprocating weights not balanced.

THE HIGH-PRESSURE BOILER WITH WELDED FIREBOX AND SYPHONS

The pressure of 280 lb. per sq. in. was adopted in place of 220 lb. per sq. in., the highest hitherto in use on the Southern Railway, in order to limit the cylinder dimensions. This pressure approaches the limit for simple-expansion engines, especially when the engine is working at a very early cut-off and with reduced steam chest pressure and severe wiredrawing of the steam.

The Non-Ferrous Metals Research Association's investigation into the corrosion of copper firebox plates and the wasting away of the staybolt heads showed clearly the unsuitability of arsenical copper for the temperature of 390 deg. F. recorded in the ends of the stays, the pressure of the boiler tested being 220 lb. per sq. in., corresponding to a steam temperature of 395 deg. F. At such temperatures the copper loses its elasticity. This means that after the plate expands, and cools down, it does not return to its original position or form. Arsenical copper would be less suitable for the intended pressure of 280 lb. per sq. in. with its steam temperature of 416 deg. F.

The life of steel tubes is short and the tubes have to be renewed frequently, mainly through pitting; they give trouble not only in the workshops but also in the running sheds, as they require considerable attention to keep them tight in the firebox tubeplate.

Water-softening in hard-water districts, water treatment in soft-water districts, removal of mill scale, etc., are all suggested methods for overcoming the trouble. The author has always considered the main cause to be the electrolytic action set up by the use of steel tubes in copper fireboxes. The use of steel fireboxes was therefore considered.

Steel fireboxes are used exclusively in the U.S.A. and Canada and to an increasing extent in France, South Africa, and Australia. It is difficult to believe that the U.S.A., a copper-producing country, would persist in using steel if this material were really unsatisfactory. It is often stated that steel can be

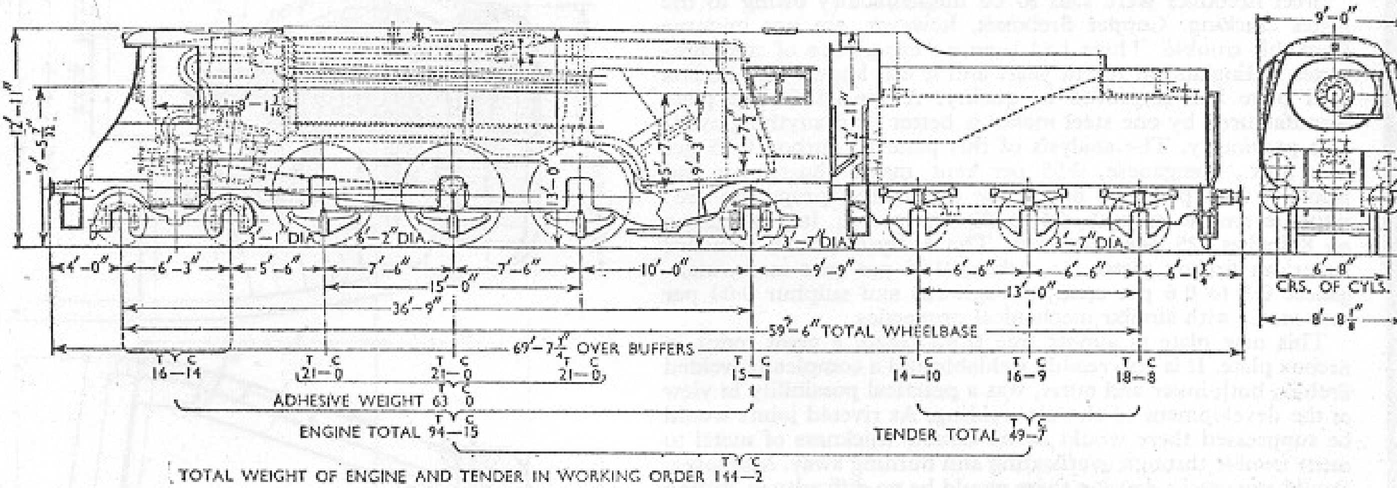


Fig. 2. Weight Diagram of Locomotive

LEADING DIMENSIONS

Boiler

Working pressure	280 lb. sq. in.
Three Ross pop safety valves	3 in. dia.
Length between tube plates	17 feet
Length of barrel	16 ft. 9¾ in.
Maximum diameter of barrel	6 ft. 3½ in.
Thickness of barrel plates	19/32 in.
,, ,, wrapper	9/16 in.
Weight of boiler empty	26·05 tons
Weight of water in boiler	8·75 tons
Volume of water in boiler = 314 cu. ft.	1,960 gal.
Volume of steam at half glass	113 cu. ft.
Area of water surface ,,	130 sq. ft.
Main steam pipe, ⅜ in. thick, 7 in. bore.	38·5 sq. ins.

Tubes (Small)

Material	steel
Number	124
Diameter outside	2¼ in.
Thickness . 0·116 in. =	11 S.W.G.

Tubes (Superheater Flue)

Material	steel
Number	40
Diameter outside	5¼ ins.
Thickness . 0·156 in. =	5/32 ins.

Superheater

Number of elements	40
Diameter outside	1½ in.
Thickness . 0·144 in. =	9 S.W.G.

Heating Surface

Firebox (including syphons)	275·0 sq. ft.
Tubes	1,241·6 ,,
Flues	934·3 ,,
Total evaporative	2,450·9 ,,
Superheater (outside)	822·0 ,,
Total combined	3,272·9 ,,

Firebox

Material	steel
Two thermic syphons	
Thickness of tubeplate	¾ inch
Thickness of back and side plates	⅜ inch
Outside length at bottom	7 ft. 10½ in.
,, width ,,	7 ft. 9 in.
,, length at top	9 ft. 8¾ in.
,, width ,, front	5 ft. 6⅜ in.
,, ,, ,, rear	5 ft. 8½ in.
Inside length at bottom	7 ft. 0 11/16 in.
,, width ,,	6 ft. 11⅛ in.
,, length at top	8 ft. 5½ in.
,, width ,, front	5 ft. 2¾ in.
,, ,, ,, rear	5 ft. 5 in.
Volume	300 cu. ft.
Bridge between flues at firebox end	13/16 inch
Area through flue tubes ,,	3·82 sq. ft.
,, small ,, ,,	2·58 sq. ft.

Grate

Length of slope	7 ft. 0 11/16 in.
Width	6 ft. 11¼ in.
Grate area	48·50 sq. ft.
Area of air passages through grate	24·25 sq. ft.

Ashpan

Area of opening, front	5·6 sq. ft.
,, ,, rear	6·6 sq. ft.

Smokebox

Length	8 ft. 1 7/16 in.
Maximum width	6 ft. 10½ in.
Height, front	4 ft. 5¼ in.
,, rear	5 ft. 11¾ in.
Steam pipes . 7 in. diameter =	38·5 sq. in.
Exhaust nozzles, number	5
,, diameter	2⅝ inches
,, total area	27·05 sq. in.
Chimney, diameter at choke	2 ft. 1 in.
,, ,, ,, top	2 ft. 5 in.
,, ,, ,, bottom	2 ft. 8 in.

Cylinders

Number	3
Diameter and stroke	18 in. by 24 in.
Volume per cylinder	3·53 cu. ft.
Clearance volume, per cent	9·8

Piston

Material	cast iron

Piston Rings

Material	cast iron
Number	3
Width	0·245 inch
Thickness	11/16 inch

Piston Speeds

At 60 miles per hour, feet per min.	1,090
At 90 miles per hour, feet per min.	1,635
At 110 miles per hour, feet per min.	2,000

Motion

Type	Bulleid

Valve

Type	piston
Diameter	11 inches
Steam lap	1⅝ inch
Steam lead	¼ inch
Maximum travel	6⅛ inches
Maximum cut-off, per cent	70
Port area (liners)	40·7 sq. in.

Valve Rings

Material	cast iron
Number per valve	8
Width	¾ inch
Thickness	⅜ inch

Connecting Rod

Length inside	8 feet
,, outside	11 feet

Wheel Diameter

Bogie	3 ft. 1 in.
Coupled	6 ft. 2 in.
Trailing truck	3 ft. 7 in.
Tender	3 ft. 7 in.

Wheel Centres

Type	B.F.B.
Material	cast steel

Tyres

Fastening	lip

Bearings

	Diameter, inches	Length, inches
Axles, bogie	6½	10 11/16
,, coupled	9	10 7/16
,, trailing truck	6¼	13 11/16
,, tender	6¼	13 11/16
Crank pins, outside	6¾	6¼
,, inside	9½	6¼
Coupled pins, leading	5½	4¼
,, driving	7½	4¼
,, trailing	5½	4¼

Springs

Bogie, helical, 12 7/8 inches free length, 5½ in. dia., Timmis section.

Coupled, laminated, 4 feet centres, loaded. 20 plates, 5 inches wide, 7/16 inch thick.

Trailing truck, helical, 1 ft. 4 in. free length, 6 in. dia. Timmis section.

Tender, laminated, 4 ft. centres, loaded. 15 plates, 5 inches wide, ½ inch thick.

Side Control Springs

	Initial load, tons	Final load, tons
Bogie	3	5·75
Trailing truck	1·0	2·0

Brakes

Engine, type	steam
,, no. of cylinders	2
,, diameter and stroke	6½ ins. by 8 ins.
,, pull	57·4 tons
Tender, type	vacuum
,, no. of cylinders	2
,, diameter	21 inches
,, pull	24·7 tons

Lubrication

Piston valves and pistons	force feed
Valve operating shaft and pins	,,

Motion, flood by rotary pump.

Axleboxes, oilboxes on back plate.

Tractive Effort

At 85 per cent boiler pressure	37,500 lb.

Weights

Adhesive	63 tons, 0 cwts.
Total engine in working order	94 ,, 15 ,,
Total engine and tender in working order	144 ,, 2 ,,

Adhesion

Factor	3·76

Tractive Power

Per ton of adhesive weight	595 lb.
Per square foot of grate area	773 lb.
Per square foot of combined heating surface	11·5 lb.

Tender

Water capacity	5,000 gallons
Coal capacity	5 tons

RATIOS

$$\frac{\text{Firebox heating surface}}{\text{Grate area}} = 5{\cdot}67$$

$$\frac{\text{Evaporative heating surface}}{\text{Grate area}} = 50{\cdot}5$$

$$\frac{\text{Evaporative heating surface}}{\text{Superheater heating surface}} = 2{\cdot}98$$

$$\frac{\text{Total area through tubes}}{\text{Grate area}} = 12{\cdot}6 \text{ per cent}$$

$$\frac{\text{Grate area}}{\text{Ashpan opening area}} = 3{\cdot}98$$

$$\frac{\text{Grate area}}{\text{Area of air spaces through grate}} = 2{\cdot}0$$

$$\frac{\text{Area of chimney at choke}}{\text{Area of exhaust nozzles}} = 18{\cdot}15$$

$$\frac{\text{Cylinder area}}{\text{Port area}} = 6{\cdot}27$$

$$\frac{\text{Cylinder area}}{\text{Steam pipe area}} = 6{\cdot}62$$

$$\frac{\text{Cylinder volume}}{\text{Steamchest volume}} = 1{\cdot}36$$

$$\frac{\text{Engine brake force}}{\text{Adhesive weight}} = 91{\cdot}1 \text{ per cent}$$

$$\frac{\text{Tender brake force}}{\text{Tender weight (full)}} = 50 \text{ per cent}$$

used for wide fireboxes but not narrow, but steel was used in the U.S.A. before the introduction of the wide firebox.

Steel fireboxes were said to be unsatisfactory owing to the plates cracking. Copper fireboxes, however, are not immune from this trouble. There had been no experience of steel fireboxes in England in recent years and it was known that firebox steel plate had improved in quality. A special firebox plate manufactured by one steel maker is better than anything available previously. The analysis of this plate is: carbon 0·15 per cent max., manganese, 0·55 per cent max., phosphorus and sulphur, 0·03 per cent max. The mechanical properties are: ultimate tensile strength, 24 to 28 tons per sq. in., elongation on 8 inches, 25 per cent min. The analysis of the standard American firebox plates is: carbon, 0·25 per cent max., manganese 0·3 to 0·6 per cent., phosphorus and sulphur 0·04 per cent max., with similar mechanical properties.

This new plate is almost free from creep, a great merit in firebox plate. It is also readily weldable and a completely welded firebox, both inner and outer, was a practical possibility in view of the development of electric welding. As riveted joints would be suppressed there would be no double thickness of metal to cause trouble through overheating and burning away. Moreover, should any cracks develop there would be no difficulty in cutting out the defective piece of plate and welding in a new piece of plate, an operation that would take little time and could be done in position.

The use of steel would effect a large reduction in weight as compared with copper, which in the case under consideration would be at least $1\frac{1}{2}$ tons. During the war, too, anything that would reduce the use of copper was desirable.

The use of steel fireboxes on recent French locomotives with 280 lb. per sq. in. pressure and over had been satisfactory and, in fact, the author found the French engineers convinced that for such pressures steel fireboxes must be used.

The successful introduction of the Nicholson thermic syphon had provided a reliable means of improving the boiler circulation whilst, at the same time, giving added security against overheating of the crownplate.

It seemed reasonable to expect good results from steel fireboxes provided that care was taken in the design to allow for the differences between steel and copper, and also that all reasonable precautions were taken to ensure that the fireboxes were treated with proper care in service. It was therefore decided to use steel fireboxes on these locomotives.

The boilers of the first ten locomotives, of which the general arrangement is shown in Fig. 4, were built by the North British Locomotive Company, and the author is much indebted to Mr. Lorimer and Mr. Black for their help in their design and manufacture. The subsequent ten boilers have been produced in the Southern Railway workshops at Eastleigh.

Firebox. The firebox is illustrated in Fig. 5. All the plates of the outer firebox, comprising the back plate, wrapper, and throat plate are welded together. The outer box is riveted to the Belpaire ring. The inner firebox plates, comprising back plate, wrapper, throat plate, and tube plate, are also welded together, the top flanges of the two syphons being welded into the roof of the firebox. The inner and outer fireboxes are welded together at the firehole.

For practical reasons the inner firebox has to be inserted through the foundation ring opening, and the shape of the inner box has to be checked to ensure that this is possible.

All holes in the pressed plates are drilled before the plates are assembled together. In the case of the wrappers, the plates are drilled on the flat before bending, as are the barrel plates before rolling, an advance in manufacturing technique that has speeded up production considerably. The foundation ring is double riveted throughout, and is welded from four pieces.

The welding technique employed in the Southern Railway workshops is as follows. The foundation ring is placed on a jig and levelled, and the side, back, throat, and tubeplates are bolted in position. All the joints between these members are single "V" butt welds with the edges bevelled to give an included angle of 70 deg. with a $\frac{1}{16}$ inch root face. A joint is shown in Fig. 6.

Distance pieces $\frac{3}{16}$ inch thick are placed between the plate edges, and the plates are tacked in position. After checking for alignment the assembly is placed in a manipulator, shown in

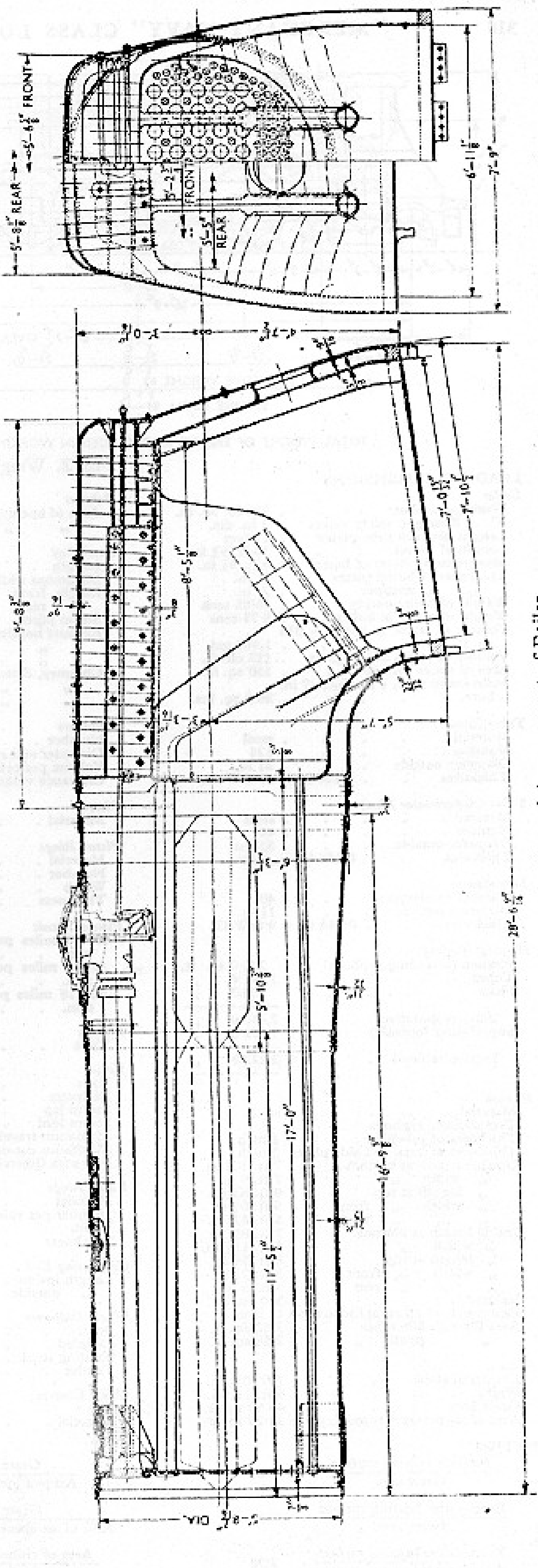


Fig. 4. General Arrangement of Boiler

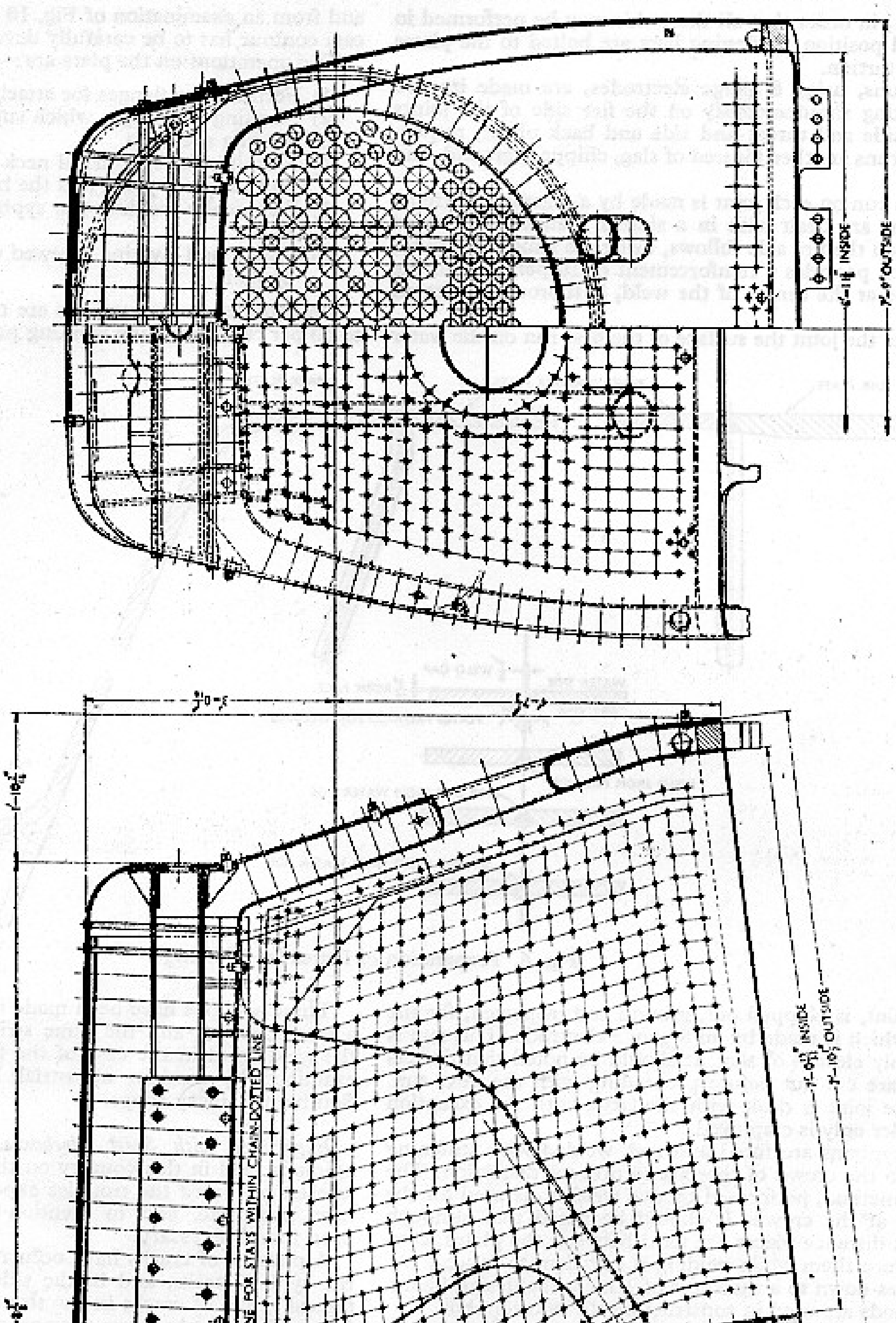


Fig. 5. Arrangement of Firebox

Fig. 7, Plate 1, in order that all the welds may be performed in the downhand position. Stiffening bars are bolted to the plates to prevent distortion.

The first runs, using 8 gauge electrodes, are made by two welders, working simultaneously on the fire side of the joints between the side and throat and side and back plates, respectively. These runs are then cleared of slag, chipped, ground, and inspected.

The second run on each joint is made by a 6 gauge electrode, and these runs are dealt with in a similar manner. The third and final run on the fire side follows, using a 6 gauge electrode; this run, which provides a reinforcement of 10 per cent on the plate thickness at the centre of the weld, is thoroughly cleared of slag.

To complete the joint the surface of the first run on the water side of the joint, is chipped out, ground and inspected, for the sealing run which is made by an 8 gauge electrode. This run is also thoroughly cleared of slag. It should be noted that defects in each run are cut out before proceeding with the next run. The tubeplate joint is dealt with similarly, with the exception that one welder only is employed.

Next the syphons are fitted and tack welded with stiffening bars bolted to the crown of the box to prevent distortion. The "back step" method, performed by two welders, is used for the syphon joint at the crown. It should be noted that although $\frac{1}{16}$ inch thick distance pieces are used between the plates, contraction between them while welding is sufficient to squeeze the distance pieces down to a thickness of $\frac{1}{8}$ inch, the design figure. Similar methods are used in constructing the outer firebox.

The electrodes used are of the solid extruded type using an arc voltage of 28–30, with a current of 150–160 amp. for an 8 gauge electrode, and 190 amp. for a 6 gauge. All pressings are stress-relieved before welding and all welding is examined by X-ray photographs. The boxes are not annealed after welding. A view of the inner firebox is shown in Fig. 8, Plate 1, and of the assembled box in Fig. 9, Plate 2.

Syphons. The construction of the syphons is shown in Fig. 10, Plate 2.* This is the first use of such syphons in this country, so some details of their construction will be of interest. The manufacture of thermic syphons involves the use of press blocks specially designed for the purpose, and the method of flanging is adapted for cold working the plates, which are of special firebox quality. The syphon is made from a single sheet and from an examination of Fig. 10 it will be seen that an intricate contour has to be carefully developed.

The operations on the plate are :—

(1) Forming the flanges for attachment to the crown plate.
(2) Forming the bulges which support the brick arch.
(3) Folding the plate.
(4) Forming the cylindrical neck which connects the syphon to the throat plate, and the back and front flanges.
(5) Electrically welding the syphon on the front, back, and neck.
(6) Fitting and riveting screwed stays in the flat sides of the syphon.

On completion the syphons are tested by hydraulic pressure to 50 per cent above the working pressure of the boiler.

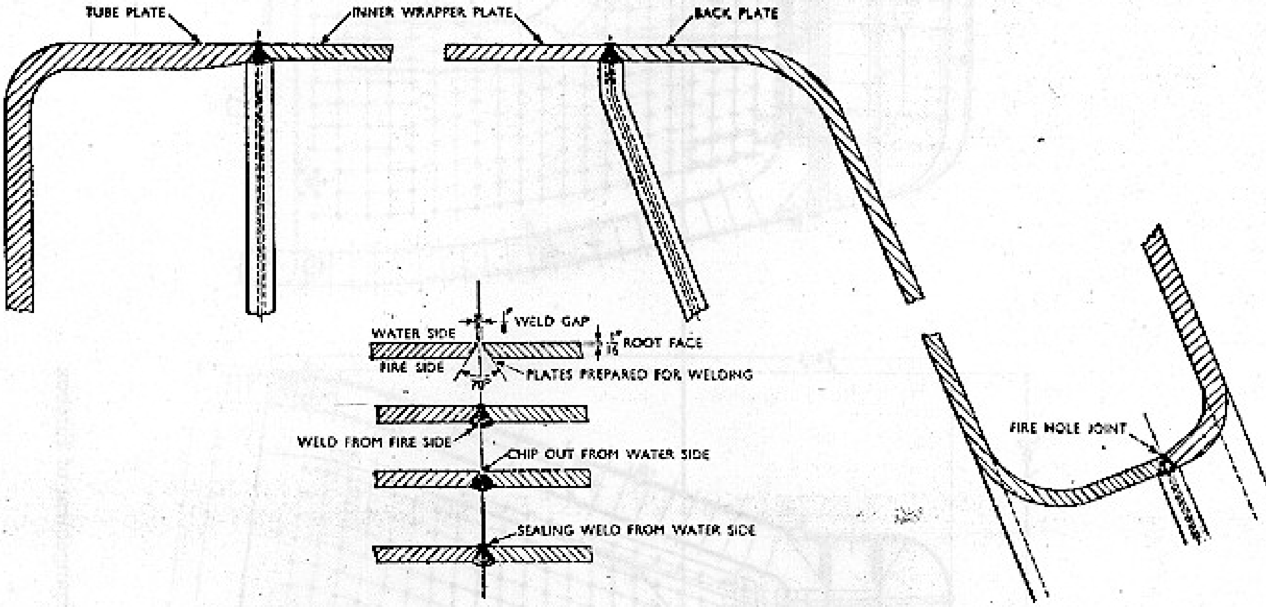


Fig. 6. Preparation of Plates for Welding

These syphons have been made for the Southern Railway by a manufacturer, and the same strict control is exercised over the welding as in the case of the fireboxes. All welds are also examined by modern industrial X-ray apparatus as in the Southern Railway shops.

Experience with Steel Fireboxes. In view of the diverse opinions held in this country on the steel firebox, it will be of interest to record the troubles experienced and how they have been overcome, and to mention improvements which have been found necessary.

A number of cracks have occurred in the throat plate under the syphon necks, and in the side plates and door plates. A typical group of cracks in the throat plate is shown in Fig. 11. Many of the cracks occur at or near the top of the fire where the heat can be very fierce and where scale may form and collect. The cracks may be due in part to these causes.

The operation of pressing the openings in the throat plate for the syphon necks severely strains the plates and some buckling in the radius is unavoidable; the cracks in the throat plate are attributed in part to this cause. The practice now being followed is to cut out two openings in the throat sheet and weld in a separate diaphragm for each of the syphon holes. This method should remove any fear of cracking through undue stressing of the throat sheet.

The cracks are also ascribed to corrosion fatigue and this is no doubt a contributory cause. It will be considered later when dealing with the firebox stays. A large proportion of the cracks are surface cracks only. Such cracks as have occurred have caused no anxiety and are welded readily in situ, though specially trained and selected welders alone are allowed to do this work.

* The author will exhibit plywood models of the inner and outer fireboxes and of a syphon, which will show the press work involved.

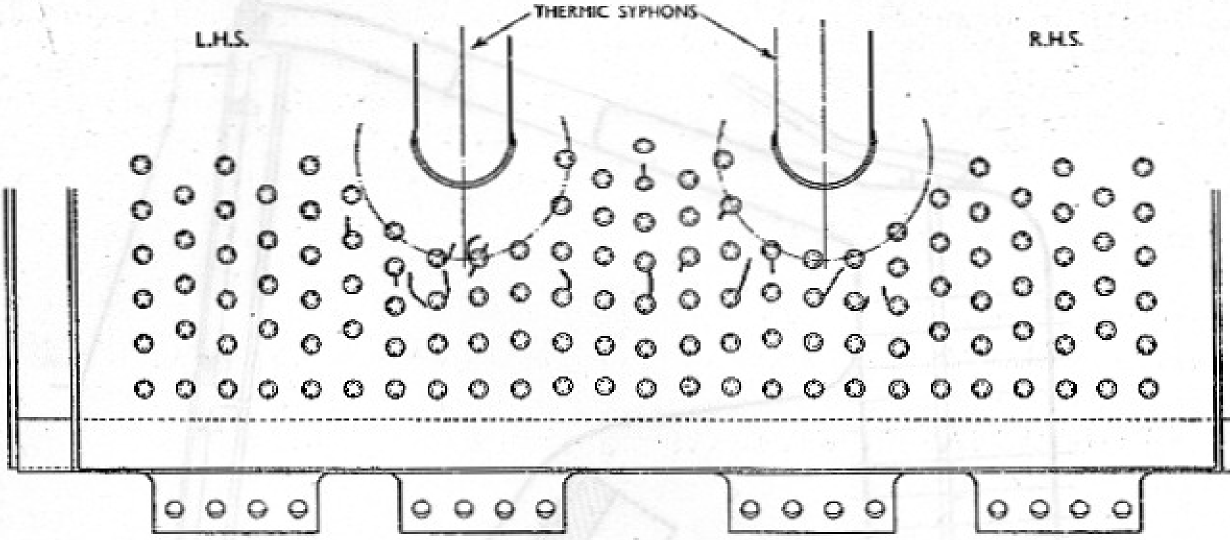


Fig. 11. Cracks in Throat Plate adjacent to Syphon Neck

These fireboxes have now been in service five years and no plate, or part of a plate, has had to be renewed. There has been no trouble at all with any weld in the fireboxes; in fact, they have not been touched since the boilers were put into service.

The repairs to the syphons have only necessitated the welding near the top flange of one small surface crack, the rewelding of the sealing weld at the neck in a few cases, and rewelding a number of cracks, mostly surface cracks about the necks.

Except for recaulking the few stays loosened as a result of low water level referred to below, not a single stay in any syphon has required attention.

Firebox Roof Plates. There have been two instances of overheated firebox roof plates as the result of low water level.

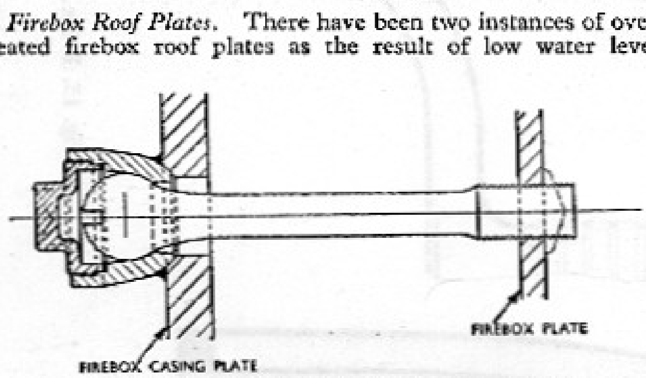


Fig. 13. Flexible Stays round Syphon Neck

Fig. 12, Plate 2, is a photograph taken inside the firebox of Engine No. 21 C.4 shortly afterwards, this being one of the two engines concerned.

All four fusible plugs, three across the forward end of the firebox and one at the centre at the back of the box, had operated and had called attention to the low water level and so prevented more serious damage.

The following is a brief description of the repairs required and how effected:—

150 roof stays leaking: these stays were recaulked.
4 superheater flues leaking slightly: the sealing welds were cut away and rewelded.
2 top rows in the left syphon leaking slightly: they were recaulked.

No new stays were required and the repairs were done at the running shed.

This is a severe test of both design and construction and there can be no doubt that the relatively slight damage was due to the effective action of the fusible plugs and to the two syphons. The syphons, in addition to the added protection they give by discharging water over the crown plate, reduce the area of plate exposed to the heat from the fire, and, by being welded into the crown, assist the heat in the top plate to transmit itself through the syphons plates to the water therein.

The results so far obtained from these steel fireboxes are gratifying, and justify the decision to introduce them. They show that the use of higher steam pressure can be considered on its merits and not be ruled out of consideration because of the copper firebox.

Stays. Steel stays were used throughout. Flexible stays were used only round the syphon necks and the design of these is shown in Fig. 13, the other stays being direct stays. In order to keep down the diameter of the stays so as to make them as flexible as possible, they are spaced at 3½-inch centres, the

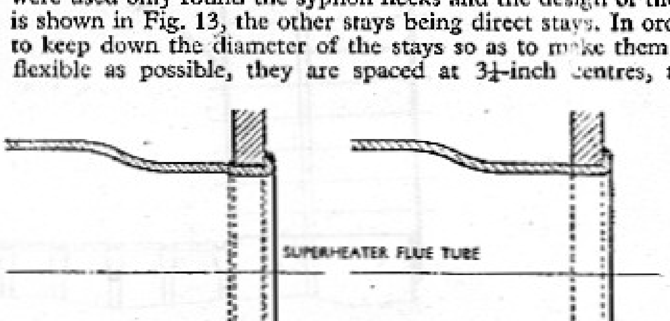


Fig. 14. Fastening of Tube in Firebox Tubeplate

diameter being ¾ inch in the body and ⅞ inch over the screwed ends. The water legs were widened and the increased length was expected to reduce breakage. The results as regards leakage have been extremely good and when the firebox is kept really clean it is practically free from leakage.

There have been a number of broken stays in service, but they do not show any grooving due to corrosion. The average number of stays renewed in the first ten boilers after an average mileage of 141,000 per engine is 97·4. Fig. 5 shows the location of the stays renewed in the boiler of Engine No. 21 C.7, in which the largest number, namely 123, have been replaced after a mileage of 134,000.

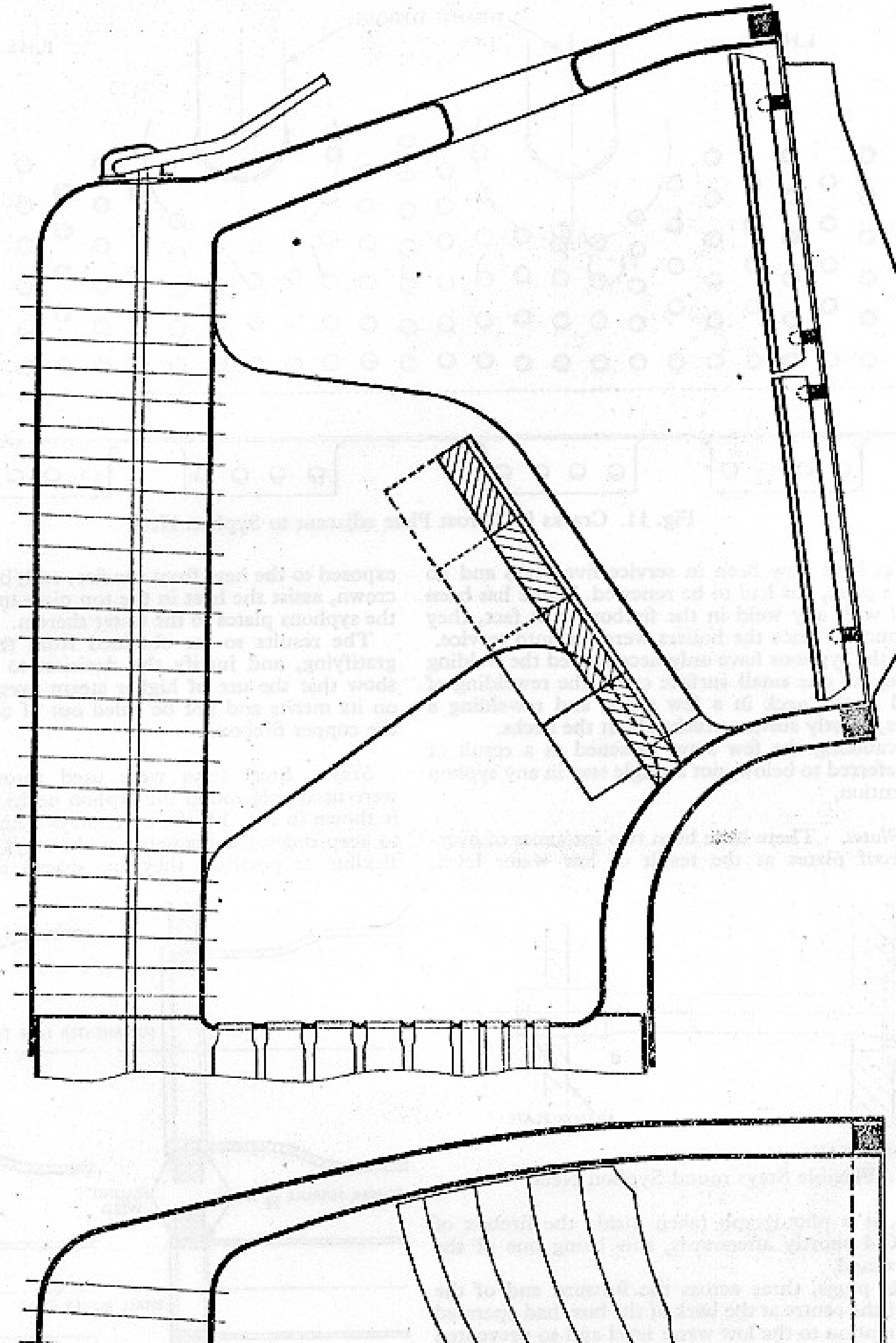
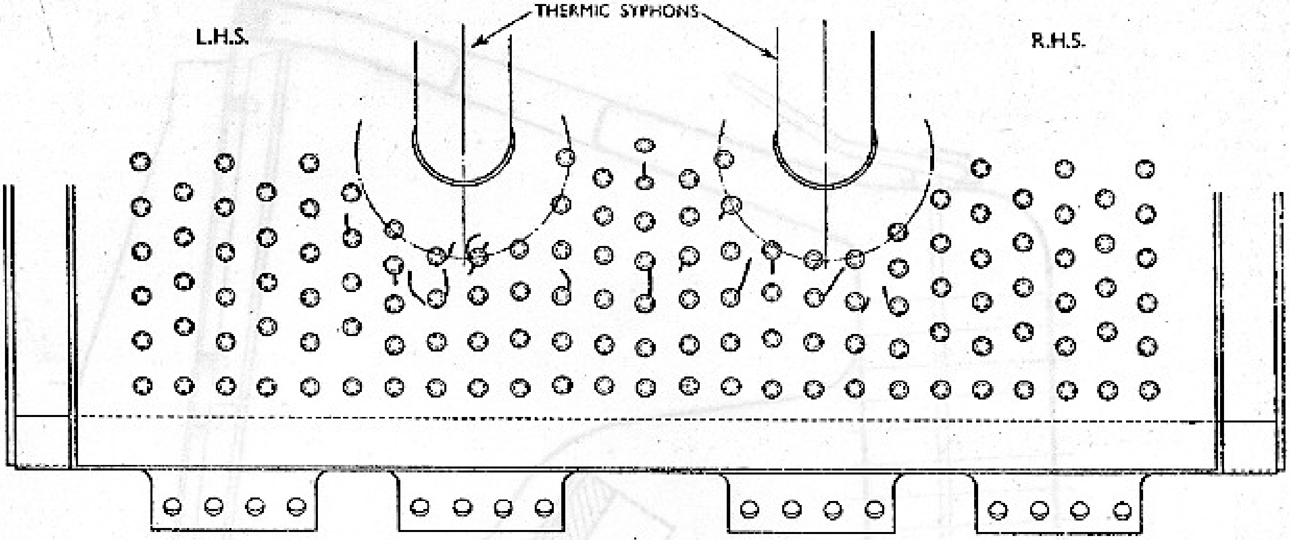


Fig. 15. Brick Arch



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Except for recaulking the few stays loosened as a result of low water level referred to below, not a single stay in any syphon has required attention.

Firebox Roof Plates. There have been two instances of overheated firebox roof plates as the result of low water level.

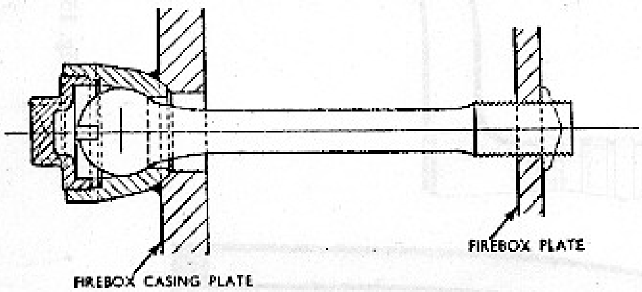


Fig. 13. Flexible Stays round Syphon Neck

Fig. 12, Plate 2, is a photograph taken inside the firebox of Engine No. 21 C.4 shortly afterwards, this being one of the two engines concerned.

All four fusible plugs, three across the forward end of the firebox and one at the centre at the back of the box, had operated and had called attention to the low water level and so prevented more serious damage.

The following is a brief description of the repairs required and how effected:—

- 150 roof stays leaking: these stays were recaulked.
- 4 superheater flues leaking slightly: the sealing welds were cut away and rewelded.
- 2 top rows in the left syphon leaking slightly: they were recaulked.

No new stays were required and the repairs were done at the running shed.

This is a severe test of both design and construction and there can be no doubt that the relatively slight damage was due to the effective action of the fusible plugs and to the two syphons. The syphons, in addition to the added protection they give by discharging water over the crown plate, reduce the area of plate exposed to the heat from the fire, and, by being welded into the crown, assist the heat in the top plate to transmit itself through the syphons plates to the water therein.

The results so far obtained from these steel fireboxes are gratifying, and justify the decision to introduce them. They show that the use of higher steam pressure can be considered on its merits and not be ruled out of consideration because of the copper firebox.

Stays. Steel stays were used throughout. Flexible stays were used only round the syphon necks and the design of these is shown in Fig. 13, the other stays being direct stays. In order to keep down the diameter of the stays so as to make them as flexible as possible, they are spaced at 3¼-inch centres, the diameter being ¾ inch in the body and ⅞ inch over the screwed ends. The water legs were widened and the increased length was expected to reduce breakage. The results as regards leakage have been extremely good and when the firebox is kept really clean it is practically free from leakage.

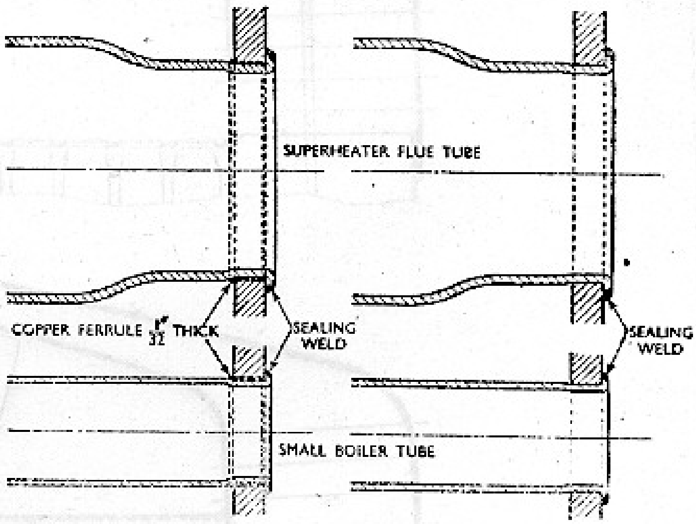


Fig. 14. Fastening of Tube in Firebox Tubeplate

There have been a number of broken stays in service, but they do not show any grooving due to corrosion. The average number of stays renewed in the first ten boilers after an average mileage of 141,000 per engine is 97·4. Fig. 5 shows the location of the stays renewed in the boiler of Engine No. 21 C.7, in which the largest number, namely 123, have been replaced after a mileage of 134,000.

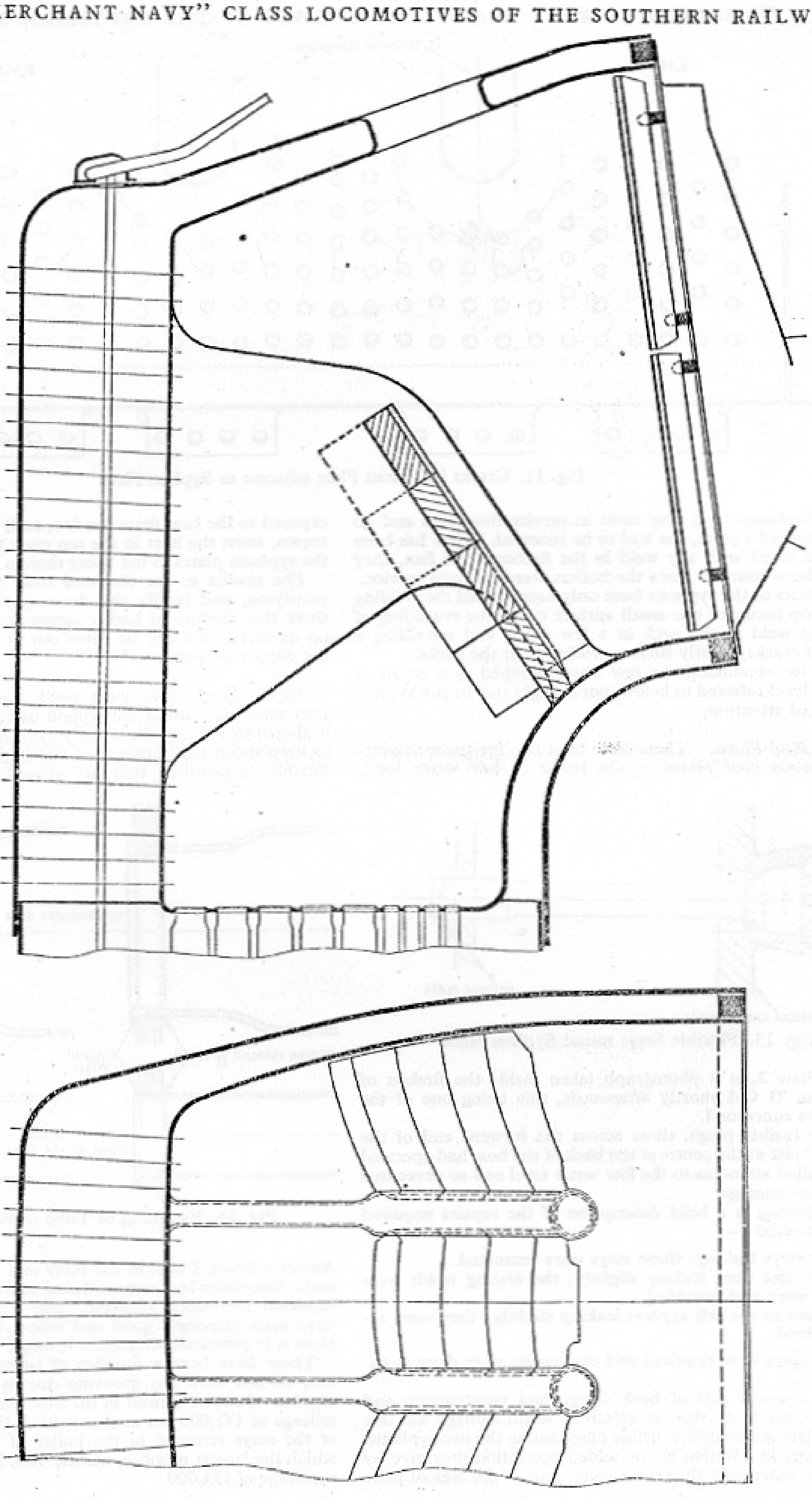


Fig. 15. Brick Arch

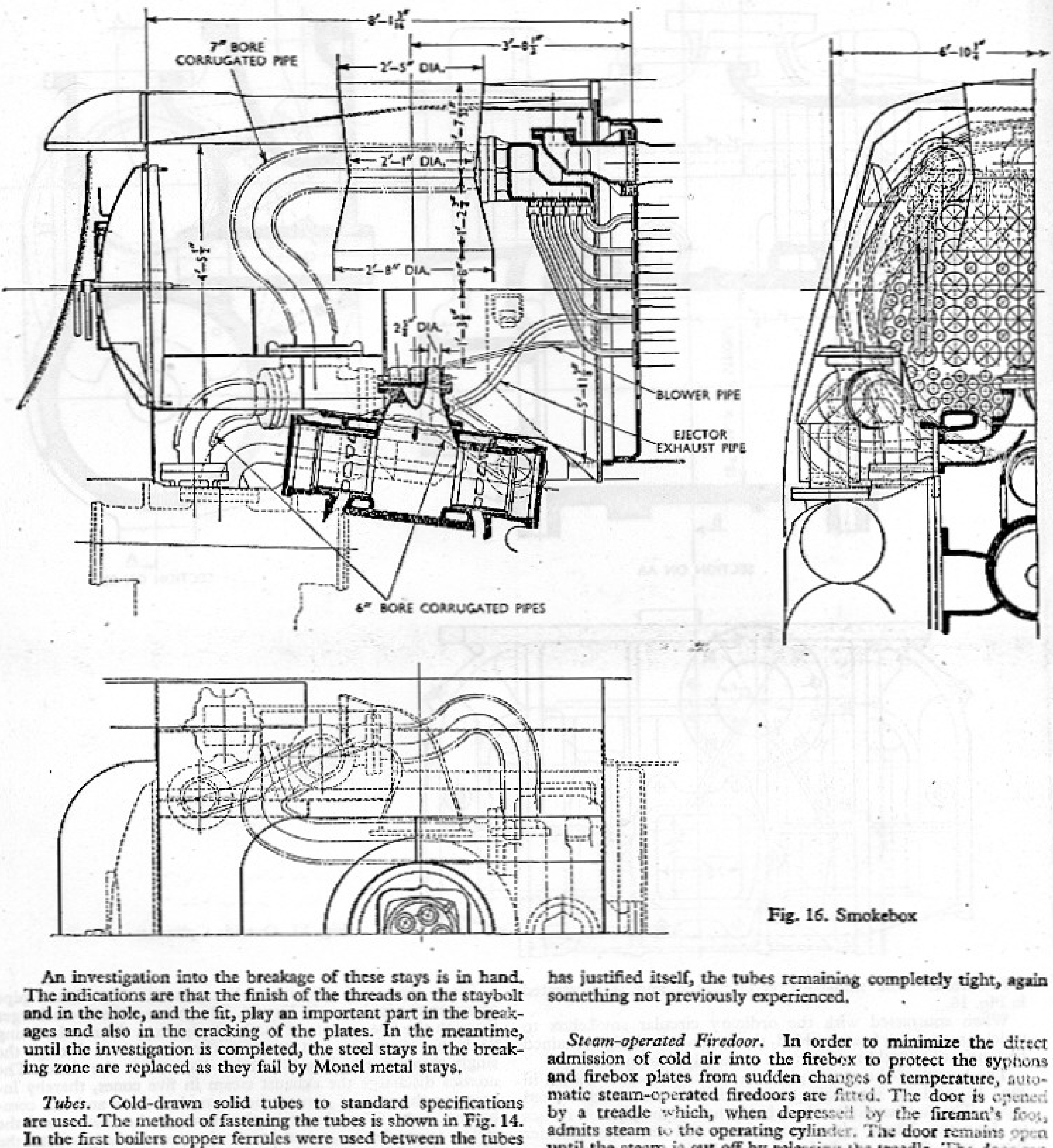


Fig. 16. Smokebox

An investigation into the breakage of these stays is in hand. The indications are that the finish of the threads on the staybolt and in the hole, and the fit, play an important part in the breakages and also in the cracking of the plates. In the meantime, until the investigation is completed, the steel stays in the breaking zone are replaced as they fail by Monel metal stays.

Tubes. Cold-drawn solid tubes to standard specifications are used. The method of fastening the tubes is shown in Fig. 14. In the first boilers copper ferrules were used between the tubes and the tubeplate, following standard U.S.A. practice, but 1/32-inch ferrules. These have now been discarded as they have been found to be unnecessary. The tubes are expanded into the tubeplate and beaded. A sealing weld is made round each tube on the firebox tubeplate.

The results obtained exceed all expectations. The tubes of the first ten engines were renewed after an average mileage of 130,000 whilst in the workshops for repairs. They were fit to run a farther mileage had it not been thought desirable to replace them during general repairs so as to ensure that they would require no attention before the engines came in for the next general repair. The fastening of the tube to the tubeplate has justified itself, the tubes remaining completely tight, again something not previously experienced.

Steam-operated Firedoor. In order to minimize the direct admission of cold air into the firebox to protect the syphons and firebox plates from sudden changes of temperature, automatic steam-operated firedoors are fitted. The door is opened by a treadle which, when depressed by the fireman's foot, admits steam to the operating cylinder. The door remains open until the steam is cut off by releasing the treadle. The door can in this way be opened and closed for each shovel of coal fired almost automatically. The arrangement was adopted from American practice and is excellent in operation. It provides additional protection against any steam blow in the firebox.

Brick Arch. A better brick arch arrangement has been made possible as a result of fitting the two syphons. The arch is in three sections and the outer sections are brought much higher up the sides of the firebox than is possible with the ordinary arch, thereby increasing the air space over the fire, and giving a much better support to the arch. The arch is shown in Fig. 15.

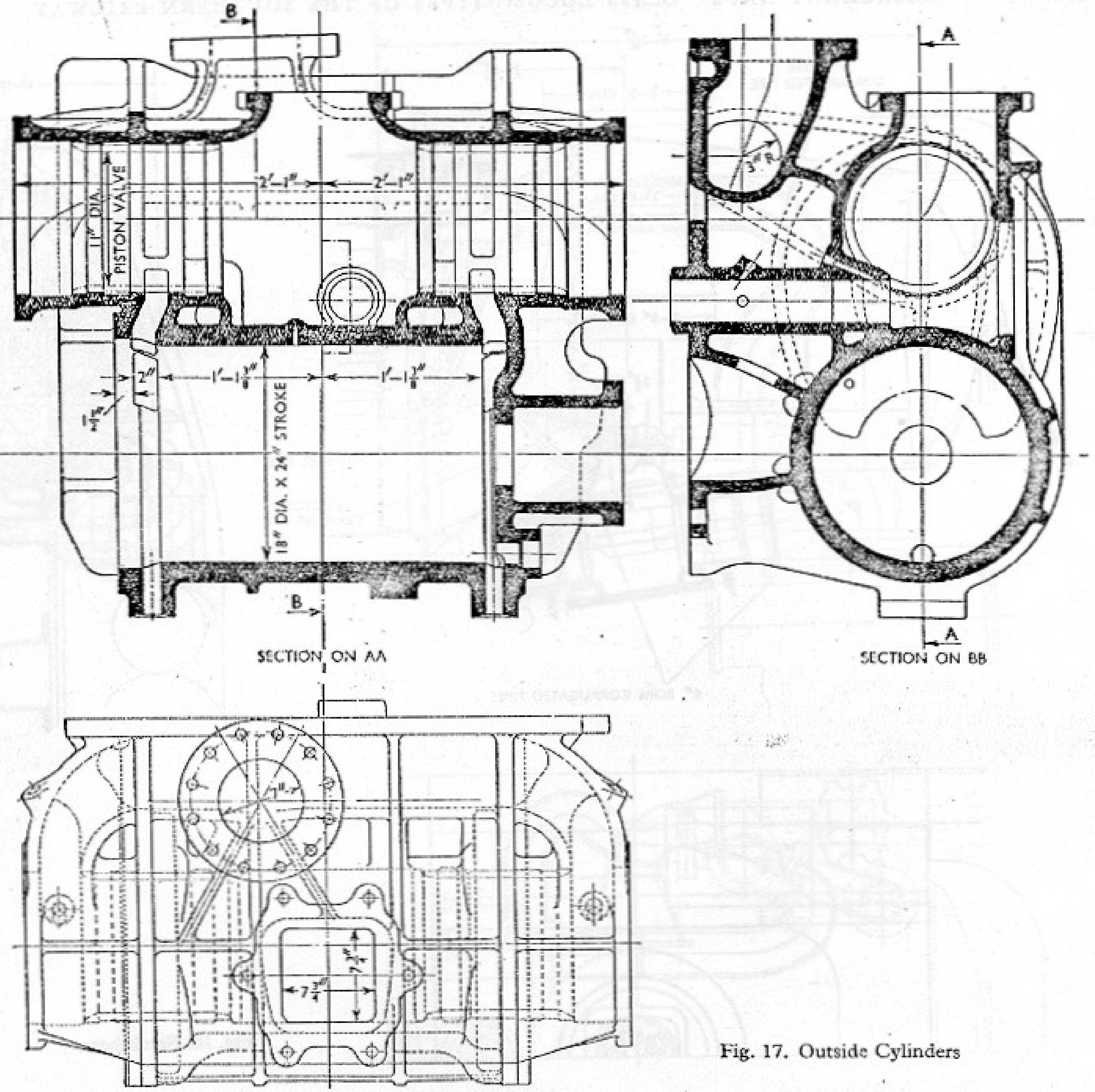


Fig. 17. Outside Cylinders

Smokebox. The smokebox is fabricated and is illustrated in Fig. 16.

When contrasted with the ordinary circular smokebox to which practice has been wedded, the freedom in design obtained by fabricating could not be more strikingly demonstrated.

The layout of the steam pipes in the smokebox is shown in Fig. 16, and an interesting feature is the use of corrugated pipes. The first engines, when built, had plain pipes 7 inches in diameter. These pipes were very rigid and the cylinder steam inlet flanges cracked and even broke due to expansion stresses. The plain pipes were therefore replaced by corrugated pipes.

The two steam pipes from the header are 7 inches in diameter and are continued down to the steam inlets of the outer cylinders at the same diameter. The middle cylinder is fed by two 6-inch pipes branched off the outer 7-inch pipes, each feeding one end.

The flexibility of these pipes is surprising and should ensure steamtight joints over a long period. Since they were fitted no further trouble at the flanges has occurred.

Blast Pipe and Chimney Arrangement. The blast pipe arrangement is shown in Fig. 16. The exhaust steam discharges through the five nozzles of the blast pipe top, the nozzles being 2⅝ inches diameter, and passes to the atmosphere through the single chimney which is 2 ft. 1 in. diameter at the choke. The nozzles discharge the exhaust steam in five cones, thereby increasing the area of contact between the steam and the combustion gases. The blower is placed round the nozzles and the steam from the large and small ejectors discharges into the cavity, thereby preventing a vacuum therein, which might draw in char from the smokebox.

CYLINDERS AND MOTION

Three separate cylinders are used as being more readily cast in the foundry and more convenient to machine. They are not in line, the inner cylinder being behind the outer cylinders and higher in the frames. All three cylinders drive the intermediate coupled axle. The outside cylinders are shown in Fig. 17. The incoming steam enters the casting at the top flange leading to the

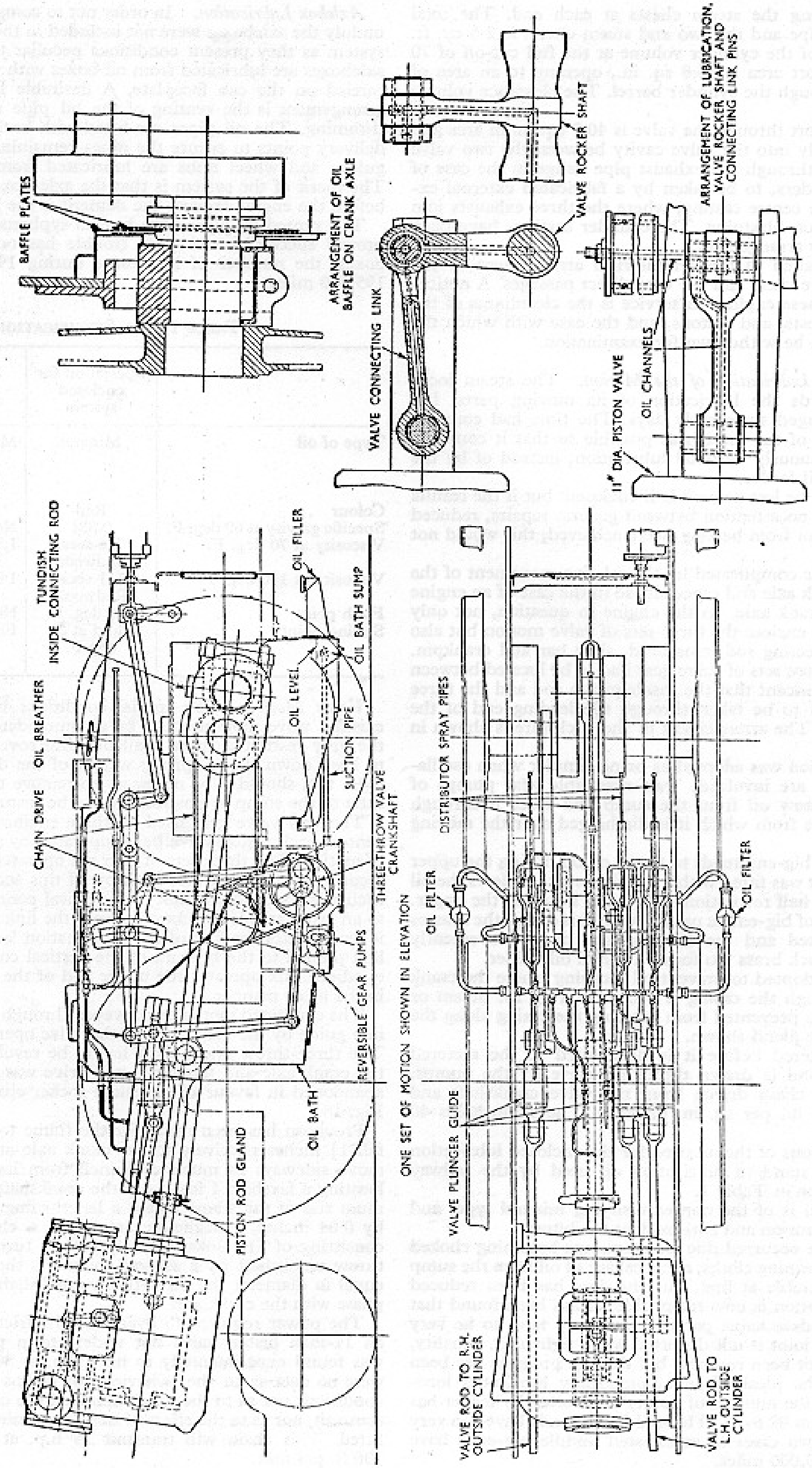


Fig. 18. Oil Bath Arrangement showing Chain Drive

cored pipe feeding the steam chests at each end. The total volume of this pipe and the two end steam chests is 2·6 cu. ft. or 105 per cent of the cylinder volume at the full cut-off of 70 per cent. The port area is 36·8 sq. in., opening to an area of 254·5 sq. in. through the cylinder barrel. The clearance volume is 9·8 per cent.

The exhaust port through the valve is 40·7 sq. in. in area and discharges directly into the valve cavity between the two valve heads. It passes through the exhaust pipe flange in the case of the outside cylinders, to be taken by a fabricated external exhaust pipe to the centre casting, where the three exhausts join under the common blastpipe. The cylinder castings have been simplified by this arrangement.

Attention is called to the symmetrical arrangement of the cylinder and valve chest and the very direct passages. A noticeable feature of these engines in service is the cleanliness of the valves, steam chests, and pistons, and the ease with which the piston valves can be withdrawn for examination.

Enclosure and Lubrication of the Motion. The steam locomotive, as regards the lubrication of its moving parts, has remained unchanged since early days. The time had come to enclose as much of the motion as possible so that it could be lubricated continuously by flood lubrication, instead of by the driver with his oil feeder.

The parts may be less accessible if enclosed, but if the results desired, namely, no attention between general repairs, reduced wear, and freedom from heating, were achieved, this would not matter.

The problem is complicated by the relative movement of the frame to the crank axle and especially so in the case of an engine with an inside crank axle. In the engine in question, not only was it decided to enclose the three sets of valve motion but also the middle connecting rod, crosshead, slide bar and crankpin. Moreover, the three sets of valve gear had to be located between the frames. This meant that the inside piston rod and the three valve guides had to be taken through the leading end of the casing or sump. The arrangement of the enclosure is shown in Fig. 18.

Flood lubrication was adopted as being simpler when oscillatory movements are involved. Two reversible gear pumps of normal design draw oil from the sump and force it through distributing pipes from which it is discharged over the moving parts.

As the middle big-end tends to throw oil off during the upper half revolution, it was fitted with a tundish which collects the oil during the lower half revolution and retains it during the upper. The forked type of big-end is used as with this design the brasses are well supported and the oil ways are more conveniently arranged. The back brass too forms a useful oil holder.

The method adopted to prevent oil escaping where the crank axle passes through the casing is shown in Fig. 18. Steam or water vapour was prevented from entering the casing along the piston rod by the gland shown.

The oil is filtered before it is distributed to the metered delivery pipes, and is drawn through a sieve by the pumps. The pumps are chain driven from the valve crankshaft and deliver oil at 20 lb. per sq. in. pressure. The sump holds 40 gallons of oil.

The specifications of the oil used for the enclosed lubrication system and the standard lubricating oil used by the railway company are given in Table 1.

The special oil is of the non-emulsifying mineral type, and contains anti-corrosion and anti-oxident inhibitors.

At first trouble occurred due to the pumps becoming choked with fluff from cleaning cloths, etc. Leakage of oil from the sump was also considerable at first, but this loss has been reduced and the consumption is now reasonable. It has been found that the faces of the detachable parts of the sump have to be very rigid so that the joint is not distorted when tightened. Finality, has, of course, not been reached, but definite progress has been made towards the ideal of an automatically lubricated locomotive. As it is, the number of points to be oiled by feeder has been reduced from 92 to 31. The middle big-ends have run very well, and only two cases of overheated middle big-ends have occurred in 1,400,000 miles.

Axlebox Lubrication. In order not to complicate the problem unduly the axleboxes were not included in the pump lubrication system as they present conditions peculiar to themselves. The axleboxes are lubricated from oil boxes with worsted trimmings carried on the cab faceplate. A desirable feature in such an arrangement is the venting of the oil pipe round the worsted trimming. The oil pipes are fitted with broken syphons at the delivery points to ensure the pipes remaining full of oil. The guides and wheel hubs are lubricated from the same boxes. The merit of the system is that the axle-boxes can be given oil before the engine moves; the demerit is the piping involved.

The vented oil pipes with broken syphons at the boxes have proved successful and little trouble has occurred with axleboxes, the number of hot boxes during 1944 being one per 195,000 miles.

TABLE 1. OIL SPECIFICATIONS

	Special oil for enclosed system	Standard S.R. oil as used for open motion
Type of oil	Mineral	Mixture 85 per cent filtered dark mineral and 15 per cent rape.
Colour	Red	
Specific gravity at 60 deg. F.	0·881	Not to exceed 0·930.
Viscosity at 70 deg. F.	716 secs. Redwood	1,350–1,400 secs. Redwood.
Viscosity at 140 deg. F.	111 secs. Redwood	145–155 secs. Redwood.
Flash point	395 deg. F.	Not below 380 deg. F.
Setting point	Fluid at 20 deg F.	Fluid at 20 deg. F.

Valve Motion. The special conditions were such that no existing valve motion could be accommodated satisfactorily in the very restricted space available. Moreover, it was desirable to keep down the unsprung weight of the driving crank axle: then, too, should it be necessary to remove the driving axle, as little of the sump as possible should be disturbed.

The new valve gear used on these engines was therefore invented, each piston valve being operated by an independent set of motion. The three sets of gear are operated by a three-throw secondary crankshaft. Each throw of this secondary crankshaft oscillates its quadrant link by a vertical connecting rod pinned to an arm extended backwards from the link: at the same time, it reciprocates the foot of the combination lever by a horizontal link pinned to the big end of the vertical connecting rod. The quadrant link operates the upper end of the combination lever in the usual manner.

The combined motion is conveyed through a plunger working in a guide by the valve rods to the valve operating rocker shaft. The three-throw crank shaft has to be revolved in phase with the crank axle and though a gear drive was considered, it was abandoned in favour of the silent rocker chain drive shown in Fig. 18.

Provision has been made for the frame to rise 2 inches and fall 1½ inches relatively to the crank axle and for this axle to move sideways as much as ¼ inch from its mid-position. By locating a layshaft 4 feet from the crankshaft centre, the maximum rise of the frame meant a lengthening of the hypotenuse by 0·04 inches, a negligible amount in a chain 11·8 feet long consisting of 118 links. The layshaft in turn drives the three-throw crankshaft by a second chain. As the chain wheels are equal in diameter the three-throw crankshaft is driven truly in phase with the crank axle.

The power required to overcome the frictional resistance of an 11-inch piston valve not under steam pressure and cold, was found experimentally to be 3 h.p. at 300 r.p.m. As there were no data as to the behaviour of chains under locomotive conditions nor as to the maximum load the chain might have to transmit, nor as to the effect of snatch, a chain 2 inches wide was fitted. This chain will transmit 75 h.p. at a chain speed of 130 ft. per min.

	Cut off	Pre-admission				Lead			Valve opening			Cut off						Angle pre-admission to cut off		Exhaust opens						Expansion				Exhaust opens above full port		Exhaust closes				Valve travel
		%		Angle								%			Angle					%			Angle			%		Angle				%		Angle		
		F	B	F	B	F	B	Diff.	F	B	Diff.	F	B	Diff.	F	B	Diff.	F	B	F	B	Diff.	F	B	Diff.	F	B	F	B	F	B	F	B	F	B	
FORWARD																																				
Outside	15%	99·0	99·1	169	169	1/8"	1/8"	–	12/64"	12/64"	–	15½	15	½	45¼	47¾	-2½	56¼	58½	65	64	1	105¼	109	-3¾	49½	49	60	61¼	12/64"	12/64"	64	65	109	105¾	3 40/64"
Inside	·	98·9	99·1	169	169½	·	·	–	13/64"	13/64"	–	16	14	2	45¼	46½	-1¼	56¼	57	65¼	63	2¼	106	108½	-2½	49¼	49	60¾	62	13/64"	13/64"	63	65¼	108½	106	3 42/64"
Outside	20%	99·1	99·2	170	170	·	·	–	15/64"	16/64"	–	20	20	–	51¼	55½	-4¼	61¼	65½	68½	67¼	1¼	109¾	113	-3¼	48½	47¾	58½	57½	16/64"	16/64"	67¼	68½	113	109¾	3 48/64"
Inside	·	99·2	99·3	171	172¼	·	·	–	16/64"	16/64"	–	20¾	19¼	1½	52	54½	-2¾	61	62½	70½	67¼	3¼	111¼	113¾	-2½	49¾	48	59¼	59	16/64"	16/64"	67¼	70½	113¾	111¼	3 48/64"
Outside	25%	99·5	99·5	172	172½	·	·	–	20/64"	20/64"	–	25	25	–	58	63	5	66	70½	72½	70¾	1¾	115	117¼	-2¼	47½	45¾	57	54½	20/64"	20/64"	70¼	72½	117¼	115	3 56/64"
Inside	·	99·2	99·4	171½	172¾	·	·	–	20/64"	20/64"	–	25¾	24¼	1½	58½	62¼	-3¾	67	69½	73¾	70½	3¼	115¾	117¼	-1½	48	46¼	57¼	55	20/64"	20/64"	70½	73¾	117¼	115¾	3 56/64"
Outside	30%	99·5	99·6	172	173	·	·	–	23/64"	24/64"	-1/64"	29½	30	-½	63¾	69¼	-5½	71¾	76¼	75½	73¼	2¼	118½	120¼	-1¾	46	43¼	54¾	51	24/64"	23/64"	73¼	75½	120¼	118½	3 63/64"
Inside	·	99·4	99·6	172¼	173¾	·	·	–	23/64"	24/64"	-1/64"	30½	29	1½	64	68½	-4½	71¾	75¼	76½	72¾	3¾	119	120½	-1½	46	43½	55	52	24/64"	23/64"	72¾	76½	120½	119	3 63/64"
Outside	40%	99·6	99·7	173¾	174¾	·	·	–	31/64"	34/64"	-3/64"	40	39¾	¼	76¼	81	-4¾	82½	86¼	80¼	77¾	2½	125¾	126	-¼	40¼	38	49½	45	34/64"	31/64"	77¾	80¼	126	125¾	4 17/64"
Inside	·	99·6	99·8	174	175	·	·	–	32/64"	36/64"	-4/64"	41	39	2	77	81	-4	83	86	81½	77¾	3¾	126½	126½	–	40½	38¾	49½	45½	36/64"	32/64"	77¾	81½	126½	126½	4 20/64"
Outside	50%	99·7	99·7	175	175¾	·	·	–	42/64"	47/64"	-5/64"	50½	49¼	1¼	88½	92	-3½	93½	96¼	84½	82	2½	132¼	132	-¼	34	32¾	43¾	40	47/64"	42/64"	82	84½	132	132¼	4 41/64"
Inside	·	99·7	99·8	175	175¼	·	·	–	43/64"	50/64"	-7/64"	51½	48¼	3¼	88¾	91½	-2½	93¾	96¼	85¼	81½	3¾	132½	132	½	33¾	33¼	43¾	40½	50/64"	43/64"	81½	85¼	132	132½	4 45/64"
Outside	60%	99·8	99·8	175¾	176½	·	·	–	58/64"	66/64"	-8/64"	61½	58½	3	101	102¼	-1¼	105¼	105¾	88¼	85¾	2½	138¾	137¾	1	26¾	27¼	37¼	35½	66/64"	58/64"	85¾	88¼	137¾	138¾	5 12/64"
Inside	·	99·8	99·9	176	176½	·	·	–	57/64"	69/64"	-12/64"	62¼	58	4¼	101	103	-2	105	106½	88½	85½	3	139	137¾	1¼	26¼	27½	38	34¾	69/64"	57/64"	85½	88½	137¾	139	5 12/64"
Outside	65%	99·8	99·8	176½	177	·	·	–	70/64"	78/64"	-8/64"	67	63¼	3¾	108	108¼	-¼	111½	111¼	90	87½	2½	142¼	140¾	1½	23	24¼	34¼	32½	78/64"	70/64"	87½	90	140¾	142¼	5 36/64"
Inside	·	99·8	99·9	176	176½	·	·	–	68/64"	82/64"	-14/64"	67	63	4	107	108½	-1½	111	112	90¼	87¼	3	142	140½	1½	23¾	24¼	35	32	82/64"	68/64"	87¼	90¼	140½	142	5 38/64"
Outside	70%	99·9	99·9	177	176½	·	·	–	84/64"	94/64"	-10/64"	72	68	4	114¼	113¾	½	117¼	117	91½	89½	2	145	143½	1½	19½	21½	30¾	29¾	94/64"	84/64"	89½	91½	143½	145	6 2/64"
Inside	·	99·9	99·9	177½	177	·	·	–	81/64"	98/64"	-17/64"	72¼	67½	4¾	113½	114	-½	116	117	91¾	89¼	2½	145¼	144	1¼	19½	21¾	31¼	30	98/64"	81/64"	89¼	91¾	144	145¼	6 3/64"
BACKWARD																																				
Outside	15%	98·7	99·3	166½	170	1/8"	1/8"	–	12/64"	13/64"	-1/64"	13	17	-4	40	50½	-10½	53½	60½	65	63	2	104½	107	-2½	52	46	64½	56½	13/64"	12/64"	63	65	107	104½	3 41/64"
Inside	·	99·1	99·4	167¾	171½	·	·	–	10/64"	14/64"	-4/64"	13	17½	-4½	40	51½	-11½	52¼	60	67	63¾	3¾	106¼	108¼	-2	54	46	66¼	56¾	14/64"	10/64"	63¾	67	108¼	106¼	3 40/64"
Outside	20%	99·2	99·4	169½	171½	·	·	–	13/64"	17/64"	-4/64"	17	22½	-5½	46½	58½	-12	57	67	68¾	67	1¾	109¼	111¾	-2½	51¾	44½	62¾	53¼	17/64"	13/64"	67	68¾	111¾	109¼	3 46/64"
Inside	·	99·3	99·5	169½	172½	·	·	–	12/64"	18/64"	-6/64"	17¼	22½	-5¼	46½	59	-12½	57	66½	70½	66½	4	110½	112	-1½	53¼	44	64	53	18/64"	12/64"	66½	70½	112	110½	3 46/64"
Outside	25%	99·3	99·4	170¾	172¾	·	·	–	16/64"	22/64"	-6/64"	22¼	28¼	-6	54	66¼	-12¼	63¼	73½	72¾	70	2¾	114¾	115½	-1	50½	41¾	60½	49¾	22/64"	16/64"	70	72¾	115½	114½	3 54/64"
Inside	·	99·4	99·6	171½	174¼	·	·	–	15/64"	24/64"	-9/64"	22½	27¾	-5¼	53¾	66½	-12¾	62¼	72¼	74½	70	4½	116¾	116½	-¼	52	42¼	62½	50	24/64"	15/64"	70	74½	116½	116¾	3 55/64"
Outside	30%	99·4	99·5	171½	173½	·	·	–	20/64"	27/64"	-7/64"	27½	33	-5½	61	72½	-11½	69¾	79	75½	72½	3	118¼	118½	-¼	48	39½	57¼	46	27/64"	20/64"	72½	75½	118½	118¼	3 63/64"
Inside	·	99·5	99·6	172	174¼	·	·	–	18/64"	29/64"	-11/64"	27¾	32¼	-4½	60¼	72	-11¾	68¼	77¾	76½	72¼	4¼	119	119	–	48¾	40	58¾	47	29/64"	18/64"	72¼	76½	119	119	3 63/64"
Outside	40%	99·6	99·7	173½	175½	·	·	–	28/64"	38/64"	-10/64"	38½	42¼	-3¾	73¾	83½	-9¾	80½	88	81	77¼	3¾	126	124¾	1¼	42½	35	52½	41½	38/64"	28/64"	77¼	81	124¾	126	4 19/64"
Inside	·	99·6	99·7	173¼	175½	·	·	–	27/64"	41/64"	-14/64"	39	41¼	-2¼	73½	83	-9½	80¼	87½	81½	76¾	4¾	126¼	124¾	1½	42½	35½	52¾	41¾	41/64"	27/64"	76¾	81½	124¾	126¼	4 20/64"
Outside	50%	99·7	99·7	174	175¾	·	·	–	40/64"	55/64"	-15/64"	49½	50¾	-1½	86	93¼	-7¼	92	97½	84¾	81	3¾	131¼	130¾	1½	35½	30½	45¾	37	55/64"	40/64"	81	84¾	130¾	131¾	4 47/64"
Inside	·	99·7	99·8	174¾	176¾	·	·	–	38/64"	56/64"	-18/64"	50	50	–	86¼	93¼	-7	91½	96½	85¾	81	4¾	133	130½	2½	35¾	31	46¾	37¼	56/64"	38/64"	81	85¾	130½	133	4 46/64"
Outside	60%	99·8	99·8	175½	177	·	·	–	56/64"	75/64"	-19/64"	61	60	1	100	103½	-3½	104½	106½	89	85¾	3¼	139¼	136¼	3	28	25¼	39½	32¾	75/64"	56/64"	85¼	89	136¼	139¼	5 17/64"
Inside	·	99·8	99·9	176¼	177½	·	·	–	54/64"	76/64"	-22/64"	61½	58½	3	99¾	103	-3¼	103½	105½	89½	85¼	4¼	139½	136¾	2¾	28	26¾	39¾	33¾	76/64"	54/64"	85¼	89½	136¾	139½	5 18/64"
Outside	65%	99·8	99·8	175½	177	·	·	–	68/64"	88/64"	-20/64"	66	63¾	2¼	105½	108¼	-2¾	110	111½	90½	87	3½	141¾	138¾	3	24¼	23¼	36½	30½	88/64"	68/64"	87	90½	138¾	141¾	5 44/64"
Inside	·	99·8	99·9	176	177¼	·	·	–	66/64"	92/64"	-26/64"	67	63¼	3¾	106¾	108½	-2	110½	112¼	90¾	87	3¾	142¾	139½	3¼	23¾	23¾	36¼	31	92/64"	66/64"	87	90¾	139½	142¾	5 46/64"
Outside	70%	99·9	99·9	176¼	177½	·	·	–	81/64"	102/64"	-21/64"	71½	68½	3	112½	113½	-1	116½	116	92	89	3	145¾	142½	3¼	20½	20½	33¼	29	102/64"	81/64"	89	92	142½	145¾	6 7/64"
Inside	·	99·8	99·9	176½	177¾	·	·	–	80/64"	108/64"	-28/64"	72¼	68¾	4¾	113	113½	-½	116½	116	92¼	93¾	-1½	146	142¾	3¼	20	25½	33	29	108/64"	80/64"	93¾	92¼	142¾	146	6 12/64"

Fig. 19. Table of Valve Events

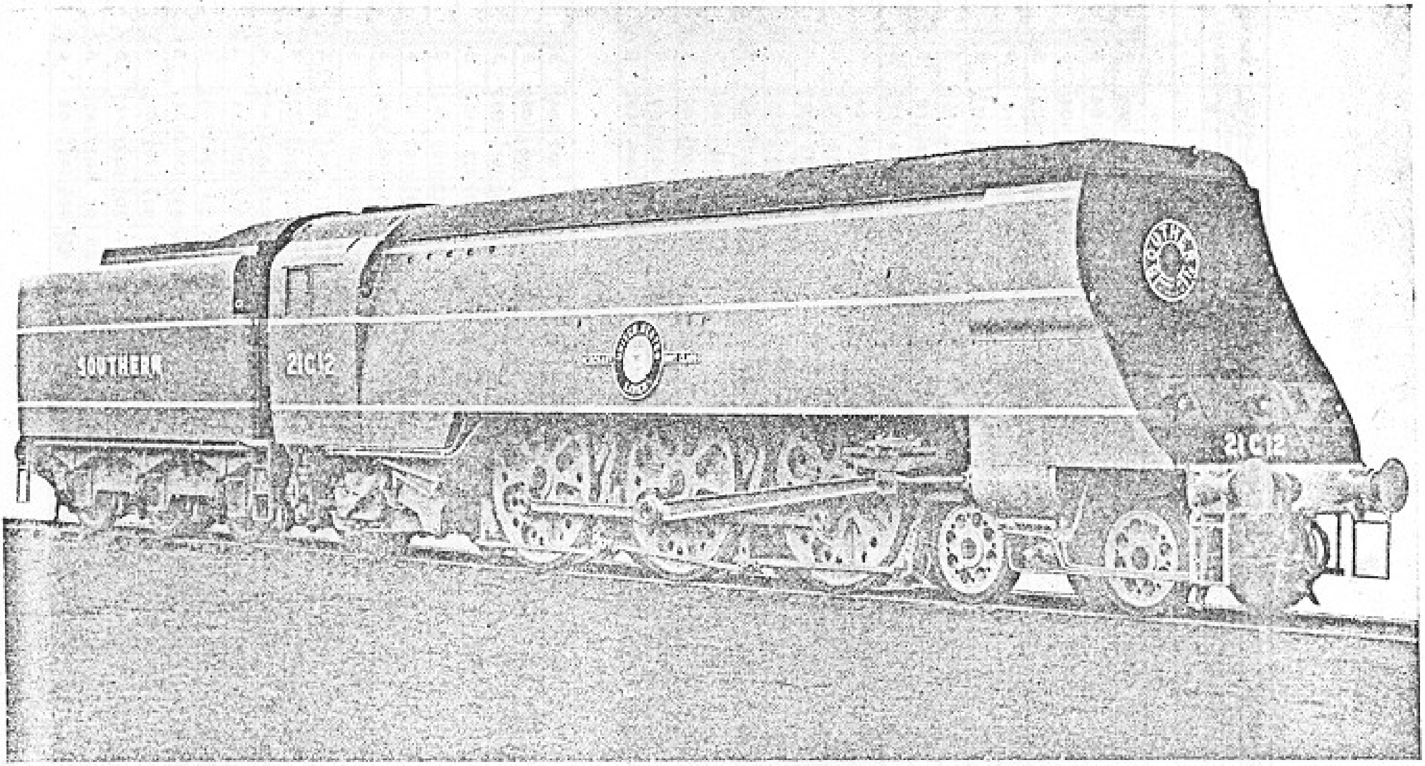


Fig. 3. Side View of Locomotive

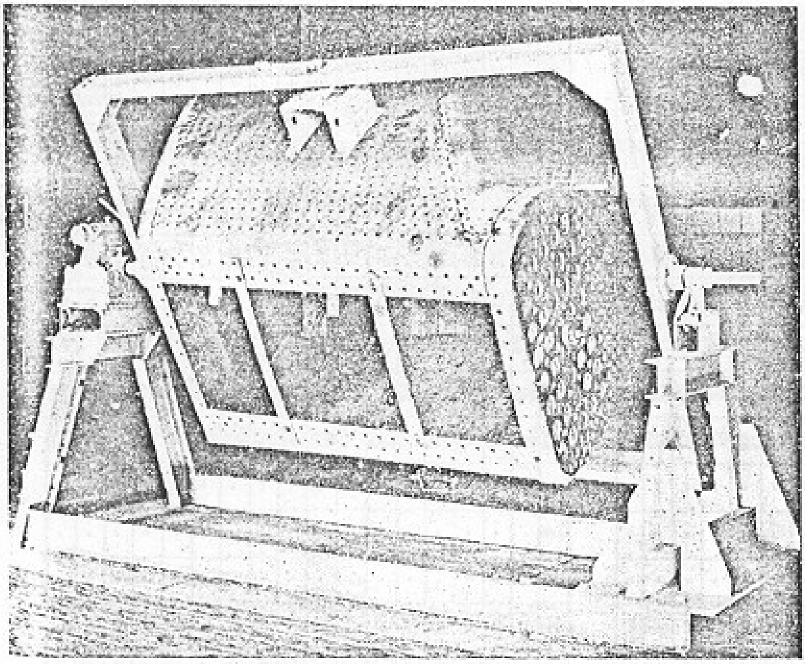


Fig. 7. Manipulator for Welding

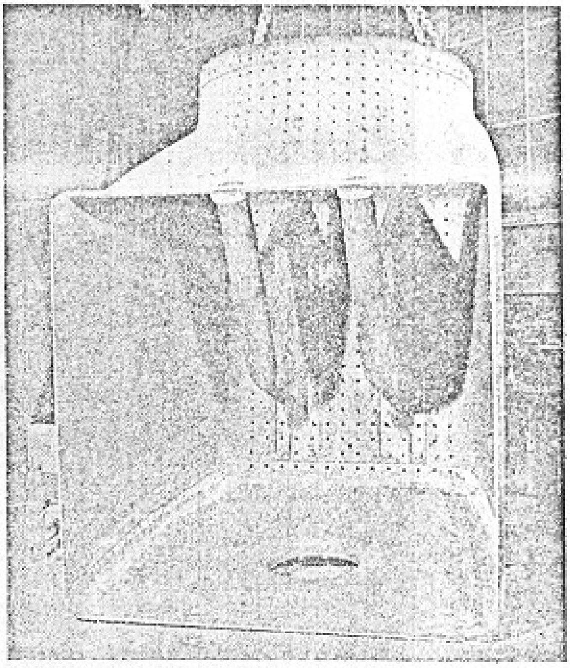


Fig. 8. View of the Inner Firebox

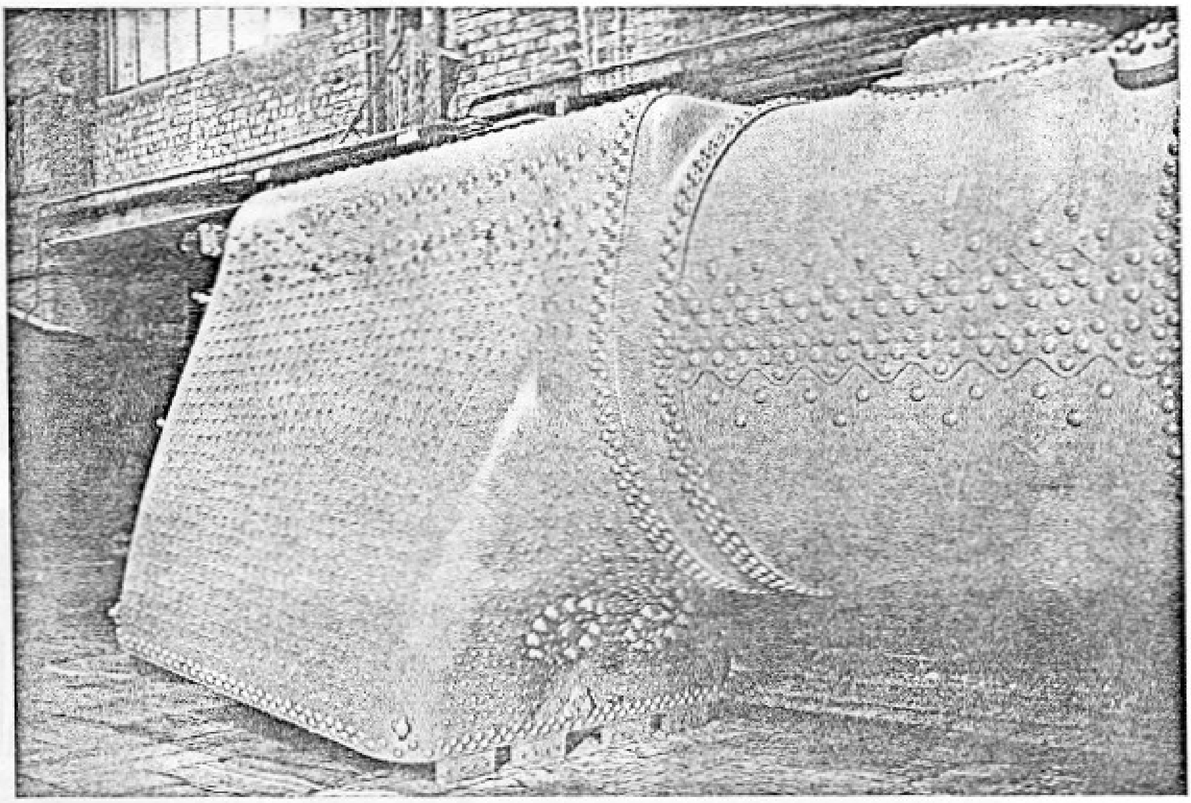


Fig. 9. View of Assembled Firebox

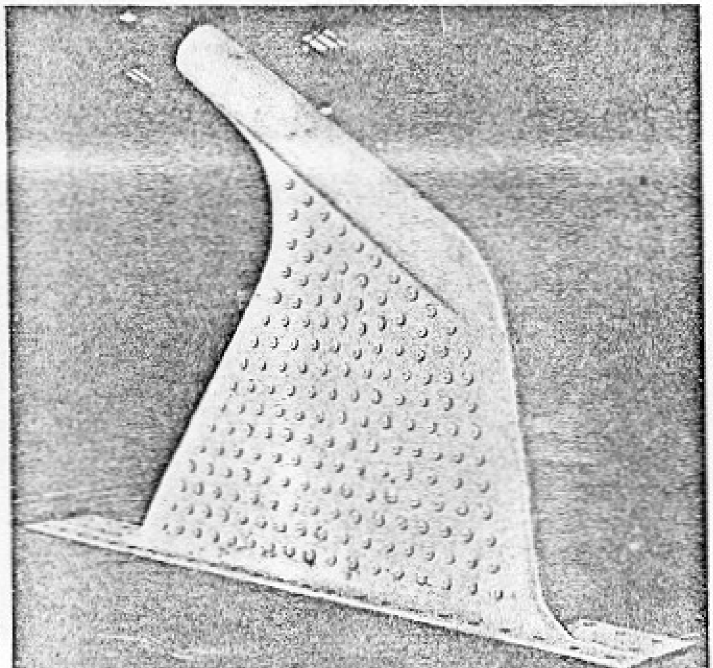


Fig. 10. Showing the construction of Nicholson Syphons

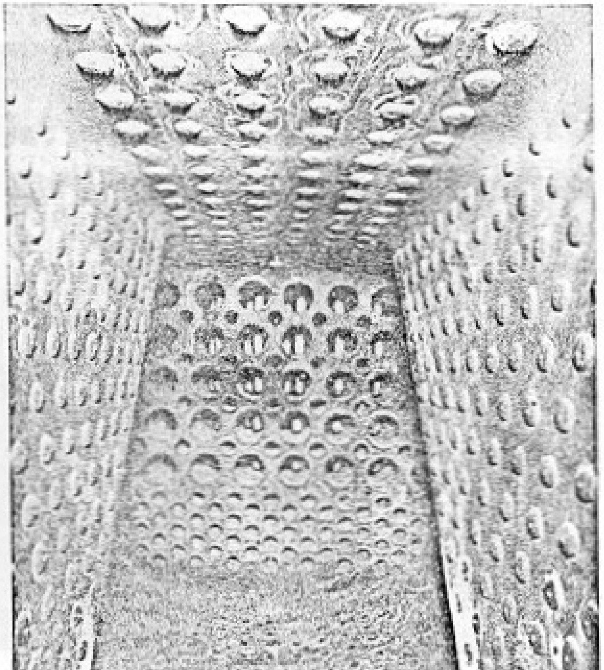


Fig. 12. Showing Overheated Firebox Roof Plates

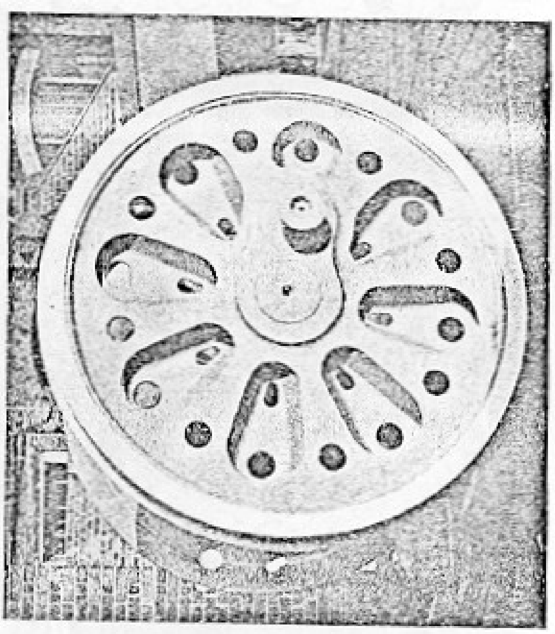


Fig. 21. Wheel of the B.F.B. Type

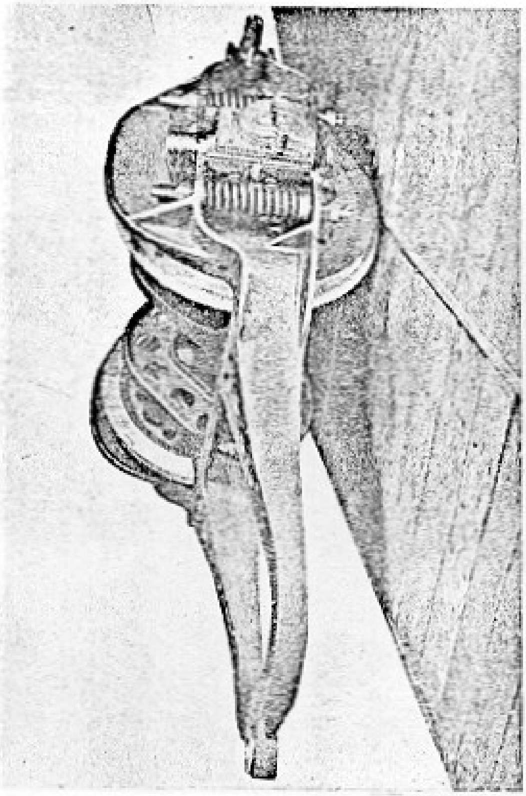


Fig. 25. View of Trailing Truck

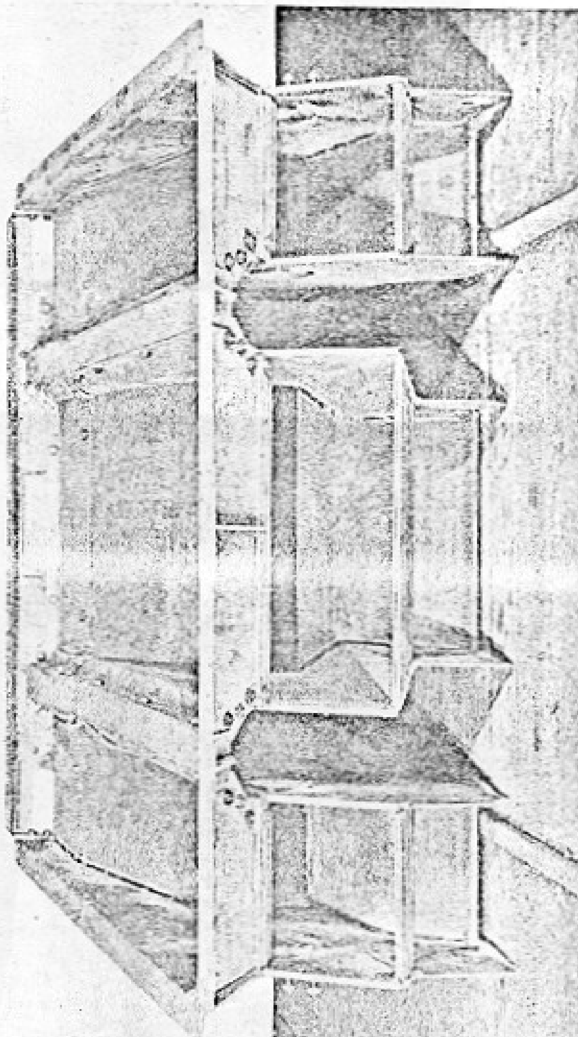


Fig. 26. View of Ashpans before Air Doors are Fitted

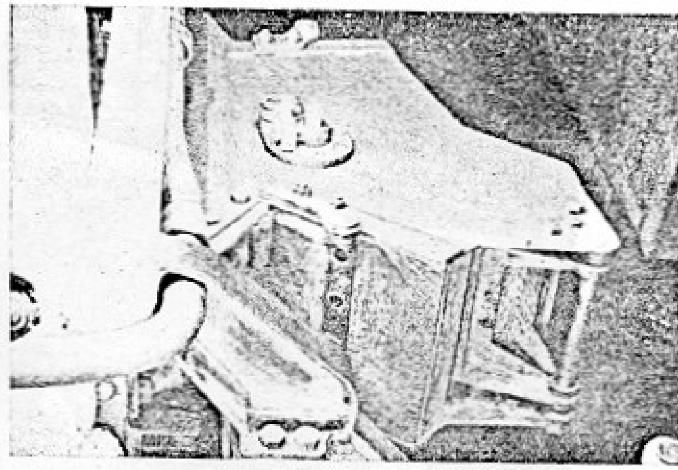


Fig. 27. Outside Ashpan showing Hopper

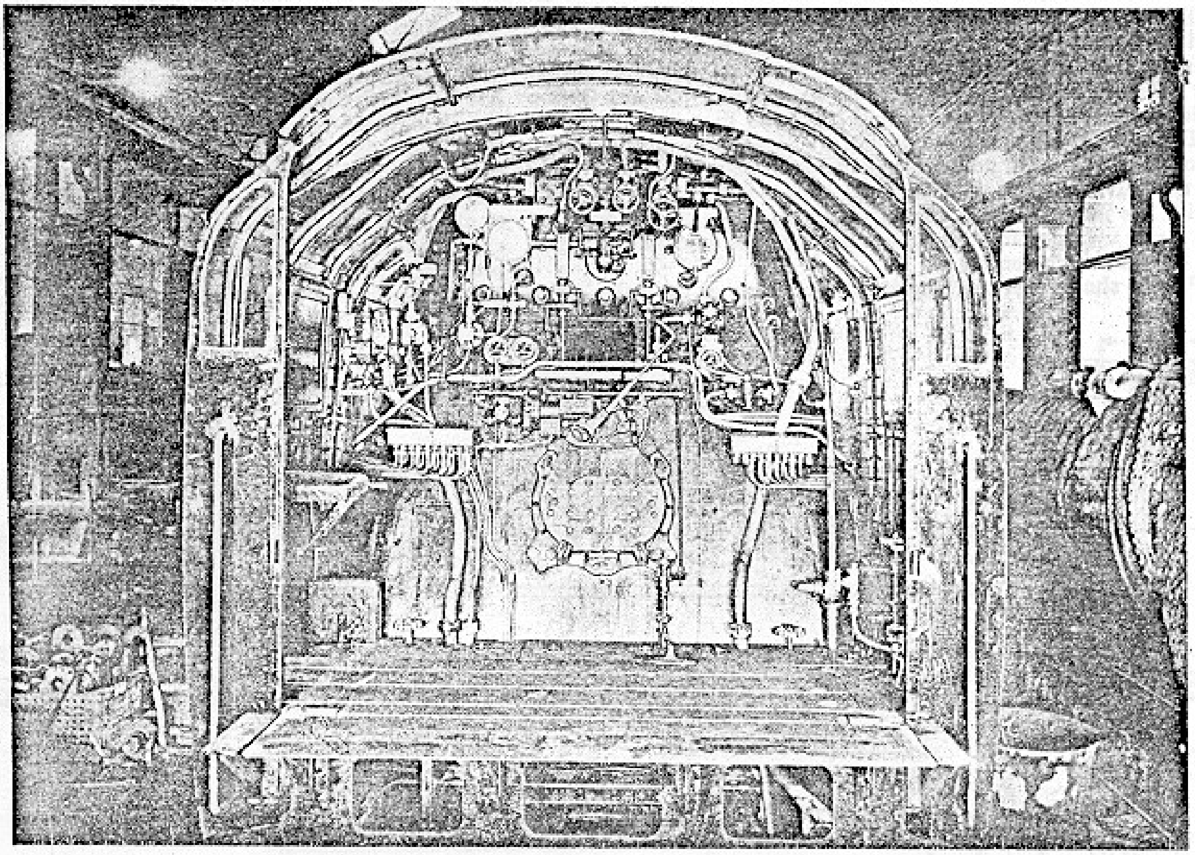


Fig. 30. View of Cab showing Glazed Screens

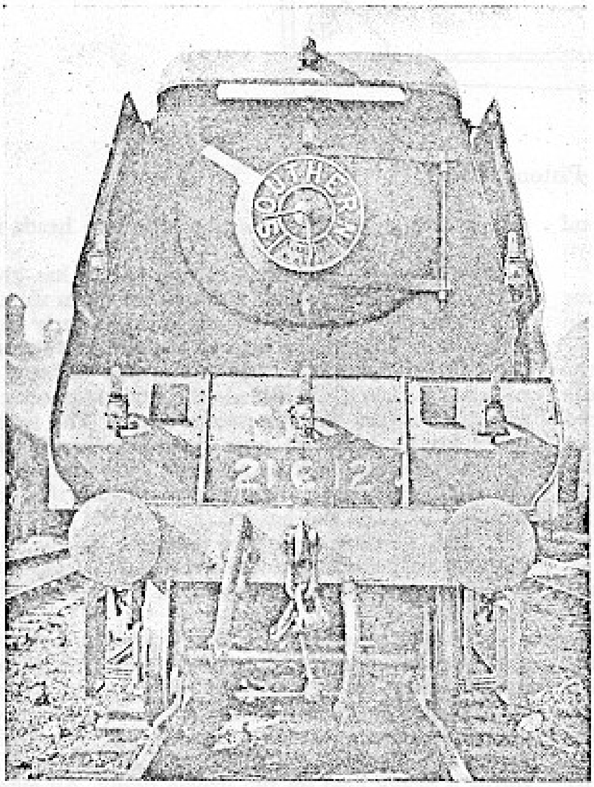


Fig. 29. Arrangement of Front of Locomotive

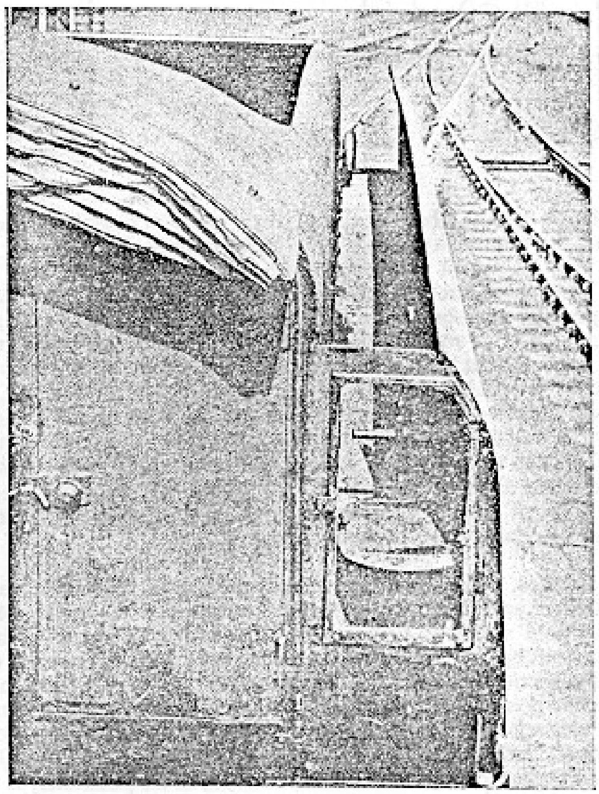


Fig. 31. View of Trough along the Tender

The weight of the toothed wheel secured to the axle is 125 lb. and half the weight of the chain is 30 lb., a total of 155 lb. Three eccentrics plus the portion of the eccentric rods carried by the axle would have weighed 1,281 lb., so that the new drive reduces the unsprung axle weight by 1,126 lb.

The valve motion is shown in Fig. 18. The throw of the three-throw crank shaft for convenience of layout was made 4½ inches. As the valve travel is 6¼ inches the rocker shaft in the exhaust cavity has unequal arms, the driving arm being $2\frac{27}{32}$ inches for the inside cylinder and $2\frac{31}{32}$ inches for the outside cylinders, and the driven 8-inch centres.

Fig. 18 shows that the lengths of the levers of the valve gear relative to the throw of the three-throw crankshaft are good and the angularity small. The valve events obtained are shown in Fig. 19, and it will be seen they are excellent.

The valve motion itself has given no trouble and has one especially commendable feature in that the valve events remain unchanged in service, the engine keeping its regular beat.

A point that was considered was the effect of slackness in the chain. Assuming a sag of as much as 3 inches, the design of the rocker chain is such that most of the sag under load is absorbed by the rise of the rockers up the teeth. Only the small remainder affects the valve events, which will be delayed. This can be corrected by altering the cut-off. The chain drive has behaved well, in spite of the many misgivings the use of chains gave rise to, and no chains have broken to date.

Circlips. For locating motion pins, etc., "circlips" of both internal and external types are employed in place of conventional methods using taper pins or washers and split pins. The circlip, designed so that the moment of inertia of the cross-section at any point is proportional to the bending moment at that point, can be removed and replaced without detriment to its material. This application, new to locomotive practice, has proved satisfactory in service, no failure of a circlip having been reported. The total number used, in all positions, is 99 per engine.

Piston Valves. With higher pressures, piston valves with inside admission and outside exhaust have been favoured, to reduce the pressure on the valve spindle packings. The arrangement interferes with a free exhaust and the gland trouble is not eliminated.

In these engines a new method of operating the piston valves has been introduced, each pair of piston valves being driven by a rocker in the exhaust cavity. No valve spindles are used and so the glands are suppressed and with them the objections to outside admission. The rocker is arranged across the cylinder and when uncoupled the arm in the exhaust cavity drops clear to allow the piston valves to be withdrawn. The arrangement is shown in Fig. 18. Piston valves 11 inches diameter have been provided, which in conjunction with large steam chest liner port areas give an improved steam distribution. The weight of one piston valve complete with the two heads is 99 lb.; it is illustrated in Fig. 20.

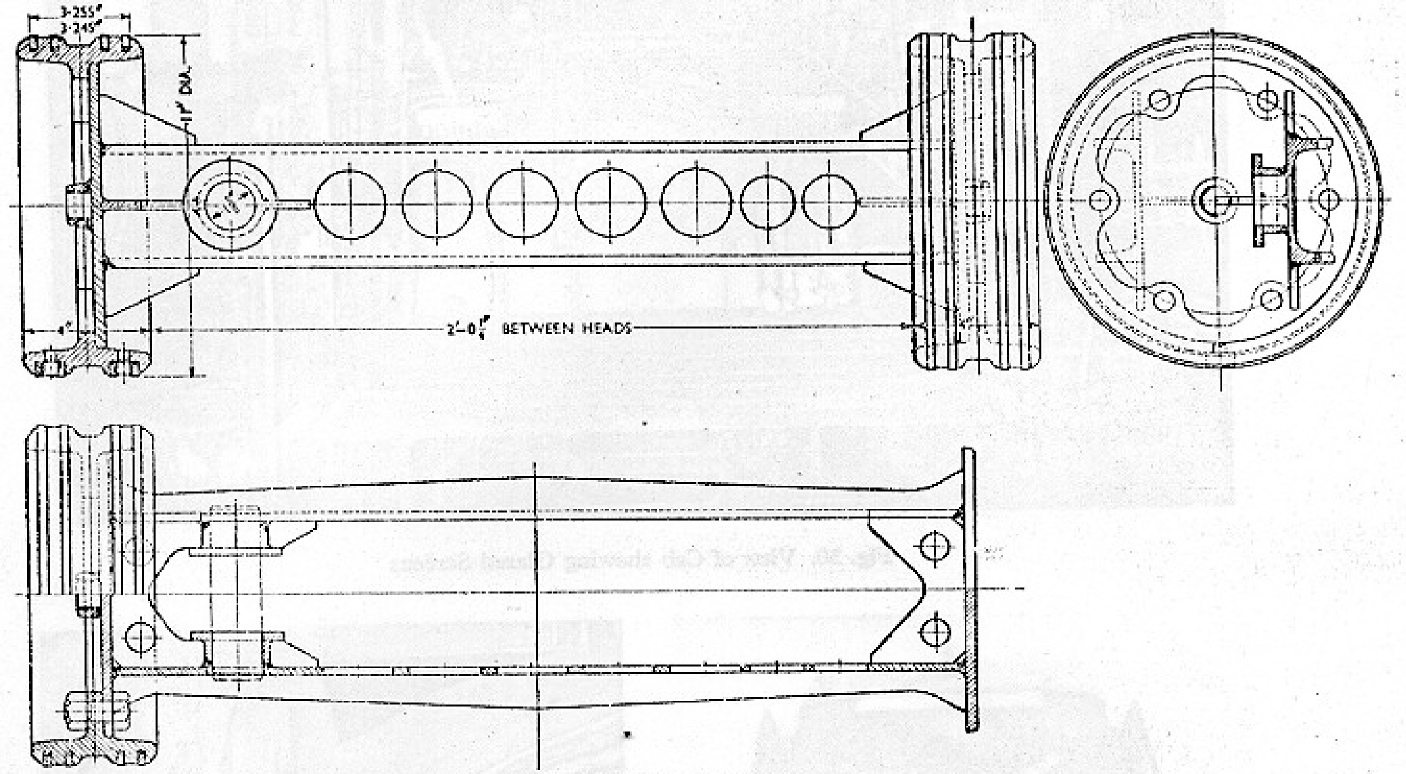


Fig. 20. Piston Valve

This arrangement of the piston valves has given no trouble and the wear of the rings is much less than usual. Trouble was experienced with the first engines in the early days through the breaking of the driven arm of the piston valve rocker shaft of the middle cylinders. The cause was difficult to trace. The middle cylinder as first made did not incorporate any balancing passage between the two steam chests. The front steam chests were fed by a 6-inch pipe from the 7-inch pipe to the left cylinder and the back by a 6-inch pipe from the 7-inch pipe to the right cylinder. It was expected that the pressures would equalize through the header.

Dr. H. L. Guy suggested it might be due to a sudden rise in pressure at the moment the valve uncovered the port to admit steam to the cylinder, resulting in a pressure difference on the two valves.

An indicator diagram taken from the forward steam chest showed that the steam pressure was not steady but varied continuously, though without any violent differences. It was argued that if the variations in the two steam chests did not coincide in point of time, there would be a difference in load on the two piston valve heads and this difference, if large, would throw a heavy load on the driven crank. An external balancing pipe was fitted and no further trouble was experienced. The middle cylinders now incorporate two balancing passages each 12·6 sq. in. in cross-sectional area, cast in the cylinder block connecting the two steam chests.

The lubrication of the valve rockers is shown in Fig. 18. The method of conveying oil to the upper end of the rocker and the pins will be noted: the results have been satisfactory.

Reversing Gear. The gear is reversed by steam. The objections to steam reversing gears frequently expressed in the past was found to be due to the steam-operated gear not remaining set.

Large oil passages are provided from the filling plug to the ends of the hydraulic cylinder, which constitutes the damping

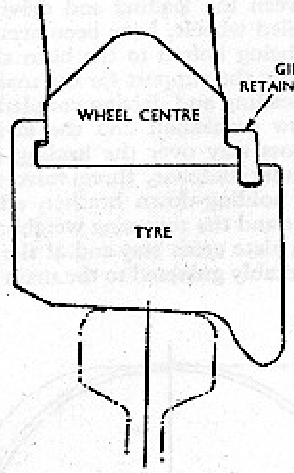


Fig. 22. Wheel Rim and Tyre with Gibson Ring Fastening

and locking device. Creeping was due to the hydraulic cylinder not being completely full of oil. This was traced to air bubbles entrapped when filling, giving a false indication that the cylinder was full, and since attention has been given to the filling pipes and passages to prevent air being entrapped, the cylinders can be filled right up. The gear will now remain in the position at which the driver sets it.

WHEELS AND TYRES

The most obvious departure from traditional practice is to be seen in the wheel centres used throughout these engines and tenders. The usual locomotive wheel consists of a cast steel spoked centre on which is shrunk a rolled steel tyre, and it has undergone little alteration since the earliest days.

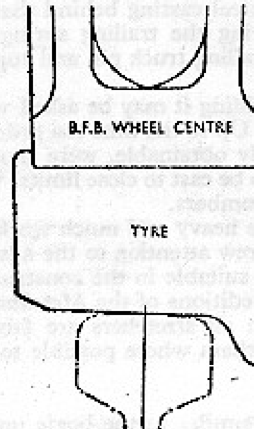
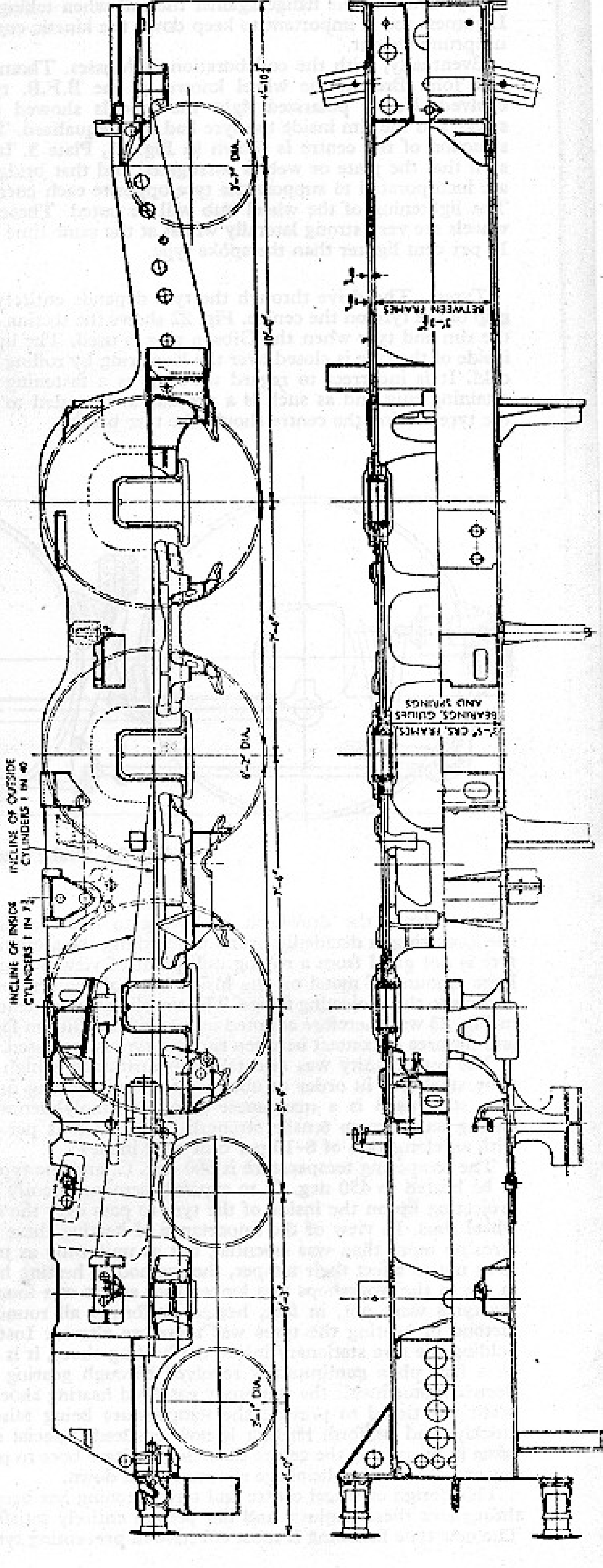


Fig. 23. New Tyre and Fastening

When the rims of spoked wheels in the shops for retyring are examined, flexing between the spokes is revealed by the condition of the rim and the inside of the tyre, resulting in fretting corrosion of the tyre. The stresses set up in a rim when a tyre is shrunk on were investigated by polarized light on celluloid models in the laboratory at Ashford and showed great variation from spoke to spoke.

A locomotive wheel has not only to support the vertical load but has to have considerable lateral strength to support the



heavy thrust of the flange against the rail when taking curves. Lightness too is important to keep down the kinetic energy and unsprung weight.

Eventually, with the collaboration of Messrs. Thomas Firth and John Brown, the wheel known as the B.F.B. type was evolved. Under polarized light the models showed that the stresses in the rim inside the tyre had been equalized. The construction of the centre is shown in Fig. 21, Plate 3. It will be seen that the plate or web is corrugated and that bridge pieces are incorporated to support the tyre opposite each corrugation. The lightening of the wheel hub will be noted. These driving wheels are very strong laterally whilst at the same time they are 10 per cent lighter than the spoke type.

Tyres. The drive through the tyre depends entirely on the grip of the tyre on the centre. Fig. 22 shows the section through the rim and tyre when the Gibson ring is used. The lip on the inside of the tyre is closed over the loose ring by rolling it down cold. It is incorrect to regard the ring as a fastening: it is a retaining ring and as such is a precaution intended to prevent the tyre leaving the centre should the tyre break.

MISCELLANEOUS FEATURES

Main Frames. The main frames are shown in Fig. 24. The plates are 1⅛ inches thick and 3 ft. 11½ inches at their greatest depth.

The shape of the hornsheets above the boxes should be noted; the large radii were chosen to reduce concentration of stress at the corners. No holes are drilled here as it is the place where cracks usually develop and wedges are not fitted. In addition to the usual horn stays, the cross stretchers in front of the leading coupled wheel, between the leading and driving, and the driving and trailing coupled wheels, have been arranged to reinforce the horn stays by being bolted to the horn sheets as well. The forward stay provides the support for the main brake shaft. The stay between the leading and driving coupled wheels also supports the three-throw crankshaft and the layshaft of the chain drive. The top cross stay over the leading coupled axle carries the middle cylinder slidebar, three valve plunger guides and the boiler front holding-down bracket, additional cross braces carrying the links and the reversing weighbar shaft. Forward of the cylinders is a plate cross stay and at the leading end there is a buffer plank, suitably gusseted to the main frames.

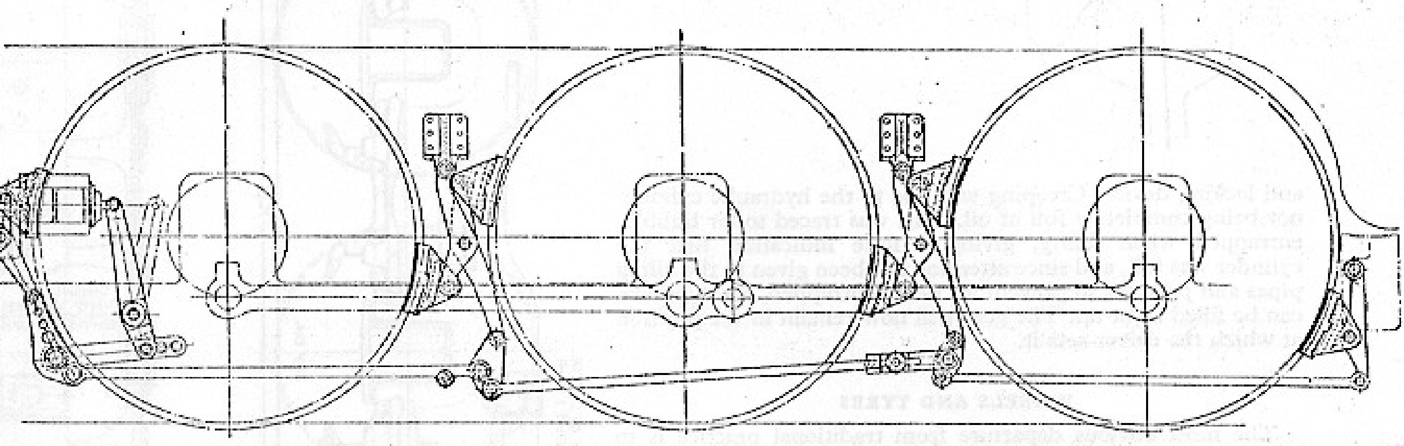


Fig. 28. Brake Gear showing Hangers and Clasp Brake

Apart from the drawback of having to roll the rim over the loose ring, a decidedly brutal proceeding, the section of the tyre is not good from a rolling mill point of view owing to the large amount of metal on the inside bore of the tyre on cross corners to the projecting flange. The simpler arrangement shown in Fig. 23 was therefore adopted instead of the Gibson fastening and the area of contact between rim and tyre is increased.

The opportunity was also taken to introduce a high-tensile alloy steel tyre in order to obtain maximum wearing qualities. The steel used is a manganese-chromium-molybdenum steel having an ultimate tensile strength of 63–69 tons per sq. in. with an elongation of 8–10 per cent on 2 inches.

The tempering temperature is 600 deg. C. and the tyres have to be heated to 450 deg. C. to expand them sufficiently for the projecting lip on the inside of the tyre to pass over the driving wheel rims. In view of the importance of heating these special tyres no more than was essential, but as uniformly as possible so as not to affect their temper, the method of heating hitherto in use in the workshops was looked into and it was found that the tyres were not, in fact, heated uniformly all round. The method of heating the tyres was therefore altered. Instead of holding the tyre stationary inside the heating shoes, it is placed on a face plate continuously revolved through gearing by an electric motor inside the stationary gas-fired heating shoes. The heating is timed to prevent the temperature being raised too quickly, and uniform heating is now ensured. Special care is taken in measuring the centre diameter and tyre bore to prevent any excess over the shrinkage allowance laid down.

This design of wheel centre and tyre fastening has been used throughout these engines, and has proved entirely satisfactory. The new type fastening is most effective in preventing tyre slip.

The trailing ends of the frame are bolted to the cast steel dragbox and to the substantial steel casting behind the trailing coupled wheels, this stay carrying the trailing spring hanger bracket, the anchorage for the trailing truck pin and supporting the boiler.

In view of the wide use of welding it may be asked why cast steel frame stretchers were used. Up to the time the orders were placed steel castings were readily obtainable, were thoroughly reliable, and could be expected to be cast to close limits. Welders were not available in sufficient numbers.

The castings as delivered were heavy and much work had to be done to lighten them. This drew attention to the advantages of fabrication by welding where suitable in the construction of the main frames. In the smaller editions of the *Merchant Navy* engines now under construction all stretchers are fabricated, pressings being incorporated in them where possible to reduce the amount of welding.

Leading Bogie. The bogie is similar to the bogie under the *Lord Nelson* engines. The side control springs have an initial load of 3 tons and at full travel of 3½ inches a maximum load of 5¾ tons.

Trailing Truck. The trailing truck illustrated in Fig. 25, Plate 3, is pivoted at the frame stretcher forming the inside boiler support, and is loaded through supports placed behind the axle centre line and fixed to the truck frame, which are free to move transversely on slides attached to extensions from each side of the dragbox.

The frame is a single steel casting which houses beneath the points of support the springs controlling the side movement.

These control springs are initially loaded to 1 ton, with a total load of 2 tons at the maximum throw-over of $5\frac{1}{16}$ inches.

The bearing springs are of the coil type having the following characteristics:—

Free length, 1 ft. 4 in.
Length in position, 1 ft. $2\frac{1}{4}$ in. with a load of 4 tons.
Deflexion per ton, $\frac{7}{16}$ inch.

They are connected by crossbeams supported from the axleboxes which have been designed to suit the outside journals 1 ft. $1\frac{3}{4}$ in. long × $6\frac{1}{4}$ inches diameter and lubricated by under-feed pads. The engines ride extremely well and comfortably.

Ashpans. The ashpans, three in number, are designed to ensure a free flow of air over the whole grate area and to avoid the restrictions in the space under the grate along the sides experienced with the single central ashpan. Each section is fitted with self-cleaning ash hoppers fitted with curved doors, all operated from the ballast.

Fig. 26, Plate 3, shows the arrangement. The ashpans are made of $\frac{1}{4}$-inch plate and the bottom $\frac{3}{16}$-inch. Back and front air doors are provided and in addition there is a small cleaning door at the back to dislodge any ash accumulation at the back of the pans. Fig. 27, Plate 3, shows a view of the ashpan side and door in position.

Brake Gear. These engines are fitted with the steam brake. The wheels are fitted with clasp brakes, thereby obviating the thrust against the horns set up when single blocks are used. The brake block area in contact with the tyres is increased, which improves the dissipation of heat when braking, and the blocks require changing less frequently. Fig. 28 shows the arrangement of the hangers and levers.

Lagging. On these engines the lagging casing is carried by the main frames, instead of by the boiler. A very light welded frame of cold-rolled sections has been used and the outer casing made of 20 gauge plate. The cab is constructed on the same lines. The usual side platforms have been suppressed.

This construction is at least 17 cwt. lighter than it would have been had the usual practice been followed. The exterior form of the casing was partly the result of the lightweight form of construction adopted. The channels, being cold rolled, have to be rolled in circular curves. The form was also partly determined to ensure a clean exterior without projections, the advantages of which were obviously attractive.

The contour of the top of the casing is governed by the Belpaire corners of the firebox. The casing could have followed the shape of the boiler more closely, but this would have been more costly as each rib of the framework would have differed from the next, whereas now all are alike.

One advantage of this form of construction is that the work can be done by sheet metal workers. Another is that it is merely a casing and so can be removed in sections or as a whole without disturbing the fittings or mountings.

The Front of the Engine. Locomotives with long boiler barrels and short chimneys suffer from steam and smoke drifting down along the barrel and obscuring the look-out on the leeward side.

The cause is attributed to eddy currents, set up by the passage of the smokebox through the air, fanning out sideways, and setting up a pocket of low pressure along the side of the barrel behind the chimney centre line, into which the steam and smoke are drawn down. The more efficient the exhaust design, especially at early cut-offs and low steam-chest pressures, the worse the trouble, as there is less energy left in the exhaust to carry the steam and smoke away. Under certain weather conditions drivers experienced difficulty in observing the signals with the original front end.

This led to a series of experiments on models in the wind tunnel at Southampton University, followed by tests in service. As a result the front of the engine is now arranged as shown in Fig. 29, Plate 4, and the difficulty has been overcome. The

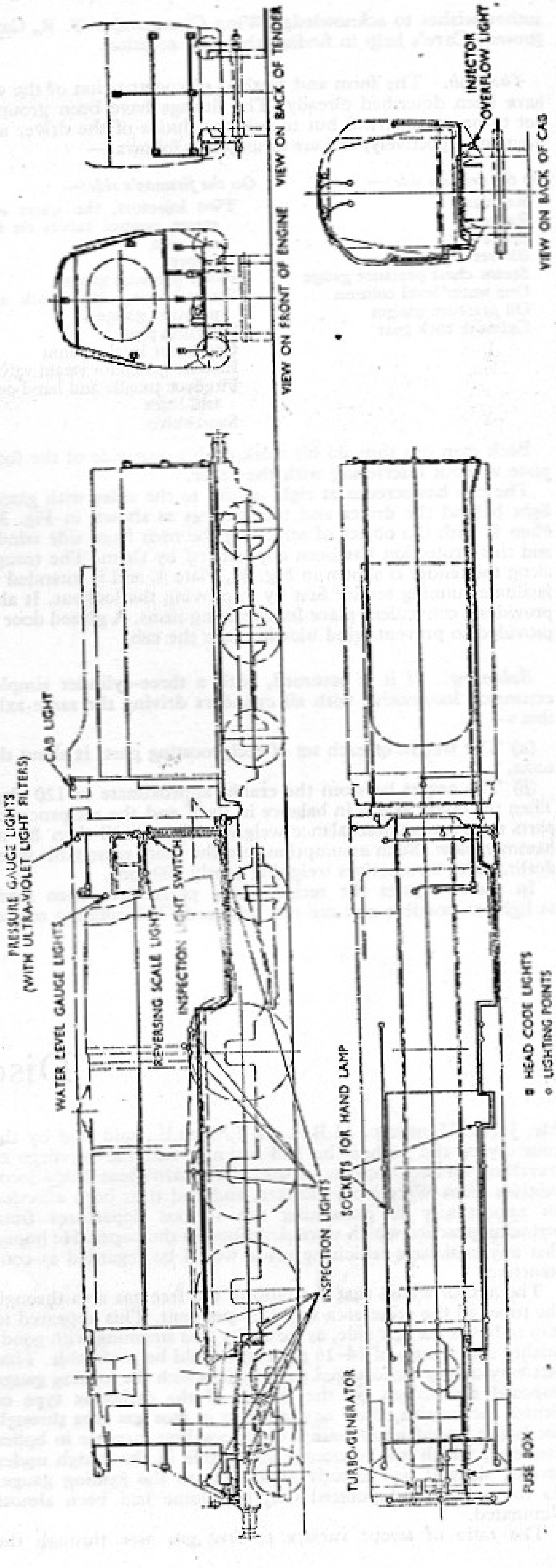


Fig. 32. Electric Light Equipment

author wishes to acknowledge Wing Commander T. R. Cave-Browne-Cave's help in finding this neat solution.

The Cab. The form and method of construction of the cab have been described already. The fittings have been grouped not to be symmetrical but to suit the duties of the driver and fireman respectively, and are arranged as follows :—

On the driver's side:—

- Regulator
- Reverser
- Brake valve
- Blower
- Steam chest pressure gauge
- One water level column
- Oil pressure gauges
- Cylinder cock gear

On the fireman's side:—

- Two injectors, the water and steam control valves on the cab side
- Dampers
- Boiler pressure gauge
- Steam-heating stop cock and pressure gauge
- Watering pipe
- One water level column
- Electric generator steam valve
- Firedoor treadle and hand control lever
- Sand valve

Each man can thus do his work on his own side of the footplate without interfering with the other.

The cab has screens at right-angles to the sides with glazed light behind the driver and the fireman as shown in Fig. 30, Plate 4, with the object of screening the men from side winds, and this protection has been appreciated by them. The trough along the tender is shown in Fig. 31, Plate 4, and is intended to facilitate running tender first by improving the lookout. It also provides a convenient place for the firing irons. A glazed door is provided to prevent wind blowing into the cab.

Balancing. If it is assumed, with a three-cylinder simple-expansion locomotive with all cylinders driving the same axle, that :—

(*a*) The weight of each set of reciprocating parts is about the same.

(*b*) The angles between the cranks approximate to 120 deg. Then the crank axle is in balance in itself and the reciprocating parts need no counterbalance weights. There will then be no hammer blow. Such assumptions are the more reasonable when dealing with locomotives weighing nearly 100 tons.

In these engines the reciprocating parts have been made as light as possible and are not balanced. The rotating masses on the other hand are balanced completely in the wheels. The crank axle is built up but the crank webs are not extended as has been usual in recent practice. The result was to save dead weight as the extended web would have weighed 490 lb. per web, whereas only 548 lb. were needed for balancing in the wheels, a saving of 432 lb. The fact that the reciprocating parts have not been balanced has not been attended by any ill effects and there is no indication in the riding of the engine that these parts are not counterbalanced. Tests over Barnes Bridge at 78 m.p.h. showed the complete absence of disturbing forces at the rail.

Auxiliary Fittings: Electric Light. The engines are fitted with a generator set driven by a $\frac{3}{4}$ h.p. steam turbine running at 4,000 r.p.m. and rated at 350–500 watts. The light points provided are shown in the wiring diagram Fig. 32.

The gauge faces in the cab are black, with luminous figures. These are illuminated by a lamp in the cab roof enclosed in a box fitted with a glass which only allows ultra-violet rays to pass through, so that there is no visible light from it. The gauges can be clearly read at night and when running into a tunnel during the day.

The water in the gauge glass is illuminated by a narrow band of light directed at the water columns through a slit in the fitting. A light controlled by the fireman is fitted below the footplate to light the injector overflow at night. The headlamps are electrically lighted and inspection lights are provided to facilitate examination of the running gear.

Tender. The tender tanks are fabricated, the tank plates being $\frac{5}{16}$-inch thick. Additional water filling holes have been provided at the leading end of the tender at both sides, so that the fireman can fill up without climbing to the top of the tender; they also enable the water level to be checked easily.

The weight of the tender empty is 20 tons 10 cwt. The capacity is 5 tons of coal and 5,000 gallons of water, making the total weight in working order 47 tons 16 cwt.

Acknowledgement. The author wishes to acknowledge the encouragement he has received from his General Manager, Sir Eustace Missenden, in the development of these locomotives, and the help he has been given by his assistants, draughtsmen, works managers, foremen and men in designing and building of these engines, and the running shed staffs and enginemen for the way they have looked after and handled them.

Discussion

Mr. James Hadfield, M.B.E., M.I.Mech.E., said that by the courtesy of the author, he had recently had the privilege of travelling on the footplate of one of the *Merchant Navy* locomotives from Waterloo to Exeter, and had thus been afforded an opportunity of examining the various departures from orthodox practice which were described in the paper. He hoped that any criticisms which he made would be regarded as constructive.

The author stated that the ratio of the free gas area through the tubes to the grate area was 12·6 per cent. This appeared to him to be on the low side, as for really free steaming with good-quality coal a ratio of 14–16 per cent would be preferable. That fact very clearly emphasized the way in which the loading gauge imposed restrictions on the design of the orthodox type of British locomotive, since any increase in free gas area through the boiler would necessitate a corresponding increase in boiler diameter, which was obviously impossible in the design under review, since it was already almost up to the loading gauge. As the author had pointed out, the dome had been almost eliminated.

The ratio of swept surface to free gas area through the tubes, which was a measure of their heat-absorbing efficiency, was 510 for the flues and 408 for the small tubes, as compared with what he thought was the normally accepted optimum figure of 400. That again illustrated the limitation imposed by the loading gauge, since to decrease the figure of 510 for the flues would mean reducing the length between tubeplates and thus in turn reducing the heating surface. In order to compensate for that loss of heating surface it would be necessary to have additional tubes, which again could be done only by increasing the boiler diameter—which, as he had already pointed out, was almost impossible.

Reference was made in the paper to the necessity for providing steam pipes and passages sufficiently large to ensure the cylinders being fed with a minimum pressure drop. The steam speed through the main steam pipe in the boiler would appear to be about 60 ft. per sec., and through the superheater elements about 70 ft. per sec., both speeds being comparatively low; and that led him to think that fairly high steam temperatures should be attained unless the superheater acted to some extent as a steam drier. While no dimension appeared in Fig. 4, p. 319, for the height between water level at half-glass and the regulator steam intake, it would appear to be rather small, probably about 12½ to 13 inches; and if moisture was carried over to the superheater the final steam temperature would be reduced. In that connexion, 1 per cent of moisture would reduce the final temperature of superheat by some 12 deg. F. Could the author give some indication of the actual superheat obtained?

As one who was responsible for the manufacture of the thermic syphons, it was very gratifying to learn that they had proved so thoroughly satisfactory in service. It was mentioned in the paper that difficulty had been experienced in pressing the openings in the throat plate for the syphon necks, and perhaps some little improvement in the design of the press blocks might be brought about, since the firm with which he was associated had long produced that type of pressing without undue difficulty.

The author was to be complimented on the extent to which he had replaced riveted joints by welding, and on the most excellent results achieved. There could be no doubt that the author had succeeded in employing welding in locomotive construction to a far greater extent than had previously been attempted in this country.

With regard to the most ingenious valve gear, it was stated that the unsprung driving axle weight had been reduced by 1,126 lb. In view of the great need to keep down the weight, it would be interesting to learn how the total weight of the gear compared with that of a well-designed Walschaerts gear of orthodox type. One would imagine that the Bulleid gear would weigh more, particularly if the sump casing were included in the calculation. Excluding the two chain-drives from the crank axle to the three-throw crankshaft there were thirteen pins, inclusive of the reversing link trunnion, between the three-throw driving shaft and the outside piston valve, against eight in the normal Walschaerts valve gear. Moreover, the normal type of valve gear could be arranged as a straight-line drive in plan, whereas the special gear in question introduced a rocking shaft at each piston valve; and, as the levers of that rocking shaft effected a magnification in travel of about 2½/1, it would appear that any wear in the numerous pin joints would result in some lost motion of the valve. It would be of interest if the author could give any figures for wear related to mileage.

He noted that the tender tank was also of welded construction. Whether the tender tank should be welded or riveted was rather an old controversy now, and it would be most interesting to learn what results had been achieved in service.

The figures given of the bogie side controls were very interesting, and in that connection he understood that the loads were carried on sliding supports, and that frictional resistance had to be added to the figures quoted.

He could testify from personal experience that the engines had excellent riding qualities.

Mr. R. D. Metcalfe, M.I.Mech.E., referred to the arrangement of the injectors and the vacuum-brake ejectors. Both injectors were fitted on the fireman's side and were operated at the cab side by control rods. The practice in this country had always been to have one injector on each side of the locomotive, so that if the fireman wanted to work the injector on the driver's side he had to cross the cab floor and might get in the way of the driver.

The exhaust steam from the vacuum brake ejector was introduced into the cavity of the blast pipe casing, so preventing "char" or fine ashes being drawn into the blast pipe. Many times he had found that char had been drawn down through the blast pipe into the exhaust injector; and the turning of the ejector exhaust steam into the cavity of the exhaust pipe would help a good deal to overcome this trouble.

Mr. T. Henry Turner, M.Sc., A.M.I.Mech.E., said that a mechanism as complex and important as a main-line Pacific locomotive must obviously be judged from many points of view. One must ask oneself whether it was novel, and certainly the author's locomotive was; whether it worked, and it had been seen to do so; whether it pleased the eye, which might be controversial in the case of the *Merchant Navy* locomotives, but certainly they pleased many; and sooner or later some mundane accountant would ask, did it pay? The view from which he looked at it, the particular facet of the diamond in which he was interested, was, what was it made of, and how was it made? There the paper revealed a great deal that was of outstanding interest. There was so much, however, that was novel that the author had obviously still left for himself enough material for another paper to the Institution, or to the Institution of Locomotive Engineers, of which he was a Past President. When he came to write that paper, it was to be hoped that the author would give still more details of the chemical composition of the materials that he had used.

It was a common observation that as mechanisms were perfected they tended to have a smoother exterior and become simpler in appearance, their components became fewer, and their operation almost free from vibration. In almost all those respects the *Merchant Navy* type of locomotive ran true to that rule, but the abnormally flat sides hid, or in some cases barely hid, the fact that they were just packed with novelties. He had time to speak only of a few, and would refer first to a disappointment; he regretted to see that the fuel was still one that polluted the atmosphere, and that the water was still the unsoftened, natural supply. Almost all the metallurgical details, however, commanded his admiration. They were really intriguing in many respects.

The way in which the weight of the boiler and firebox had been cut down would obviously be carried still further when the solid foundation ring went and the barrel was welded. He was reminded that nearly twenty years ago he saw in Canada low nickel alloy steels being used for the barrels of locomotive boilers, with the same purpose of saving weight. It was possible that low alloy steels might come into a later design, but so long as welding was required one felt much happier with the type of steel that the author had used for his fireboxes, and there the welding was most commendable, admirably done, and admirably controlled. Personally, he felt sure that the Southern Railway workshops and staff would benefit from the introduction of X-rays in many ways beyond merely the production of the fireboxes in question. He thought that the author had done well to introduce steel fireboxes. In saying that he knew that he did not speak as a chief mechanical engineer, with the responsibilities of that position, but merely as a metallurgist; but other countries had got away from the copper firebox, and someone had to give a lead in this country. He thought that the author had given a very good lead.

The author had shown what happened when the water ran low. The admirable action of the fusible plugs might be due in part to the fact that the Southern Railway normally used a rather large diameter for the hole compared with that of other railways, and so more steam came out as soon as the plugs had cause to act; and there were relatively few moments in which that action should take place if it was to be effective. He assumed that the diameter of the hole was the same as that of the standard tapered plug.

In 1944, and again in 1945, the author very kindly allowed him to visit the Southern Railway works at Eastleigh to see the tubes that were being removed from some of the *Merchant Navy* locomotives, and he could certainly confirm from his own observation the statement that they seemed to be in fit condition to be put back in the locomotive and run for a further mileage. There was extremely little pitting or corrosion or damage to them, and that was no doubt due to the care taken in the sheds with their washouts and so on as well as to the fact to which the author drew attention, the omission of copper in the firebox construction, so that electrolytic corrosion was reduced.

The wheels were really most ingenious in the way they met the troubles which had been encountered in the past. When he first saw the photographs of them he thought that they were fabricated, and did not like them, but now that he saw that they were cast steel he thought that they were very fine indeed. They bridged the gaps, the place where nearly all tyres broke was nicely supported, they stopped the rocking, and his only criticism would be that the inside edge of the tyre looked rather too sharp—as though it could do with a larger radius and so match the outside edge.

The enclosed motion must be regarded as one of the finest experiments to which the author had drawn attention. He had followed the "little oil bath" of the bicycle, but had had a most formidable problem with which to deal. It was to be hoped that he would persist in his experiment and make "oil-bath" locomotive motion a reality. It was worth doing, because the consequences of hot boxes and hot big-ends were very far-reaching. Personally, he doubted whether any crank axle broke that had not had a previous history of a hot bearing. If one could prevent a bearing running hot, one would probably also reduce the number of broken crank axles and all that they entailed, He wondered, however, whether the author would not go further with regard to the cast iron piston. A steel piston flash-butt welded on to the rod was in use, and would seem to offer still further reduction in weight of reciprocating parts.

There were in this country at the present time few men who could hope to put their name to a class of famous locomotives, and everyone would welcome the fact that the author had joined the select few. His paper was a model of precise and concise description, and it showed that the *Merchant Navy* locomotives bore features which distinguished them from all their predecessors. His design embraced many features which he no doubt learned in those years when he worked so hard in connexion with international railway conferences and inquiries; he had probably obtained in that way a wider knowledge of Continental, American, and world-wide practice than most engineers; but he had not only adopted those things which he found to be the best—he had also stepped out into the untrodden paths of real invention and inspiration.

To judge any creation one must take note of the background, recall the preoccupations of his staff and the author's own heavy load from Dunkirk to D-Day. The *Merchant Navy* locomotives stood out from their background; they stood out at the head of trains, and they stood out as leaders of thought. To railwaymen, Pacific main-line locomotives were more than engines; they resembled the banner, or the band, at the head of a procession; they gave direction and pride and comradeship to the whole of the railway staff. The author had raised a new banner. There was still novelty in the steam locomotive. When one looked across the lecture theatre to the portrait of the author's old chief, Sir Nigel Gresley, who also designed and wrote papers about locomotives, one felt that Sir Nigel would have wished to join the members present in congratulating the author on an outstanding paper.

Wing Commr. T. R. Cave-Browne-Cave, C.B.E., R.A.F., M.I.Mech.E. (*Member of Council*), said the author had been kind enough to refer to the work done at University College, Southampton, on the shape of the front of the locomotive. It was a good example of the way in which a model could be used in the wind tunnel to reproduce the air flow over a large moving object and to allow the effect of various changes of shape to be studied. It also showed how airflow problems other than those connected with aircraft design could be solved by means of a model in a wind tunnel.

A model some 8 feet long had been made by the Company and had been mounted in the wind tunnel at University College, so that a uniform stream of wind could pass over it moving parallel to its axis or at a moderate inclination either way. In this case the object was to study the movement of steam emitted from the chimney. Smoke was emitted from the chimney of the model and small streams of smoke were also used to explore the airflow round the front and down the sides of the model.

With the shape of the locomotive as first constructed, it was found that steam was drawn down the sides of the boiler and obscured the driver's forward view so that sometimes he could not see the signals. It was found that this movement of the smoke, emitted from the chimney of the model, satisfactorily reproduced the movement of the steam over the full-scale locomotive. Various alternative shapes were, therefore, tried on the model.

The trouble was due partly to air overflowing from the cowl in front of the smokebox and being thrown so far out from the sides of the boiler casing, that a region of low pressure was formed and the steam from the chimney drawn down into it. The cure was effected partly by leaving a more clear passage between the side plates and the boiler, so as to drive a stream of air close along the sides of the boiler, and partly by giving very free outlet over the top of the smokebox, so as to give a stream of really high-speed air over the exit of the chimney. This stream carried the steam upwards and well clear of the windows. It probably had the incidental advantage that the region of very high speed—and therefore low pressure—over the mouth of the chimney did improve the draught.

The shape of the locomotive was altered to conform with the shape determined by the model, and it was then found that the airflow over the locomotive exactly reproduced that which had been seen on the model.

It would be interesting to know whether it was found that the new shape gave greater chimney draught, as was to be anticipated.

Mr. Turner had raised the subtle question as to whether the shape of the locomotive was pleasing. That was largely a matter of judgement; but it was quite clear that if altered shapes were contemplated for the purpose of improving appearance, it would be wise to use the model to study both appearance and the effect upon airflow.

He would like to raise one further point, though he did so with some diffidence. Part of the cinematograph film exhibited during the presentation of the paper had shown the flow of oil over the moving mechanism inside the enclosed gearbox, and the author had referred to the difficulty caused by leakage. It seemed probable that the oil flow was unnecessarily copious for lubrication, and that this large excess of oil was probably the cause of the oil leakage which had given trouble, and also, incidentally, of excessive heating of the oil. He suggested that the oil flow might be progressively reduced until there was some indication of trouble arising through diminution of the flow.

Mr. W. Cyril Williams, M.I.Mech.E., pointed out that no progress could be made in locomotive design without experiment and innovation, which required courage as well as knowledge. The locomotive described in the paper was an outstanding example of that fact so far as this country was concerned; it embodied departures from established practice, and the introduction of some features which, although proved on overseas railways, were new to this country.

The author referred at the outset to the difficulties which confronted him as a result of the severe limitations of the loading gauge and the limit of the axle load on the Southern Railway, and the design described was an illustration of the ingenuity which had been exhibited to surmount those restrictions, and of how they had affected the design. The great limitations of the British loading gauge were emphasized by the reflection that the South African loading gauge, with a rail gauge of 3 ft. 6 in., gave a width of 10 feet, instead of 9 feet as in this country, and practically the same height as in this country. While one might rightly ask whether any improvement in the present maximum axle load in this country of 21–22 tons was envisaged, the loading gauge was a permanent limitation.

The limitation of the dimensions and the operating requirements referred to in the early part of the paper gave some idea of the ingenuity required to obtain the necessary power, and Mr. Hadfield had referred to the difficulties of providing adequate and efficient boiler capacity. In view of these difficulties, and the possible need for a still further increase in tractive effort and boiler power, one could not but reflect on the potentialities of the articulated locomotive as a means of giving a new lease of life to the development of steam locomotives of high power in this country. He had in mind particularly an engine of the Garratt type, which appeared to be the only existing design affording complete freedom for the design of the boiler.

That point could be brought home by a brief reference to the Algerian double-Pacific Beyer-Garratt express locomotives, which had been running for over ten years, with an axle load of 18½ tons and with a tractive effort of 58,000 lb. at 75 per cent of the boiler pressure. He was not inferring that that tractive effort was required in the case of the Southern Railway, where no doubt the power required had been provided; but he made the point in view of the severe limitations—to which the paper referred—of the railways in this country. The Algerian locomotives were of standard gauge, with a boiler barrel diameter of 7 ft. 3 in., whereas the author's locomotive had a maximum boiler diameter of 6 ft. 3½ in. near the firebox, and a diameter of

5 ft. 8½ in. at the smokebox. The Algerian engines had 5 ft. 11 in. driving wheels, and ran the 262 miles between Algiers and Oran at over 60 m.p.h. for long stretches and climbed gradients of 1 in 45.

In support of the author's decision to fit thermic syphons, he would like to mention that over 400 had been manufactured up to the present by the firm referred to, and no complaints had been received regarding them.

In such modern engines as those of the *Merchant Navy* class one would expect to find steam-operated rocking firebars, and it would be of interest if the author gave his reasons for omitting that feature. The 48½ sq. ft. of grate was reaching the limit (set at 50 sq. ft. in the U.S.A.) for one fireman, and it would also be interesting if the author would say whether the one fireman was able to get the maximum out of the *Merchant Navy* class, and whether he did not feel that the day of the mechanical stoker was not very far off.

The provision of steam reversing gear was to be welcomed, for there could be no doubt that the time had come when in this country it was necessary to provide, on the heavier locomotives, that easy "finger-tip" control which was expected in these days. He had had the great pleasure of riding on the *Merchant Navy* class, by the courtesy of the author, and would like to refer to their very fine running qualities. Having been on many locomotives throughout the world, he was particularly impressed by the footplate; at last full attention had been given to it in this country, and it was very pleasant to ride on it and see the thoughtful attention which had been given to the arrangement of all the fittings, and the extra room and comfort provided.

Mr. R. H. P. Nott, S.I.Mech.E., said that he understood that in normal running with locomotives not fitted with a steam-operated firedoor, it was customary to leave the door open during most of the run, with the result that cold air was drawn in over the top of the fire. Although presumably in the case of the *Merchant Navy* locomotives that was not permissible, because of possible damage to the thermic syphons and the steel firebox, in orthodox locomotives with a copper firebox he understood that it was advantageous, because the excess air passing over the fire promoted better combustion. That seemed to be borne out by the fact that the smoke emission on the *Merchant Navy* locomotives was greater than on other types, such as the *Lord Nelson* class. If that were so, it would be interesting to know whether anything could be done with the orthodox locomotive firebox to improve over-fire air admission, while at the same time having a steam-operated firedoor.

Regarding the potential advantages of higher initial steam pressures, it would appear that with the advent of the steel firebox, boiler pressures up to at least 300, and possibly 325 lb. per sq. in., would be practicable. With the recent developments which had also taken place in the improvement of the engine side of the locomotive by the streamlining of valve passages and the author's improved valve gear, might not there be a case for a reconsideration of the compound locomotive? He understood that the Midland compounds were satisfactory up to a point, but did not show any sufficient advantage in steam consumption, or in other ways, to justify their use as compared with the simple-expansion locomotive. In view of the higher steam pressures now being used, could not that decision be reversed?

He would like some information about the cost of the *Merchant Navy* type locomotive. He noticed that nobody so far had raised the question of how much more the author's very interesting and ingenious machine cost in comparison with the orthodox steam locomotive.

Finally, with regard to the streamlined casing, he understood that in certain quarters in this country it was considered that, from the aerodynamic point of view, streamlining was not worth while on British railways, and that, as the outer casing added considerably to the weight of the locomotive, the removal of existing streamlining from locomotives was under consideration. With the advances which had taken place during the war in the production of aluminium alloys on a large scale and at a rate comparable with mild steel, would not it be worth while considering an aluminium alloy streamlined casing if, as in the case of the *Merchant Navy* locomotives, it was considered desirable from aerodynamic considerations to fit it?

Mr. W. F. McDermid (South Woodford, Essex) congratulated the author not only on an excellent paper, but also on an excellent locomotive. One wondered why the gear case had not been thought of before.

His own particular interest, however, was centred on the steel firebox. It was just prior to 1900 that he himself ran into trouble with fireboxes and stays—copper and bronze—and after a couple of years he suggested to his chief, the late Mr. James Holden, that all these troubles might be eliminated by adopting steel fireboxes and stays. As a result he was handsomely rebuked and given a lecture on the thermal advantages of using copper; but Mr. Holden did not say a word about the disadvantages of its excessive expansion.

When one assembled copper plate and steel plate side by side and joined them with cross-stays, one plate was pushing up from the foundation ring and the other, relatively, was standing still, so that every stay was bent into an S-bend.

Obviously the thing to do was to use two similar metals, and, as it was not possible to use copper for the wrapper-plate, one should therefore use steel for the firebox.

The author had shown in Fig. 5, p. 320, just where the stays failed, and from that drawing it would be seen that at the top of the firebox the lacing together was so complete that there was not much room for the firebox plate to encroach vertically on that area at all; but the stays in the top row failed, and so did those at the corners. He thought he could say why that was so.

He would like to know whether the author had examined any of the stays taken out, because he was inclined to think that if they were examined, evidence would be found to show that they had been in *compression*. That might sound paradoxical, but one had to consider the vertical thrust of the side-plates of the firebox and the horizontal thrust of the top-plate. The resultant of those two forces was a thrust *outwards*. As against that there were, inside the wrapper-plates, two stiffening-plates held together by the cross-stays, and the stays that failed were immediately under these.

In the corner position, where the damage was more extensive, he thought the outward thrust was amplified by the stiffness of the throat plate and the back plate.

He would suggest that the author, who had shown himself to be such a pioneer, should construct or select a similar engine with a copper firebox, so that, by testing, it could be settled just how much there was in the alleged superior steaming with a copper box. He himself thought that the copper box might be regarded as the original sin, so far as the locomotive was concerned.

Turning now to the author's method of fixing tyres, he recalled that on certain occasions, when he had been in charge of a locomotive wheel shop, he had seen evidence of tyre wear on the wheel centre.

Ordinarily it occurred in cases where tyres had become loose, so that there was some doubt as to why the wheel centres had worn. However, there was evidence of chafing; but in those days a tyre was not heated scientifically: perhaps one-third of a tyre was pushed into a furnace mouth and heated, and then the tyre was turned about a little until the whole was hot.

Examining some of the wheel parts after service, one could sometimes detect a "semi-shear" on the rivets in opposite directions, showing that there had been a local pull there. The paper described the use of a revolving table to ensure even-heating of tyres, and he was convinced that that method should be adopted generally.

If one considered the stresses set up when heating, one would find that even-heating was the secret of success when heating anything for hardening—milling cutters, for instance.

He noticed that there was a steam brake on the locomotive and a vacuum brake on the tender. That involved the use of the vacuum ejector when running light, thus using steam unnecessarily.

The objection to steam brakes was that there was delayed action due to cold cylinders, and that might lead to serious consequences. When engaged on the question of the unification of brakes, however, one of the experiments which he made, with a view to the easy conversion of Westinghouse-fitted engines to steam-braked engines, was to take a tender engine with a 13-inch brake cylinder on the tender and another on the engine, substitute sheet-lead for the leathers, and provide a proportional steam-valve which was given a $\frac{1}{16}$-inch diameter permanent bypass or leak, so that steam continually seeped through and kept the cylinders warm. That permanent leak was a remedy for the delayed action of the steam brake; with it, the brake could be applied instantly, and it was perfectly satisfactory.

Major-General A. E. DAVIDSON, C.B., D.S.O., M.I.Mech.E. (*Past-President*), thanked the author for allowing him to go round the Brighton shops of the Southern Railway, where the next class of engines, on similar lines to those described in the paper, were being built. The private manufacturers of locomotives in this country were usually tied to a very detailed specification drawn up by the customer or by the consulting engineer. They would be very glad to be able to "double" the roles of user and manufacturer, as the author had done with great success. On the question of steel or copper fireboxes, the private locomotive manufacturers, he believed, were able—and would be very glad—to fit steel fireboxes, but their customers often would not have them, and the decision lay with the customers. In a recent case where some locomotives were being designed for a number of users, the steel firebox was suggested, but by a majority vote they decided on copper. Private manufacturers could do little towards the adoption of steel fireboxes until their customers were prepared to take them. No doubt the present paper would give them more confidence in steel.

The cylindrical neck which the author used for the thermic syphons seemed a very good idea, and it was a pity that it was not shown in Fig. 10, Plate 2, which illustrated the syphon alone. The grate was excellent, and in the author's latest design even more welding was being done, because the solid foundation ring was replaced by a U-shaped foundation ring, and the sides were welded to the two arms of the "U".

The absence of balancing of the reciprocating parts was interesting. To one who was used to road traction, it was a great surprise to find that weights had to be added for various purposes on a locomotive, either to balance reciprocating parts or to get the proper distribution on the axles. In the case of the normal type of wheel, where many hundreds of pounds were added in balancing weights, there had been trouble recently because some steel founders, new to the work, had not been able to leave enough room in the wheel "pocket" to accommodate the specified weight of lead.

He took it that the author was in close liaison with his signal engineer to ensure that all the signals were easily seen from the driver's side of the cab, because the driver had not much chance of getting to the other side.

He would like to know how the welded-in tubes were removed, if that ever became necessary. One had seen many pictures of welding, but no illustration to show how "unwelding" was done.

Mr. O. V. S. BULLEID, in reply, said that Mr. Hadfield's comment on the ratio of swept surface to free gas area through the tubes was only true within limits, as the heating surface could be increased either by lengthening the tubes or increasing the diameter. If the tubes were lengthened unduly, they might become so long that the effective heat from the gases would be exhausted before the end of the tube was reached; and although the paper figure showed an increased heating surface, the actual increase would be unobtainable from the heat of the gases. Alternatively, if the diameter was increased sufficiently to allow the gases to escape freely, they would not give up their heat in the time available; so, although the ratio of 1 to 400 was a target, no limit had been laid down for the deviation which could be made from this figure without affecting the steaming of the boiler.

It was desirable for the flow of steam through the superheater elements and steam pipes to be as low as possible, in order to obtain the maximum amount of heat from the superheater elements and to provide a considerable reservoir of steam in the steam pipes as near to the steam chests as possible. It had not been possible up to the present to take readings of the superheater temperature, but as soon as this had been done the figures would be published.

In connexion with the pressing of the throat plate, it had now been found that the best method of preparing the "necks" to receive the thermic syphon, in the throat plate, was to press them separately as diaphragms, and insert them by welding in position, as this procedure eliminated the forcing through of the neck from the plate—which had already been pressed on the outside edges and was therefore fairly rigid.

Regarding the amount of welding carried out on these engines, it should be pointed out that welding would have been used to a much greater extent had the times not been so difficult.

The comparative weights of the Walschaerts and Bulleid valve gear (one set of gear) were: Walschaerts, 1,150 lb.; Bulleid, 945 lb. It was true that the number of pins was increased; but attention should be drawn to the perfect lubrication under which they worked, compared with the dust and grime, with consequent wear, of the exposed gear; also account should be taken of the fact that there were no glands to be packed on the stuffing boxes—the failure and repair of which was all too familiar an item—so that on balance appreciable advantages were to be gained by enclosing the valve gear in a casing under continuous lubrication.

The welded tender tank had given every satisfaction in running; so much so that all tender tanks subsequently built were of similar construction.

It was difficult to understand why Mr. Turner should view a wheel with suspicion if it were fabricated, and yet would be quite happy when he knew it was a casting. In the former case it was reasonably safe to assume that the metal was homogeneous, including the welding if properly carried out, while castings had been known to contain blowholes.

He thanked Mr. Turner for his remarks about the oilbath, as it confirmed his own view; and it was only the extreme difficulty in obtaining a suitable arrangement which had prevented the axleboxes being included in them.

Steel piston heads had been tried, but the wear was so rapid that they had been replaced by cast iron heads, which were giving excellent results.

In reply to Wing Commander Cave-Browne-Cave, there had been no noticeable improvement of the chimney draught owing to the fitting of the new front end. In connexion with the heating of the oil owing to the copious amount pumped, tests carried out on the temperature of the oil showed that it was generally at the temperature of the atmosphere.

In reply to Mr. Cyril Williams, it had already been pointed out that these engines were constructed during the war; and although rocking grates were discussed, it had been found impossible to incorporate them in the design owing to the difficulties of the time. Mechanical stokers would be fitted in the future, as grates of 50 sq. ft. and upwards were definitely too large for one fireman to charge under the heaviest conditions of working.

For Mr. Nott's information, it was customary to leave an ordinary firehole door open slightly to provide secondary air to the fire. This was allowed for in the present automatically-controlled firedoors by holes and passages which permitted a similar quantity of air to be drawn into the firebox, even though the door was closed; this arrangement also caused the air to be heated by the door before entering the firebox.

Compounding had been considered; but, due to limitations of the loading gauge and to weight restrictions, it had not been found possible to get a suitable system which would show any saving compared with the simple engine. The cost of the *Merchant Navy* locomotives was no greater than other modern locomotives. Aluminium alloy casings had been considered, but had not been used, as the prevailing conditions were all against such fittings.

In reply to Mr. McDermid, the water-space stays fitted to the boiler were under constant consideration, but up to the present no satisfactory explanation could be given why the stays broke in the particular areas illustrated. The investigations on stays were proceeding.

The method of shrinking the tyres on to the wheel centres had proved most satisfactory. It should be pointed out that the machining of the surfaces in contact, i.e. the surface of the wheel centre and the bore of the tyre, was such as to give a very close contact between tyre and wheel centre and was a much smoother surface than in the case cited by Mr. McDermid.

No difficulty had been experienced through the steam to the steam brake cylinders condensing and retarding the action of the brake; so it had not been found necessary to ensure that the cylinders and pipe line were kept warm.

In reply to General Davidson, when it was necessary to remove the tubes, the welding and bead were chipped away, and the surface was prepared to receive the new weld.

Communications

Mr. W. Barr (Motherwell) wrote that the comments he had to make concerned the metallurgical aspect, with particular reference to the steel firebox. He would like to thank the author for having so spectacularly vindicated the beliefs which he himself held in common with most metallurgists, regarding the possibilities of steel in this direction. It was quite incidental, but none the less gratifying, that the adoption of steel fireboxes by British railways would bring more "grist" to the mills in which he was particularly interested and which had specialized in the production of steel for this purpose.

It was also gratifying to note that the author had adopted welding in the construction of the firebox, the steel for which, it should be emphasized, was particularly amenable to this process. In the manufacture of these firebox plates to a tensile strength of 24–28 tons per sq. in. the carbon content did not exceed 0·15 per cent, so the material could be regarded as foolproof so far as weld cracks in the parent metal were concerned. The carbon content of American firebox plates, on the other hand, was permitted to go as high as 0·25 per cent, so that, from the point of view of weldability and general ductility, it was obvious that the British product was superior, which fact enhanced the argument in favour of the use of steel by British railways.

In comparing steel with copper, the author had rightly stressed the superiority of the former in regard to welding. At the same time emphasis should be laid on the methodical and carefully thought-out welding technique employed throughout, details of which were given in the paper.

What the Southern Railway had accomplished in the construction of these locomotives would be an inspiration to further progress and he himself would like to have the author's opinion concerning the application of welding in the firebox extended even to the stay bars. In this connexion reference had been made to minor troubles experienced in the initial stages of service due to minor surface cracks, all of which appeared to have originated at the staybolt holes. He had had the opportunity for examining some of these cracks and he was of the opinion that they were a manifestation of corrosion fatigue. It was at least significant that evidence of leakage was apparent where cracks had occurred. Such leakage could be obviated by welding, either in the form of a sealing run around the riveted heads of existing stays, or, better still, by adopting welding throughout and so eliminating the screwed thread which was a well-known source of trouble. The examples of broken stay bars exhibited on the table before them had all fractured in the threaded portion, due to stress concentration at the bottom of the threads. Incidentally, he would like to know if the author had considered the possibilities of rolled threads for stay bars. Due to the compressive surface stresses set up in a rolled thread it would offer greater resistance to fatigue failure than was the case with a machined thread.

In concluding, he joined with the other speakers in congratulating the author on the design and construction of this locomotive embodying so many novel features. It was a very real contribution to the national effort and would add considerably to the prestige of British engineering.

Mr. Clarence O. Becker, M.I.Mech.E., wrote to ask if the author—who, in referring to the overheating of the crown sheets of two locomotives, had mentioned that the fusible plugs had operated and had prevented further damage—would give a drawing and particulars of the plugs used, and show the depth to which they were screwed into the crown sheet.

Referring to the multiple blast nozzle shown in Fig. 16, p. 324, he thought that U.S. Patent No. 1,239,370 (4th September 1917) taken out by his friend Mr. William Elmer, Special Engineer, Pennsylvania Railroad, seemed to have anticipated this design.

Lieut.-Commr. D. R. Carling, M.A., R.N.V.R., A.M.I.Mech.E., wrote that the author was to be congratulated not only on the success of his design, but also on his courage in introducing the various innovations to British practice (against some of which there had been widespread prejudice in this country) on such a large scale—in fact, on a scale which really allowed the innovations to be judged on their merits.

Usually such experiments were tried on one or two engines, and probably some of the failures of experimental features had resulted from that fact. A single odd engine, however good in itself, could be a nuisance, and such nuisances rarely got proper attention.

The fact that steel fireboxes had for years been the rule in America and in large parts of Europe, as well as in several of the Dominions and Colonies, was proof enough that a well-designed and well-made steel box could be successful. The earlier failures in Britain might largely be attributed to incorrect design, and sometimes to incorrect material.

It was wise of the author to avail himself of the experience of those who had made so many steel fireboxes for export.

Welding appeared to be essential for the inner firebox if trouble was to be avoided, but it was important that all the precautions described should be taken to ensure really sound work. Perhaps the author would state whether he was in favour of an ultimate move to the all-welded boiler.

The low-water episode described on p. 322 was of interest, as it showed that the syphons provided enough water to protect the crown sheet, but not so much as to prevent the fusible plugs from melting.

Incidentally, thermic syphons were not quite new in Britain, having been used experimentally before, for example, in the late Sir Nigel Gresley's *Bantam Cock* 2–6–2 tender locomotive of 1941.

It was not clear whether the fire door permitted some secondary air to enter to assist complete combustion and reduce smoke, or if it was virtually airtight when closed. Some secondary air was usually desirable.

The blast pipe, even for a multiple-nozzle type, seemed to be very close to the chimney. It was, surely, desirable to have as long a cone of exhaust steam as possible, to entrain the products of combustion, provided the blast orifice was high enough to avoid danger of being buried in any large accumulation of smokebox ash. The blast pipe could have been placed a good deal lower if the inside piston valve had not been on the centre line of the locomotive directly above the cylinder. This position of the valve seemed to cramp the bottom of the otherwise admirable smokebox, and did not seem to be necessitated either by the special valve gear or by considerations of space and directness of ports. If the valve were placed at the same distance from the centre line of the cylinder, but about 30 deg. above the horizontal, close to the frame, the blast pipe could be lowered considerably. Possibly there was some good reason against this which was not visible in Fig. 16, p. 324.

If a hot big-end occurred, however rarely, how were the crew made aware of it? Was it necessary for it to reach the state of being audible, or was some device used as a warning, in the way that "stink bombs" were used on the London and North Eastern Railway?

The new type of tyre seemed to be a great improvement: possibly even more uniform tyre heating would result from the use of an electric tyre heater, the tyre being heated as the shorted secondary of a transformer.

The spacing of the main frames at the centre lines of the bearings had much to recommend it, and one wondered why it had not been done before on wide firebox engines: it achieved at least some of the benefits of bar frames without giving rise to the difficulties which the latter might entail in workshops laid out to deal with plate frames.

Mr. Alan E. L. Chorlton, C.B.E., M.I.Mech.E. (*Past-President*) wrote that the paper showed that the author had made the most outstanding changes in locomotive practice that had been witnessed for many years. He had not been afraid to design and try many novel ideas in various parts of the engine.

He would like to ask the author why eight-coupled express engines had not been a success in this country, whereas in Canada and the U.S.A. they were standard practice. This question did not apply to the Southern Railway, but to the northern lines; for example, on the London, Midland and Scottish Railway there were heavy gradients and the weight of trains was steadily increasing, and the six-coupled *Pacific* locomotives slipped considerably.

He also asked why no other British railways besides the Southern used blast pipes with multiple exhaust nozzles.

Cast steel frames were general in Canada and the U.S.A., and were also used on large Diesel locomotives with which he had been associated. What did the author think of cast steel frames?

Mr. E. S. Cox, M.I.Mech.E., wrote that the most interesting feature of the *Merchant Navy* engines was the introduction of the steel firebox with its thermic syphons. Experience in America seemed to connect good steel firebox performance with fully treated water, and it would be interesting to know how sensitive the Southern Railway boiler was to this factor. He understood that external water treatment was applied individually to the tenders of these engines; but this method, although standard in France, and easily controllable on a small number of important engines, was difficult to control on a large scale. In this connexion, again, American experience was uncertain in the choice between presence or absence of the copper ferrule at the firebox end of the tubes, but only with rigidly controlled water did it seem possible to rely fully on the connexion without such ferrules. One feature in the firebox design was difficult to understand, namely, the seeming reluctance to use flexible stays in the "breaking" zone; to avoid them the unusual step was taken of employing non-ferrous stays in an otherwise all-steel design. In view of the world-wide acceptance of the flexible staybolt, it would be interesting to learn the reason for this—a feature in which this firebox differed from almost all other large steel fireboxes of which he himself was aware.

Turning to the valve gear, after re-reading the paper carefully, the question which still arose was "Why was it necessary to design a new type of link motion and enclose it with the inside big-end in a casing, difficult to design and maintain?" Of all the parts of a locomotive, the normal Walschaert gear gave least trouble and maintenance cost, while a correctly designed and maintained inside big-end could give comparative freedom from failure when contrasted with the performance indicated by the author for his enclosed arrangement.

Taking the last point first, and referring to the well known three-cylinder *Royal Scot* 4-6-0 locomotive on the London, Midland and Scottish Railway, which had, over a period of 18 years, been engaged in top link work with fast, heavy trains, seventy engines ran 35 million miles in the eight years 1938–1945 inclusive, and sustained eighteen big-end failures in all, an average of practically 1,950,000 miles per failure. This compared very favourably with the author's figure of 700,000 miles.

Turning to maintenance, in three sets of valve gear, at service repairs averaging 65,000 miles, expansion links and valve rods might require new die-blocks. Other rods might require lapping and new pins and the eccentric straps might require re-metalling, at an average departmental cost, including material, of £20. At general repairs, every 165,000 miles, the valve rod and expansion link die paths were lapped, and bushes and oiling rings in the rest of the valve gear were renewed, in addition to what was done at service repairs, at a total cost (on the same basis) of £33. These figures represented a very low proportion of the total repair cost of the locomotive. Finally, the normal unenclosed valve gear could be dismantled, repaired, and returned to the erecting shop for refitting to the engine five days from its entry into the erecting shop for stripping.

The foregoing facts seemed to suggest that there was only a very narrow margin of advantage in adopting any more complicated forms of construction.

Mr. P. C. Dewhurst, M.I.Mech.E., wrote that the author was to be congratulated upon his combining, so successfully, features new to home practice, though well tried overseas, with others which were real innovations in the locomotive world. He himself had long advocated and successfully employed a number of the constructional features—having, in fact, championed "international" locomotive design for many years,* and his remarks were intended for the purpose of eliciting further information rather than as criticisms.

He believed that the author was right in considering that the main cause of electrolytic action in boilers was the use of steel and copper—a point mentioned specifically in his comments on Mr. Turner's recent paper on "Corrosion of Boiler Tubes".† Regarding corrosion as such, injector feed-water introduced by a plain top-feed system reduced corrosion very considerably.

Where weight was such an important consideration he could not follow the employment of the Belpaire pattern firebox. A round-topped radial-stayed firebox would have saved appreciable weight and this could have been utilized in increasing the barrel diameter, thus providing a few more (perhaps shorter) tubes and, or alternatively, increased steam space to compensate for that lost by the elimination of the "haunches" of the Belpaire outer shell. The only slight practical disadvantage of the round-topped box with radial staying (namely, that a few of the stays were not exactly radial with respect to the outside plate) had practically disappeared with the possibility of welding-on slight supplements in those places having only one thickness of plate, or of using flexible stays.

The success obtained with steel fireboxes, with the particular manner of "setting" or fixing the steel tubes in the firebox tubeplate, and with the syphons, was no surprise to one who had used the first for thirty, the second for twenty-one, and the third for ten years with eminently satisfactory results. These applications were required to meet conditions more arduous for boilers than even those encountered by the Southern Railway locomotives, conditions indeed which copper fireboxes could not withstand—in particular, the keeping of tubes tight in the firebox tubeplate. The use of ⅜-inch plate all round, except the tube area where a thickness of ⅝ inch was desirable, was good practice.

The ratio of superheating to evaporative heating surface (1 to 2·98) was a welcome figure, the superheater units occupying no less than five horizontal rows. He had tried a ratio of 1 to 3·6 upon engines required to work full-throttle combined with 60–70 per cent actual working cut-off for an hour or two continuously; but overheating of piston-rods in the packing under these extreme conditions persuaded him not to exceed that ratio. It would be of value to know the degree of superheat attained by the author's engines at maximum output, and how the piston glands behaved.

The author had stated that the tube fixing adopted upon these engines had justified itself, "the tubes remaining completely tight, again something not previously experienced". On the railway with which he had been connected recently a similar

* Proc. I.Mech.E., 1922, p. 375, "British and American Locomotive Design".

† Proc. I.Mech.E., 1944, vol. 150, p. 102.

system was in force, and no case of a tube leaking in service or having to be dealt with between general repairs had been known for a number of years. The author's method of forming the shoulder on the water side of the tubeplate was not clear; his own system was to form the shoulder on the water side of the plate by means of a "prosser" (a roller expander being used only for fixing the tubes lightly in position, ready for the prosser) which also "bellied-out" the fire side ready for the beading tool. In this connexion it was of great importance to have the correct relation between the prosser profile and the thickness of the tubeplate so as to produce the required "nip" between the shoulder and the bead, *but no more*, otherwise the diametral tightness in the hole became affected. This tube fixing, as introduced by him on the various national railways of Colombia from 1923, was fully described in a paper* and was also discussed at an informal meeting of The Institution of Mechanical Engineers in the previous year.

The author appeared to be eliminating the copper liner. The liner was used mainly in order to preserve the surface of the tubeplate holes (i.e. the "bore"), and this was a matter of importance for future re-tubing, because even slight scratches communicating from each side of the tubeplate might cause trouble. Even the flat surface on the fire side of the tubeplate was important. His practice had been to cut off the whole bead and "weld-seal" flush when taking out tubes, and to re-face the landing for the bead and weld-seal, at which time any cases needing it were touched up with electric welding and machined to a good surface and correct thickness of tubeplate. No sealing of the tubes by welding was allowed until both hydrostatic and steam tests had been satisfactorily carried out; the sealing was always done with the boiler in its natural position and with water in it.

The use of corrugated steam-pipes was an innovation; some further information on comparative maintenance and ultimate life would be welcome.

He admired the enclosing of the parts in the ingenious valve gear, but considered that there were too many pins. Moreover the two chains might lead to "lag" in the valve events, and this without giving the usual audible indications leading to running-shed attention. The valve gear might therefore require maintenance of a "nursing" character. Although reference had been made particularly to the valve-gear lubrication, nothing had been said about the outside connecting and coupling rods. Much convenience, and considerable saving in lubricants and enginemen's time, could be obtained by grease lubrication on all the outside rods. Existing rods could be equipped for grease by a very small modification of the original oil-wells.

In the description of the special method of tyre-fixing, emphasis had been laid on the importance of evenly heating the tyres for shrinking. Had the author contemplated using an electric heater of the induction type? He himself had been prevented from adopting it by war-time difficulties, but he had been much impressed by the efficacy of the method as used abroad for the tyres of tramway vehicles.

In the main frames the author had succeeded in bringing the axlebox reactions into line with each frame, whereas they were ordinarily, except in bar frames, 4–5½ inches off-set. It was noticeable, however, that quite a lot of somewhat complicated cross-staying was built into the frame system, and the author referred to "the place where cracks usually develop" and added that "wedges were not fitted". These were unsatisfactory features of the plate frame; one day someone in England would try bar frames—and be surprisingly successful!

The reaction brake hangers placed between the coupled wheels were intriguing, but whilst he appreciated the advantage of situating the brake-cylinders away from the region of the firebox, he thought that there would be "chatter" as a result of the toggle-like effect upon the "duplex" hanger system when the engine was running forward. (For running backwards the arrangement appeared to be ideal.) Did not wear and chatter, and hence more wear, develop?

It would be interesting to know whether the author had considered a modernized *Midland* (Smith-Deeley) three-cylinder compound arrangement. It would seem that the author was so limited by considerations of axle-weight versus maximum starting effort as to be prevented, like himself on various occasions, from utilizing the system. The really high pressures foreshadowed seemed to call for compounding where other conditions permitted.

It had been said that nothing could be done about the loading gauge, but could not platform edges and "between line" girders (upon certain types of underbridges) be set back to allow more room in the region of the cylinders, as he had suggested some years ago in the technical press?

A very significant feature of this locomotive design was the manner in which the adjustment of the whole optimum to the prevailing conditions had been made by the Chief Mechanical Engineer responsible for results, notwithstanding an ephemeral fashion to disparage this essential to satisfactory locomotive designing.

Lt.-Colonel L. F. R. FELL, D.S.O., O.B.E., M.I.Mech.E., wrote that he had listened to the paper and the discussion thereon, with very great interest because though he had left locomotive work thirty years ago when he was a colleague of the author, there were features about the *Merchant Navy* class locomotives that were in some ways akin to the work on which he himself had been engaged since then.

He was particularly interested to note that it had at last been proved possible to enclose the locomotive big-end and thereby dispense with the direct air cooling which, in the past, had been held to be the saving grace of the locomotive big-end design. It seemed clear that this had only been made possible by the rapid oil circulation which the author demonstrated so clearly in the film which was shown at the meeting in London, and

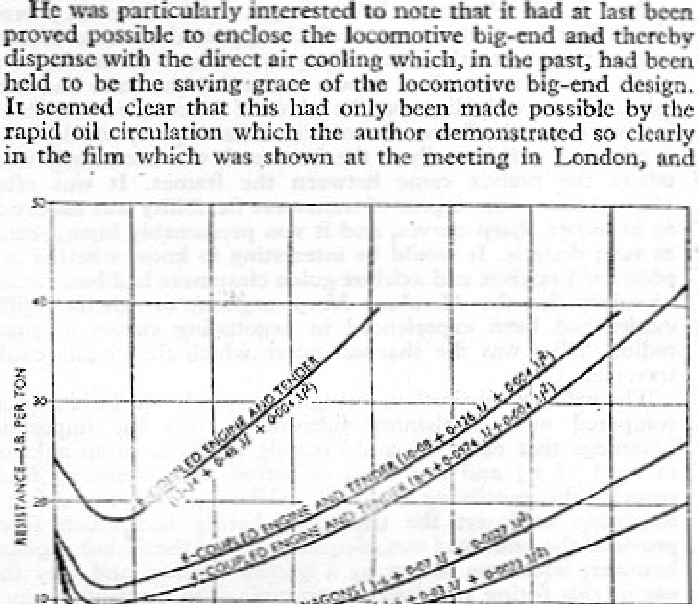


Fig. 33. Resistance of Locomotives and Rolling Stock at Various Speeds. (Lawford H. Fry's formulae)

For grades of 1 in 300 add		7·47 lb. per ton.			
,, ,, ,, 1 in 250	,,	8·96	,,	,,	
,, ,, ,, 1 in 200	,,	11·2	,,	,,	
,, ,, ,, 1 in 150	,,	14·98	,,	,,	
,, ,, ,, 1 in 100	,,	22·4	,,	,,	
,, ,, ,, 1 in 75	,,	29·96	,,	,,	
,, ,, ,, 1 in 50	,,	44·8	,,	,,	
,, ,, ,, 1 in 33·3	,,	67·2	,,	,,	
,, ,, ,, 1 in 20	,,	112·0	,,	,,	

which was responsible for conveying the heat at a high rate from the bearing surfaces to the walls of the crank chamber where it was dissipated by air cooling. For this reason he disagreed with the remarks made by Wing Commr. Cave-Browne-Cave, during the verbal discussion,† that it would be an advantage to reduce the oil circulation. This would be contrary to the normal practice on all other high-speed enclosed type engines. He agreed with Wing Commr. Cave-Browne-Cave

* DEWHURST, P. C. 1930 Jl. Inst. Locomotive Eng., vol. 20 p. 888, "Locomotive Design for Overseas Service".

† See p. 335.

that it was possible to over-lubricate a high-speed ball bearing and that very careful metering of the oil was necessary for this particular purpose. The failures of ball bearings were, however, due to an internal pumping action which burst the ball bearing cage.

He would like to ask how the resistance of the *Merchant Navy* class locomotive compared with that of normal "open" type locomotives. He considered that the question of resistance was one to which locomotive engineers normally paid rather scant attention. A typical resistance curve of an "open" type locomotive (Fig. 33) showed that at 80 m.p.h. the resistance of a passenger engine and tender was as much as 42 lb. per ton. It was true that a little of this was due to air resistance, but comparing the figure with that of a bogie coach (presenting a much larger area per unit of weight) which was only 20 lb. per ton at 80 m.p.h., it would appear that the main source of resistance of the locomotive was due to low mechanical efficiency.

He submitted that it was obviously preferable to reduce the resistance of a locomotive by increasing its mechanical efficiency rather than to attempt still further to increase its nominal tractive effort. Did the author think he had achieved this end?

Perhaps this was the answer to those speakers who were advancing the claims of Garratt type engines, the specific resistance of which might be expected to be large at high speeds.

Mr. D. W. Peacock, B.Sc. (Eng.), A.M.I.Mech.E., wrote that a feature of this engine which appeared to have escaped special notice was the unusually great stiffness of the frame to resist transverse bending. It was noticeable that care had been taken to ensure rigidity over the whole of the coupled wheelbase, in contrast to the frame of a conventional engine, which, while it might be stiff laterally at the front end, was necessarily weak where the firebox came between the frames. It was often claimed that some degree of transverse flexibility was necessary to negotiate sharp curves, and it was presumably incorporated in such designs. It would be interesting to know whether any additional axlebox and axlebox guide clearances had been found necessary for the *Merchant Navy* engines, or whether difficulties had been experienced in negotiating curves of small radius. What was the sharpest curve which the engine could traverse?

The axlebox lubrication, though apparently old-fashioned as compared with mechanical lubrication, had the important advantage that extra oil could readily be given to an axlebox in need of it; and the usual objection to a trimming feed, namely, the possibility of a hot axlebox due to the driver's forgetting to insert the trimming, hardly had much force provided the underpad was adequate. Would the author explain, however, what was meant by a broken syphon, and why the use of this fitting required the trimmings to be vented, since with a simple trimming feed and pipe to an axlebox the trimming worked excellently without any provision for venting at all.

Mr. F. A. Pudney, A.M.I.Mech.E., wrote that the author's neat arrangement of three independent sets of valve gear, with a chain drive, was noteworthy. Would the author agree that at least 20 h.p. would be required to operate all three sets under certain conditions of steaming? The author mentioned an allowance of 3 inches for sag in the chain. Did that mean 1½ inches above and 1½ inches below the horizontal, or 3 inches above and 3 inches below? Some years ago, when he was closely acquainted with chain drives for certain Diesel engine camshafts, chain stretch became serious, for as soon as any "whip" arose (a condition which could occur almost irrespective of transmitted load) chain inertia, during periods of out-of-phase or out-of-balance running, soon caused quite excessive sagging. In some instances the only possible cure was the addition of jockey pulleys; in others brass and fibre rubbing (or guide) plates were added.

It was of particular interest to read that so little trouble had been experienced in the chain drive, irrespective of the not too ideal conditions existing between the driving and the driven wheels. He asked if the chains could be readily inspected in the gear case, and whether the case was of fabricated construction, also whether any leakage had resulted from distortions in the framing.

The housing of such an amount of valve gear in an oil-tight bath represented a real step forward, but he asked if one or other of the poppet valve gears, with their many claimed advantages, had been considered when the locomotives were being designed.

Mr. H. W. Puttick, M.I.Mech.E., wrote that the Nicholson syphons appeared to be very expensive, owing to the amount of press-work involved and the large number of stays; and it seemed almost impossible to clean them effectively. The cracking of the throat plate in the vicinity of the syphon neck was probably due to contraction stresses set up from the large mass of metal in the syphon body when the boiler was being cooled off.

The syphons improved the circulation in the boiler considerably, but it seemed that this could be done equally effectively by having three 4-inch tubes set in triangular formation as shown in Fig. 34; the tubes would support the firebrick

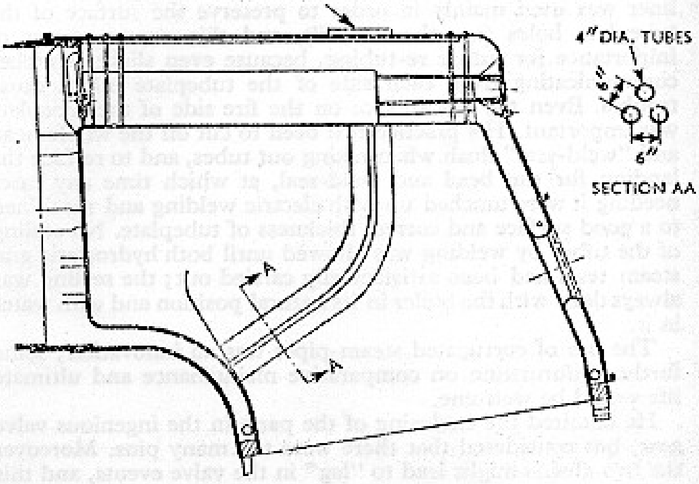


Fig. 34. Suggested Substitution of Arch Tubes for Nicholson Syphons

arch in a similar manner to the syphons. It would, of course, be necessary to have two manholes in the wrapper plate so that the tubes could be expanded, beaded, and welded in place, but it would be very easy to clean the tubes with a tube cleaner when the engines went to shed for wash-out, and to renew them if necessary at intermediate or periodic overhauls.

Even after allowing for the additional cost of the manholes, there should be a considerable saving in initial expense and weight, with very little reduction of heating surface.

He was surprised to see that inverted tooth chains were used for the valve drive. Similar chains were used for the final drive of the Drewry railcars working on the narrow-gauge hill sections of the North Western Railway (India). When new chains of similar construction were indented for in 1941, the chain makers stated that these chains should be considered obsolescent, and it would be necessary to install double-roller chains with new pinions. He would be glad if the author would state what advantage—if any—the inverted tooth had over the roller chain. In this particular case a single-roller chain could have been used, as the horse-power transmitted was quite small.

With regard to the illumination of the gauges in the cab, the luminosity obtained from ultra-violet rays on luminous figures was of a low order, and it would appear to be difficult for the fireman to read the gauges after looking at the intense glare emitted from the firebox. In India almost all locomotives were fitted with turbo-generators, which were mainly installed for the engine headlight; originally there were separate lighting fittings for the steam gauges, water gauges, and the lubricators. Owing to the excessively high maintenance, all these fittings, with the exception of the lubricator light, were taken out, and the cab was illuminated with one low candle-power lamp of 15 watts in a locally-made reflector fixed to the roof of the cab. This lamp gave sufficient light to read the gauges without being intense enough to interfere with the driver's lookout.

Mr. H. P. Renwick (Bombay) wrote to congratulate the author, first on his excellent paper, and second on his successful efforts in carrying forward the development of locomotive design on British railways. Most locomotive engineers on overseas railways looked (as he did) to British railways to give a lead, though they had no hesitation in adopting American or European practice where such appeared to offer advantages.

The author stressed the limitations of the British railways loading gauge, and it would seem that, since the maximum height and width had now been reached, the only remaining dimension left for development was length. Whether longer and heavier trains would become the rule to meet the post-war traffic trend remained to be seen. In view of the cost of lengthening station platforms, he thought that the need could only be met by more trains; but the cost of providing longer turntables should not limit the development of more powerful locomotives of increased length.

As the author points out, the desirability of providing for power to haul freight trains at passenger speeds would necessitate more powerful general-purpose locomotives.

He could not but admire the very great amount of thought that had gone into the design of the *Merchant Navy* locomotive, with the aim of giving consideration to the footplate staff who would operate them and the running shed staff who would maintain them. It was the little things that counted in maintenance; and forethought in design meant reduced time in the shed and greater availability.

There were, however, one or two points that seemed to call for mild criticism. The author had mentioned the difficulties in designing a boiler of sufficient power within the weight restrictions. He stated that there had been a number of broken firebox water-space stays, all of which had occurred in the normal breaking zone shown in Fig. 5; yet he stated that flexible stays of the Flannery type were only installed in the throat plate around the necks of the thermic syphons. It had been standard practice on Indian railways to fit flexible stays throughout this zone, with remarkably beneficial results, and he would suggest a similar provision on the *Merchant Navy* locomotives. The additional weight could be offset by the elimination of the foundation ring which might well be replaced by a U-shaped flanged plate welded to the inner and outer sheets with two seam welds.

The weight of the boiler could be carried by sliding bearer brackets at the front end and by flexible "breather" plates at the rear, as was common practice in the U.S.A.

Similarly, the author referred to the stressing of the throat plate by pressing out the syphon neck connexions. Was there any reason why the curved connexions should not be pressed separately and welded into large-diameter holes cut in the throat plate? One might go a stage further and, placing the neck connexion to the syphon farther to the rear, spin a corrugation in the neck piece to aid flexibility at this point and relieve the throat plate. The speed of water circulation through the syphon should prevent accumulation of scale in the corrugation.

He admired the author's attempt to produce an enclosed valve gear, continuously lubricated as copiously as was shown in the film exhibited at the meeting; but he could not help feeling that the possibilities of leakage from vibration with age were great, and the maintenance costs to prevent this leakage must be high. He had hoped that the author would have given some comparative figures of big-end and slide block wear between the *Merchant Navy* and the *Schools* (4–4–0) classes, particularly the man-hours expended on the two classes to reduce and refit big-end brasses and close slide bars.

Until the stage of the multi-cylinder gear-driven high-pressure locomotive of the *Sentinel* or *Besler* type had been reached, he felt that the development of the poppet valve gear with enclosed shaft drive would give the same desirable end that the author had endeavoured to attain, with much less weight and complexity.

For the benefit of overseas members, he hoped that the Proceedings would contain a more detailed description and an illustration of the motion-pin "circlips", for he felt that their greater use was a move in the right direction.

He was greatly indebted to the author and to Wing Commr. Cave-Browne-Cave for their remarks on the experimentation to decide the best shaping of the front end screening to satisfactorily lift the smoke at short cut-offs. They had explained his own failure to achieve satisfactory results with a similar problem on the Great Indian Peninsula Railway.

Mr. O. V. S. Bulleid wrote in reply to Mr. Barr that, the welding-in of stays had been under consideration for a number of years, but no entirely satisfactory method of welding had yet been evolved. The possibility of fitting rolled screwed threaded stays had also been investigated, but up to the present the stays so produced had exceeded a reasonable factor of safety by work-hardening; and so the experiments continued.

In reply to Mr. Becker, he had placed samples of fusible plugs on exhibition in the entrance hall of the Institution when he presented the paper there. It was not claimed that the multiple-jet blast pipe cap was new; but the development as fitted to this class of engine had proved most satisfactory from a steaming point of view.

Lieut.-Commr. Carling would appreciate that it was only because of prevailing war conditions during the period in which the engines were built that a completely welded boiler was not fitted, and in future design it was intended, should the cost not be prohibitive, to provide completely welded boilers. The boilers for the *Merchant Navy* class were already under construction, and were fitted with thermic syphons, before Sir Nigel Gresley fitted the syphon to the *Bantam Cock* locomotive on the London and North Eastern Railway.

For Lieut.-Commr. Carling's further information, the firedoor did admit air to the firebox. The blast pipe and chimney proved highly satisfactory in creating sufficient draught on the fire to maintain steam under the most arduous conditions of working.

A feature of the *Merchant Navy* engines was that although the blast pipe nozzles were only 9 inches above the base of the smokebox, the middle piston valve was remarkably free from smokebox char; the valves were extremely clean, and caused no distress when they were removed for examination.

There was no device fitted to enable a case of hot big-end to be detected from the cab. The method of tyre heating was very satisfactory with gas, and it was doubtful if any improvement would result by using electricity.

The question, raised by Mr. Chorlton, as to whether six- or eight-coupled wheels should be fitted to an express engine was decided by the loads and conditions of the trains to be hauled. The possibility of fitting bar frames, either of rolled steel plate or cast steel, was considered; but it was thought that the plate frames as fitted were on the whole more satisfactory for this particular engine.

The use of cast steel frames would have had to be discussed with the steelmakers, and would probably have necessitated a certain amount of experiment—which would not have been possible during the war conditions under which the engines were built.

In reply to Mr. Cox, the steel fireboxes, which had been examined since the paper was read, had shown that the water treatment first used on these fireboxes was far from satisfactory, but that the present treatment seemed to be giving the results which were hoped for. The treatment was applied in the way Mr. Cox stated, and had proved quite good. The fitting of copper ferrules between the tube and the tubeplate at the firebox end, was a controversial matter; the first twelve engines were so fitted. The last eight engines constructed were not fitted with copper ferrules. When the engines had done sufficient mileage, observations would be made with a view to deciding future practice.

There was no reluctance with regard to the fitting of flexible stays; the matter was thoroughly discussed, but owing to difficulties in design in accommodating this type of stay, they had not been fitted. In this connexion, the area which should be fitted with flexible stays had not yet been clearly defined. It must be readily apparent to anyone studying fireboxes that, where flexible stays were used, the number fitted had gradually grown. Starting with one row at the top of the firebox sides, fireboxes were now designed which were now almost completely fitted with flexible stays at the sides. This led one to conclude that the area of the plate relieved by fitting flexible stays tended to throw whatever stress it obviously carried on to the adjacent row fitted with rigid stays.

He considered that the time had arrived when the valve gear should not be exposed to the dust and grit of the road, and although the wear might not be large compared with other parts of the engine, it should, if possible, be minimized. Furthermore, the oiling of a locomotive should not be carried out by a driver with an oil feeder; the whole of the lubrication should be automatic, as it had been arranged in the case of the cylinders.

It was very remarkable that the London, Midland and Scottish Railway had gone to the trouble of fitting a new type of big-end to inside connecting rods, if the *Royal Scot* type of big-end was so successful. This big-end was of the type with two bolts in a vertical plane, the brasses being held in position by a cotter. Incidentally, he believed that other railways had found this type of big-end so unsatisfactory that, almost without exception, it had been superseded.

Mr. Cox, in his last sentence, had suggested that there might be undue complication in the motion fitted to the *Merchant Navy* locomotives; whereas the only complication—if complication it could be called—was the oilbath which prevented the motion from being readily seen, although not from being easily dismantled.

In reply to Mr. Dewhurst, the amount of weight added by using a Belpaire type of firebox was very little really; and there would have been an appreciable loss in steam space if the Belpaire box had been abandoned in favour of the round-topped type in conjunction with a boiler of increased diameter.

It had not yet been found possible to test the engine, but when this was done the smokebox superheater temperatures would be recorded.

It was very interesting to read of Mr. Dewhurst's method of re-welding the tubes into the tubeplates.

The wear in the chain driving the valve gear would undoubtedly lead to slackness of the chain; nevertheless there was no measurable wear of this type of chain after 120,000 miles. Any change in the valve events would be plainly audible in the cab, just as in any other engine. The suggestion with regard to grease lubrication would be borne in mind; indeed it had already been considered.

The gas method of heating tyres, now adopted, gave excellent results. It was possible that at some future date bar frames might be fitted; but could it be said that this type of frame was entirely free from trouble? There had been no undue amount of wear on the brake gear—nothing more than normal.

Regarding Lieut.-Col. Fell's remarks, it would be very interesting to obtain typical resistance curves of the *Merchant Navy* locomotives, but such an investigation had not yet been found possible. In connexion with the desirability of increasing the mechanical efficiency, although no data were available, it was rather remarkable how freely these engines rode, as compared with the more orthodox type of locomotive.

In reply to Mr. Peacock's comments on the rigidity of the frames, due to the cross-stays, it had not been found necessary to increase the clearances between the axleboxes and the axlebox guides; and there was no difficulty in negotiating the curves for which the locomotive had been designed. The minimum curve which this engine was designed to negotiate was of 6 chains radius.

The broken syphon and the venting of the axlebox trimmings were not related events. The syphon had been fitted to enable the length of pipe between the oilbox at the source of supply and the exit to be always filled with oil; to do this it was necessary to provide a loop at the exit end of the pipe and at such a height relative to the box that it would trap the oil in the length of pipe joining the extremities. At the apex of this loop, it was necessary to provide an air vent to break the column of oil when the trimming was taken out at the end of the journey, thereby preventing any further oil from being fed to the point of application. This was what he referred to as the "broken syphon".

The venting of the trimmings had been found necessary owing to observations carried out in the erecting shop, when it was found that an engine which had had its wheels taken out, had fed no further oil at the end of the pipe at the axlebox, after approximately forty-eight hours, although the worsted trimming was in place and the box was full of oil. This led to experiments being carried out with a similar length of pipe, and the times were noted of the rate of emergence of the drops of oil from the end of the pipe. It was found that although the rate of feed at the commencement of the worsted trimming was normal, after a period of time varying between a quarter and half an hour, the trimming ceased to feed, owing to an air lock having been caused. It was therefore necessary to provide air vents to the pipe at a point below the end of the trimming, thereby ensuring that the oil in the pipe line was always under air pressure. Experiments carried out after these adjustments had been made showed that the trimmings gave a constant predetermined rate of drops per minute. These two improvements were being fitted to all engines as they passed through the shops for repair.

Mr. Pudney had asked about the horse-power necessary to drive the three sets of valve gear. Under certain conditions of steaming, this figure might be so high as 20, but no investigations had been carried out to ascertain the power thus absorbed. Actually, however, the gear was driven in the shops by a motor and the horse-power recorded was 3 at 300 r.p.m. It must be appreciated that there was no steam in the piston valves during these experiments, although all the rings were in place.

Whilst the figure given for the sag of the chain was considered a maximum, no chain had as yet shown any appreciable amount of stretch after running up to 100,000 miles. He appreciated that there might be stretching due to chain inertia, but this had not been found to cause any distress, probably because the engine had not exceeded 450 r.p.m.

The chains could readily be examined through an inspection door at the rear of the oilbath behind the crank axle, in the case of fabricated construction. There had been no leakage caused by distortion of the framing, as the frame was of very rigid construction. Poppet valves had been considered when the engine was being designed, but this type of gear was not entirely without its difficulties.

In reply to Mr. Puttick, the Nicholson syphons were not expensive when one considered the advantages obtained by fitting them. No difficulties had been encountered in maintaining or cleaning the syphons. Although the suggestion offered for the cracking of the throat plate could not be refuted, he still thought that a considerable amount of the trouble caused was due to the pressing of the syphon necks into the throat plate.

The choice between arch tubes and thermic syphons was one which must be made by each engineer, and he himself preferred thermic syphons.

As Mr. Puttick was no doubt aware, special apparatus was generally used to clean out arch tubes, but it was not necessary with thermic syphons.

The inverted tooth for the valve gear chain drive had been decided upon as it tended to fit more closely into the tooth, and as the chain stretched the inverted tooth tended to increase its width owing to the wedge-shape pivoting about its fulcrum, which was a rocker bar.

He was quite satisfied with the electric lighting which had been fitted, particularly the ultra-violet rays for the gauges; there was no difficulty in seeing these gauges at all times of the day or night.

He would refer Mr. Renwick to his reply to Mr. Cox regarding the fitting of flexible firebox stays. He would be pleased to know whether Mr. Renwick still fitted any rigid type stays in the fireboxes, or whether part of the firebox was fitted with flexible stays and part with rigid stays. Regarding Mr. Renwick's suggested method of replacing the foundation ring by a U-shaped flanged plate, this had already been done in the *West Country* engines now being built at Brighton. Moreover, in the engines of this class now being built, curved connexions to receive the thermic syphons were pressed separately and welded into the throat plate afterwards.

The maintenance work caused by the use of the oilbath was very low, and there was no reason to suspect that it would increase with the life of the locomotive.

The fitting of circlips to the motion pins, had proved to be most satisfactory; and if Mr. Renwick was really interested, he would be glad to supply him with a drawing showing the fitting.