LOCOMOTIVE MANAGEMENT

CLEANING–DRIVING–MAINTENANCE

9th Edition *Price 10/- net*

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CLEANING
DRIVING
MAINTENANCE

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Ninth Edition

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PREFACE TO THE NINTH EDITION

THE first edition of this book was published in 1908, and during the intervening four decades the volume has long since come to be recognised as a standard textbook. In 1928 it reached its sixth edition, which was a large one, and lasted without change for eleven years. In any form of engineering practice, much may happen in the course of ten years or so, and this proved to be the case in locomotive engineering and design in the early 1930s. Scientific research played an increasingly important part in improving the thermal efficiency and general reliability of the steam locomotive. This was occasioned in part by economic requirements, and also under the urge from competitive forms of transport and alternative forms of railway prime mover.

With railway transport, electric traction was developed extensively (particularly, in this country, by the Southern Railway), and the diesel engine for the first time became a formidable competitor for various types of work. In Great Britain the use of the diesel engine has been confined to shunting, for which its flexibility is peculiarly adapted. In many overseas countries the diesel railcar inaugurated a new era of ultra-fast passenger service, and the diesel locomotive enabled high speeds to be maintained regularly, such as had not been envisaged only a few years earlier. British locomotive engineers continued to pin their faith to the well-tried steam locomotive as a prime mover, and produced machines which amply demonstrated their ability to maintain speeds in excess of 100 m.p.h. when required.

Consequently, a more drastic revision than any previously undertaken became necessary when the seventh edition of "Locomotive Management" was published in 1939, so that work might be brought into line with present-day locomotive standards, alike in regard to matters of design and construction, and those relating to cleaning, driving, and maintenance. Nevertheless, it was also borne in mind that large numbers of locomotives continue in use, which, although they are capable of discharging their duties in a satisfactory manner, do not conform to the most modern standards of design and construction. Thus, references were retained in the text to materials and manufacturing methods that have ceased to be used in new contruction of express passenger locomotives, but are far from being obsolete in ordinary operating practice. This is still the case, as the intervening six years of war resulted in a virtual suspension of technical development in locomotive construction, at any rate for peacetime needs. Moreover, war destruction and insufficiency of new building have resulted in locomotives which were destined for scrapping being reconditioned for a further period of service.

The eighth edition was published in 1942, less than four years after the issue of the extensively-revised seventh edition, largely by reason of war conditions. After the outbreak of war, there was a large increase in the number of firemen and drivers, and the more rapid promotion of the staff created a considerable demand for a book which was recognised in railway circles as a standard textbook for cleaners and firemen in studying for the examinations which must be passed before they become firemen and drivers respectively. Generally, the eighth edition was produced with comparatively minor alterations, so that the work should not go out of print, although new classes of locomotives adopted in Great Britain formed the subject of half a dozen new illustrations.

Mr James T. Hodgson, the joint author with Mr John Williams of the earlier volumes, died on January 21, 1939, immediately after the seventh edition was published. Mr Charles S. Lake, who had become joint author with Mr Hodgson for the seventh edition, assumed sole responsibility for the eighth edition, but he died on November 18, 1942, on the precise day that the first completed copies were received from the printer; thus he never saw the finished work.

With the present edition, the text has been subjected to complete revision, although no fundamental change has been made in the structure of the book. Rewording of various sections has been designed to secure great clarity and simplicity, as a result of experience in the use of the volume; developments with permanent way that have their repercussions on locomotive operation have been borne in mind; the extended use of wheel arrangements that formerly were unknown or little-used in this country has caused the locomotive classification section to be rewritten; and all references to the use of oil firing have been brought into line with the post-war position resulting from acute coal shortage.

A fire in Edinburgh destroyed the whole of the type and illustrations of the eighth edition, and it was necessary to begin afresh with production of the present book. Opportunity was taken to redraw in standard form (in the drawing office of *The Railway Gazette*) the many line diagrams which illuminate and explain the text. All the photographic illustrations are new; subjects which are felt to be incapable of substantial improvement have been repeated, but many are new photographs taken specially for this edition.

It is desired that the book should continue to be of service not only to the enginemen themselves, whose duties (responsible though they are) are confined mainly to handling the locomotives on the road, but also to the personnel of the running-shed staffs, mechanics, apprentices, and to all whose daily work brings them into contact with the "servicing," maintenance, and operation of the engines.

Many important features of locomotive equipment have been designed specially to facilitate the work of the driver and fireman, and those employed at the locomotive depots. The increasing care which is being devoted to placing equipment at the ready disposal of the driver is exemplified by the footplate arrangements of the "Merchant Navy" and "West Country" Pacifics of the Southern Railway, the most noteworthy new types to appear during the war years. Every necessary control has been placed within reach of the driver's hand, so that he may have no need to rise from his seat in ordinary running. With coal firing, the fireman's work has been eased by the pedal-controlled steam-operated fire doors, which provide a substantial assistance to manual firing. Illumination with ultra-violet lighting of the fluorescent dial marks of all the cab gauges is another improvement, as it makes everything clearly visible in tunnels or after dark without interfering with the look-out ahead. The availability of electric light all over the engine is another advantage which it is unnecessary to stress.

The chapters relating to shed regulations, to clearing house rules, and to colour-light, semaphore, lamp, and whistle signals, etc., together with the examinations thereon, have been revised to conform in all respects with present-day regulations.

The Appendices include descriptive matter and illustrations of special equipment, and give a representative selection of cab and footplate arrangements of locomotives belonging to the British and certain of the Irish railway companies. In addition, there are outline drawings of noteworthy locomotive types, with principal overall dimensions, weight distribution, and other particulars set out below them.

Grateful acknowledgment is made of the assistance in the preparation of this edition (as formerly) rendered by the respective Chief Mechanical Engineers of the British and Irish railways. The courtesy of firms manufacturing many of the specialities mentioned is acknowledged for their co-operation in preparing materials, and for loaning photographs and drawings. Thanks are due also to Mr H. A. Vallance for his care in checking details, and in the layout of the text and illustrations.

C. E. L.

LONDON, 1947

THIS BOOK IS PRODUCED
IN COMPLETE CONFORMITY
WITH THE AUTHORISED
ECONOMY STANDARDS

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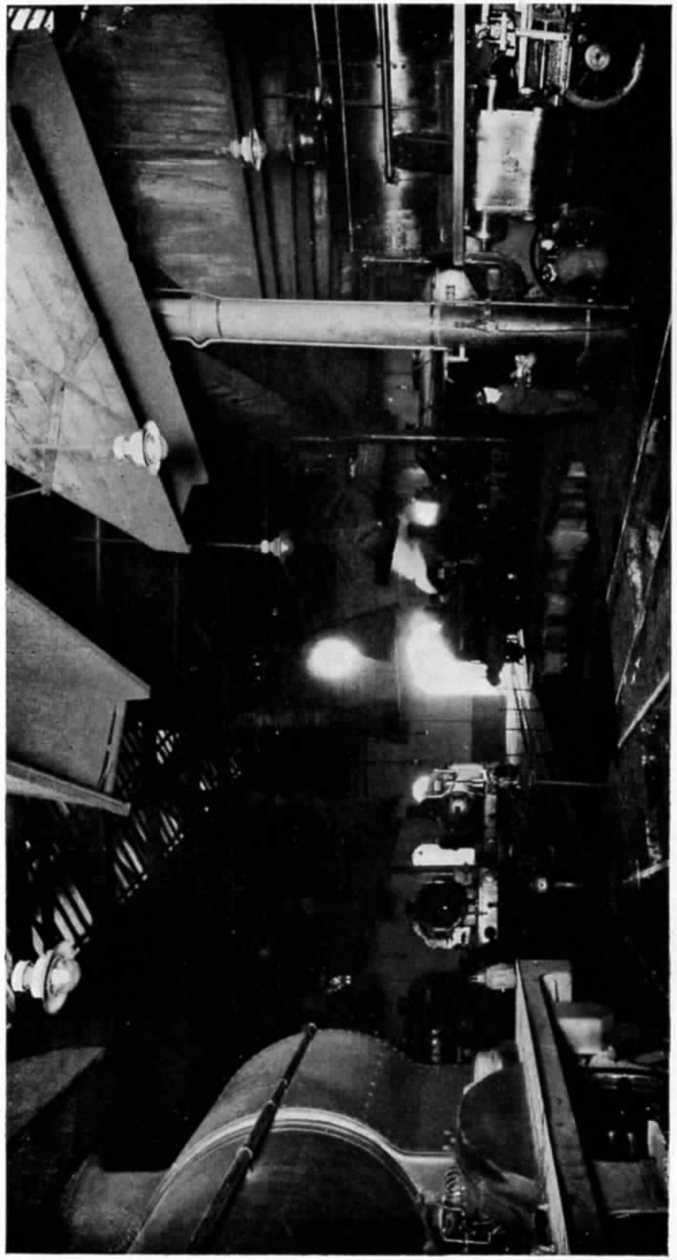


Fig. 1.—Interior of Locomotive Running Shed at Grimsthorpe, L.M.S.R.

[*To face page* 1.

LOCOMOTIVE MANAGEMENT

Cleaning—Driving—Maintenance

Chapter 1

INTRODUCTION — HOT-WATER BOILER WASHING-OUT SYSTEM — SHED REGULATIONS — LOCOMOTIVE WHEEL ARRANGEMENTS — HEAD-LAMP CODE

From cleaning to driving may sometimes appear a long and thorny path to the rising fireman or cleaner, ere the responsible position of locomotive driver is attained.

It may be taken that the young man, whose ambition is to be some day the driver of an express passenger train, already will have satisfied the locomotive superintendent or shed foreman as to his credentials, and have passed satisfactorily through the height and sight tests.

Beginning as a cleaner, in many sheds he will first be given less important jobs, but in a matter of a few months should find himself entrusted with the cleaning of express and other passenger engines, in the appearance of which the company naturally takes more pride.

It is during this engine-cleaning period that the foundation of the future driver's career is laid. To be smart, civil, and obliging, and to have his engine reasonably clean, are the very best of recommendations.

So as to be in readiness for the time when he is called upon as a spare fireman, the cleaner should be taught to note how the fireman makes up his fire, and be trained to make himself thoroughly acquainted with the different classes of oil-cans, tools, fire-irons, etc., and to give a helping hand to either driver or fireman if required, paying particular attention at the same time to the screwing up or packing of glands.

Among other things, the cleaner should watch the washer-out, the taking out of the plugs, how the rods are used for removing the dirt, replacing the plugs, filling up the boiler, cleaning or burning out the blast-pipe, and sweeping the tubes, etc.

The tubes may be swept with a tube brush, by a jet or jets of steam discharged through a portable pipe of convenient size for handling and known as the steam lance, or by the Willcox-Ramoneur hot-air impelled apparatus. With this appliance the steam used is superheated by passing it through a restricted nozzle, and mixing the steam with many times its volume of hot air; the mixture is then projected with a rotary rifling motion at a high velocity into the smoke tubes. The scouring action thus obtained accelerates the removal of soot or ashes, and the apparatus is manipulated easily by one man across the smoke-box, with the fires damped down in engines without superheaters. When the latter are fitted, as nowadays is usually the case, many of the tube ends in the smokebox may be inaccessible from the front, in which case special means are provided whereby the apparatus may be operated through the tubes from the firebox end of the boiler. This process is carried out in the running shed, and the apparatus is something apart from the devices used for cleaning the interior surfaces of the boiler tubes while the locomotive is in motion. The latter, usually called "soot blowers," are described and illustrated in Chapter 3, pp. 44-49.

When filling the boiler it will be seen that the regulator is left open as an outlet for the air which is displaced by the water in the boiler. It will also be noticed that the water does not show more than 2 in. in the glass when cold. After the fire is lit, however, the water will be seen to have expanded considerably.

The usual method of washing out locomotive boilers with cold water takes a considerable time, as the engine has to stand for a long period to cool down. To meet the demands of traffic it is often impossible to allow locomotives to stand long enough, and therefore cold water is admitted to the boilers to cool them down, thus damaging the plates, stays, tubes, etc., through the sudden reduction of the temperature, which, as is well known, is exceedingly detrimental to the life of these parts.

Then, again, the raising of steam from cold water takes some hours, so that the customary method of washing out takes altogether about fifteen hours on the average, entailing the locomotive being out of use for this period.

It is a well-known fact that the more frequently locomotives are washed out the better are the steaming results obtained, and with this end in view a hot-water boiler washing-out system has been designed, whereby the engines, on being brought into the engine shed, are blown down, washed out with hot water, and filled up, also with hot water. The temperature of the water is preferably about 180° for washing out, and about 210° for filling up.

Fig. 2 is a diagram showing a double-tank plant as installed in large locomotive running sheds on British and other railways. It is manufactured by the Economical Boiler Washing Co. Ltd., of London. The system is divided into three parts, viz., blowing down, washing out, and refilling, and the order and method of operation is as follows:—

For blowing down, the locomotive is run into the engine shed, the fire drawn, and the blow-off cock connected by metallic hose to the drop pipe 1, which forms part of the main blow-down line 2 of the system. The steam and water from the boiler pass along the main blow-down line 2 into a separator A, where they strike a baffle plate 3, and are broken up into a spray or film. Hot water is filtered and passes into the wash-out tank D. The steam separated from the water passes along pipe 4 to heater B,

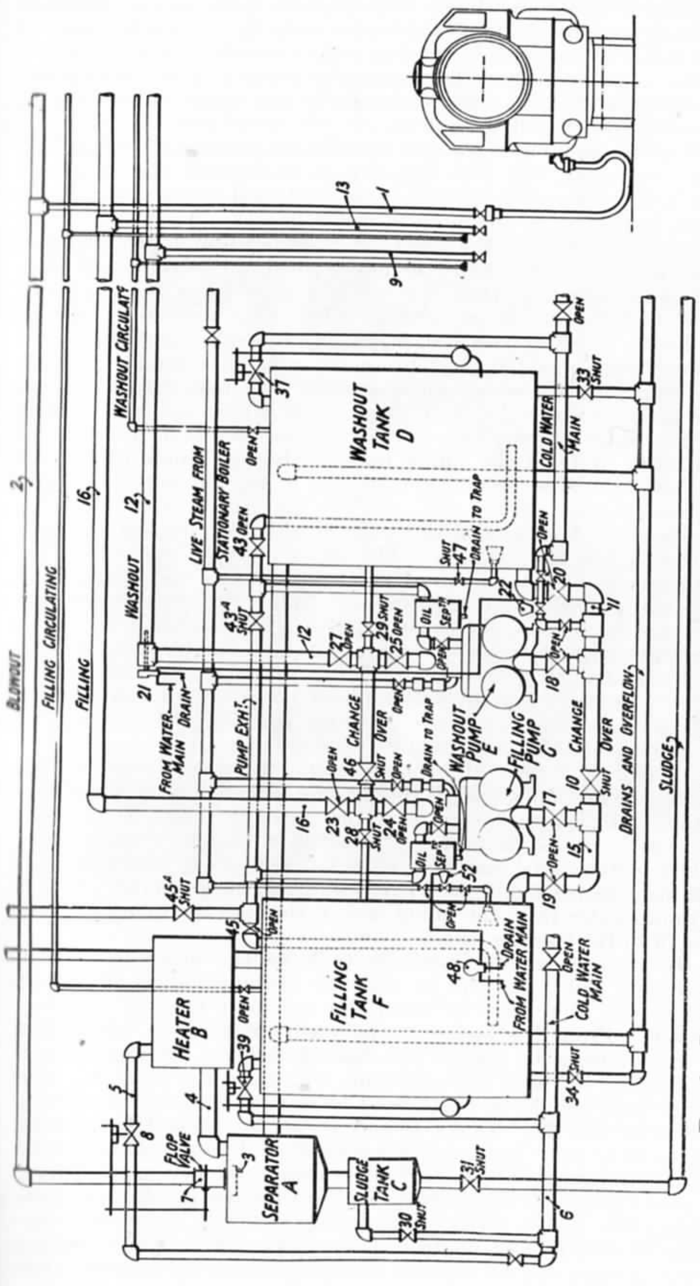


FIG. 2.—DIAGRAM OF ECONOMICAL HOT-WATER BOILER WASHING-OUT PLANT, DOUBLE-TANK SYSTEM.

wherein it heats by direct contact cold fresh water admitted through the pipe 5 from cold water main 6. This admission of cold water to heater B is automatically controlled by flop valve 7 in the main blow-down line operating valve 8 in the cold-water supply pipe 5. The water heated by the steam in the heater B passes into the filling tank F.

The washing-out system will next be described. When the boiler is empty, the blow-off cock is closed and the plugs are removed. Armoured rubber hose is connected to the drop pipe 9, which forms part of the main wash-out line 12. Water is pumped by the pump E from the wash-out tank D through pipes 11 and 12 to the shed. The boiler is now washed out in the usual way, and it is necessary that the rodding should not be neglected when washing out is proceeding. The next process is that of refilling. To effect this it is necessary to replace the plugs and connect the blow-off cock by means of the metallic hose to the drop pipe 13, which forms part of the main filling line 16. The boiler is now filled with clean water which has been heated by the steam blown out of the locomotive, and pumped by the pump G from the filling tank F through pipes 15 and 16 to the shed. The fire is now started in the firebox and steam generated.

The filter A is fitted with a cage filled with broken coke which acts as a filtering medium. This filter must be opened up for examination at intervals and the coke cleaned and renewed as required according to conditions. When it is necessary to overhaul the pumps, valves 20 and 27 or 19 and 23 must be closed to avoid waste of water. If only one pump is under examination, it is essential that the valve on the pump exhaust should be closed. In the event of either pump being out of use through any cause, arrangements are provided whereby the sequence of operations can be maintained. These are as follows :—

In case of failure of wash-out pump E, close valves 18, 19, 23, and 25 and open valves 10 and 46. This will allow the filling pump G to pump water from the wash-out tank D through the wash-out delivery 12 to the shed as usual. Similarly for failure of the filling pump G, close the valves 17, 20, 24, and 27 and open valves 3 and 46. This will allow the wash-out pump E to pump water from the filling tank F through the filling delivery line 16 to the shed as usual.

To transfer water from one tank to the other in case of emergency only, this can be done by opening valves 46 and 28 and closing the valve 27 from the wash-out tank D to filling tank F. From the latter to the wash-out tank D, the valves 46 and 29 must be opened and No. 23 closed. A sludge tank C is provided to catch the sediment, etc., from the filter A. This sludge tank should be flushed out at least once a day by opening valves 30 and 31. Tanks D and F can be drained by opening valves 33 or 34. The balance valves 37 and 39 are connected by lever and rod to outside ball floats connected by flexible tubing to tanks D and F respectively and are for the purpose of maintaining the water levels. The pump exhaust is directed into tanks D and F, and controlled by valves 43 and 45. All the pump exhaust can be directed into either tank by closing valves 45 or 43 and opening the valve 43A. A vent to the atmosphere for this pump exhaust is provided and controlled by the valve 45A. Provision is made for heating the water in tanks D and F by means of live steam through valves 47 and 52.

Thermostats are provided to maintain the temperature of the wash-out and filling waters, that for the wash-out water is placed in the wash-out delivery at 21, controlling diaphragm valve 22, which admits cold water to the wash-out suction for cooling purposes. The thermostat for the filling water is placed

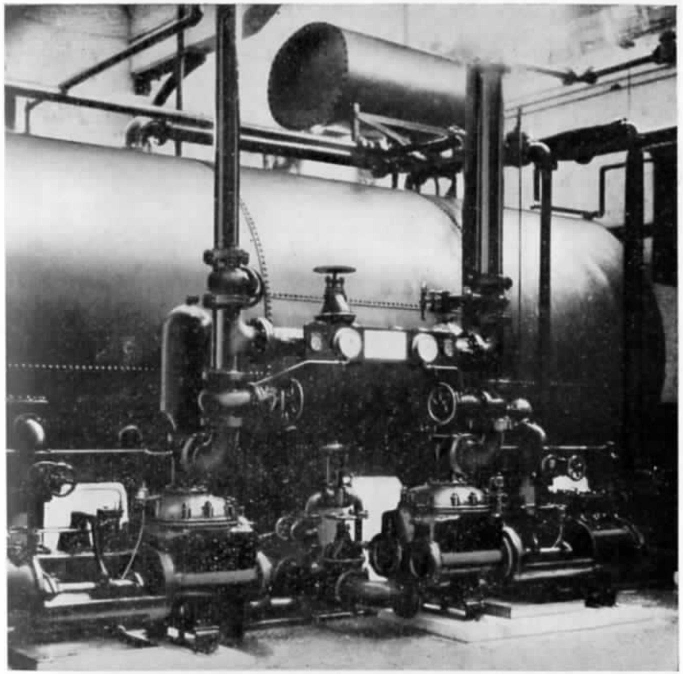


Fig. 3.—Example of Economical Single-Tank Hot-Water Boiler Washing-Out Plant.

on the filling tank 48 and controls diaphragm 52 admitting or cutting off live steam. An oil separator is fitted to the pump exhaust on each pump and these are drained at intervals through a trap. Each valve on the diagram drawing Fig. 2 is marked in its normal position " open " or " shut," and care must be taken to see that all valves are returned to normal positions after such alterations have been made.

Similar plants known as single-tank installations are supplied for smaller running sheds. Fig. 3 illustrates one of these.

By the use of this system, it has been proved that on an average twelve hours per engine is saved in washing-out time. Fig. 4 shows the system in use.

In addition to the above plant designed and used for washing out locomotive boilers, apparatus has been introduced for washing locomotives, somewhat on the lines of the "hosing-down" principle applied to road motorcars, although only to a limited extent in engine sheds.

A plant of this kind was installed at the Kings Cross locomotive

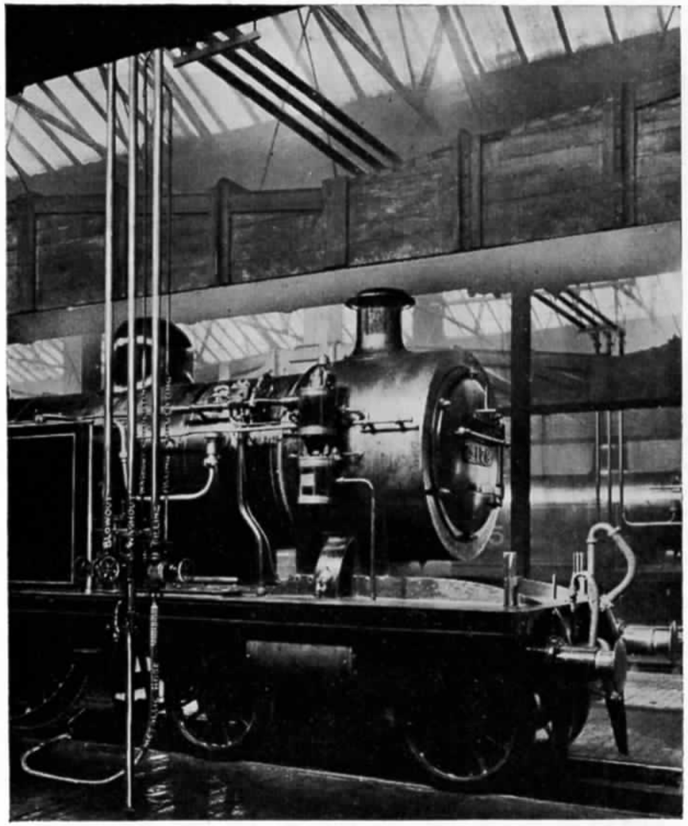


Fig. 4.—Washing Out a Locomotive Boiler by the Economical Hot-Water System.

depot, L.N.E.R. (Fig. 5). It deals with the wheels, motion, and all parts below the footplate of tank engines. The time allowance is approximately three hours for one man to clean one engine, which represents a saving of about half the time previously taken. The water supply is obtained from the main, passing into a large storage tank, where it is heated by a steam coil from an adjacent stationary boiler to a temperature of approximately 120° F. All delivery pipes throughout the shed are lagged, and every endeavour is made to maintain

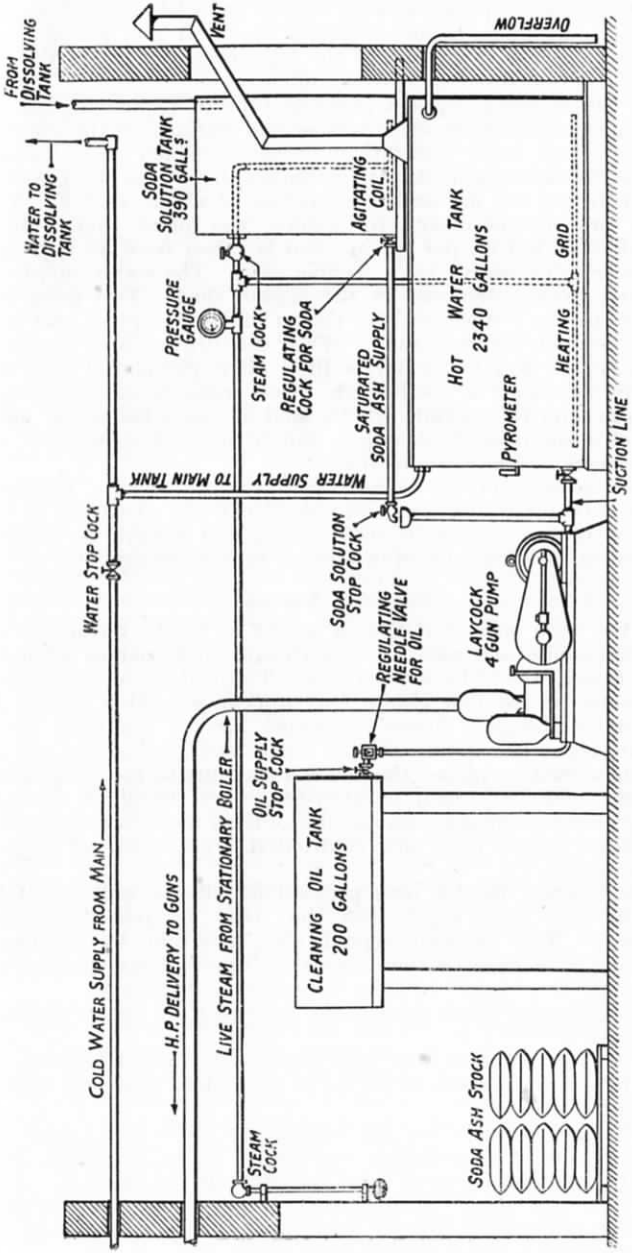


Fig 5.—Diagram of Locomotive Spray Cleaning Plant at Kings Cross Running Shed, L.N.E.R.

the temperature of the water as near 120° F. as possible. The operators are provided with leather gauntlets and protective clothing. In this system chemicals are used and mixed with hot water at the pump where the high pressure of 375 lb. per sq. in. is obtained on the delivery side.

At the Hornsey depot a portable type of apparatus, known as a high-pressure locomotive washer and working on the injector principle, has been brought into use in which the cleaning medium consists of a mixture of steam and hot water at a pressure of 400 lb. per sq. in., and temperature of about 195° F. The steam pressure necessary to operate the plant under these conditions is 100 lb. per sq. in., and is taken from an adjacent engine or other source by a flexible pipe. The water supply is obtained from a hydrant in the engine shed. Two guns are coupled to the "injector" by means of flexible pipes and discharge 300 gal. per hour each. When the dirt has been removed by the steam and hot water, a little oil is introduced into the mixture to impart a good finish. One engine cleaner operates each gun, and the motion, wheels, and all parts below the footplate of a suburban tank engine can be cleaned thoroughly by two cleaners in just over one hour.

The cleaner, in the course of his work, has a splendid opportunity for inspection, and should call the attention of his foreman to any defect in the motion, and always be on the look-out for missing nuts, split pins, or broken springs, etc.

Fitters' Labourers

It has been suggested that it would be to the advantage of both companies and men if every cleaner could act as labourer to the fitters, if only for a short time. To the departmental heads this course at the first glance may appear somewhat costly, as it involves changing fitters' labourers just at the time when they are becoming useful. On the other hand, against the cost of learning should be placed the benefits accruing to the companies, through these very men in after-life, when firing or driving, having greater confidence on account of their more comprehensive knowledge, when they are confronted with cases of engine failure, etc.

The cleaner, for his own protection, will do well to study carefully any shed regulations that may be posted by the company. The foreman should also ascertain by judicious questions from time to time that the cleaners have understood thoroughly the purport of these important instructions.

The following shed regulations are used by many railway companies :—

1. No one but a driver, shed engineman, passed fireman, or other person authorised to do so, is allowed to move an engine in steam.

2. Engine cleaners are not allowed to move any engine in steam in any circumstances whatever. When necessary, the properly authorised person must be requested to move it. Any cleaner or any other unauthorised person found disregarding this order will render himself liable to instant dismissal, and to have proceedings taken against him.

3. No engine in steam must be moved without the whistle first being sounded by the man in charge.

4. No driver, shed engineman, passed fireman, or other authorised person must move an engine, WHETHER IN STEAM OR NOT, without first satisfying himself that no cleaners or others are engaged in any work about the engine, or upon any engine or engines which may be closely approached or moved by it. Any men so engaged must individually be told clearly that the engine is about to be moved (*it is not sufficient merely to sound the whistle*), and the person giving the warning must obtain from each man an acknowledgment that he has heard and understood the warning, and such person must intimate to all concerned when the movement of the engine is completed. *This instruction applies when approaching any engine on which men are working, whether the intention is to stop short of it or not.*

5. The regulations laid down in Clause 4 must also be followed in the case of a dead engine being moved with a pinch bar. The person responsible for moving the engine must himself warn all concerned that the engine is about to be removed.

6. Targets, warning boards, or flags are provided, and any fitter, cleaner, or other person, before beginning to work at an engine, must see that either targets, warning boards, or flags are exhibited in a conspicuous place on the engine. When two or more persons are working at an engine the person in charge of the work is responsible for exhibiting and removing the targets, warning boards, or flags, as the case may be. When the person in charge has satisfied himself that all the work is completed, and the other persons, if any, who have been at work have left the engine, the targets, warning boards, or flags, as the case may be, must be removed and deposited in the place appointed for the purpose. In no circumstances whatever may an engine be moved until the targets, warning boards, or flags, as the case may be, have been removed by the person responsible for performing such duty.

7. A driver or other authorised person, taking an engine to shed, or disposing of an engine on any siding, must, before leaving it, closely shut the regulator and see that the hand brake is screwed hard on, open the cylinder cocks, and put the reversing lever or screw into mid-gear. The same precaution must be taken *when any dead engine is placed in any shed, or on any siding.*

8. Fitters, shedmen, cleaners, and others must not begin work on an engine without first seeing that the reversing lever or screw, regulator, cylinder cocks, and brake have been left as described in the preceding clause. If they find any of them not so left, they must at once report the case to the foreman on duty.

9. Before attempting to enter the motion of an engine in steam, enginemen and other authorised persons must see that all the precautions prescribed in Clause 7 have been taken, and, in the case of a tender engine, that the brake on the engine is, when practicable, also applied. Further, this regulation also applies to engines anywhere on the railway, so that in all instances before enginemen or other authorised persons leave the footplate of an engine to enter the motion of an engine or to do anything to any part of an engine or tender, they must take every

precaution to avoid any risk of the engine moving in the slightest degree while the necessary duties are being carried out.

Drivers or other authorised persons must not interfere with a reversing lever or screw wherever the engine is standing, until they are satisfied no one is attending to any part of the engine.

10. Cleaners and all other persons must cease working on an engine before it is moved.

11. Chargemen cleaners are reminded that it is their duty to be with their men as much as possible, and to see that they are instructed in the rules for safe working for their protection while at work. When cleaning the wheels, gear, etc., if any crack or flaw is seen by the cleaner, he should at once point it out to his foreman.

12. In no circumstances, excepting in the performance of absolutely necessary duty, must anyone be allowed to ride on the footsteps or side footplating of an engine which is being taken into or out of the shed or shops, or when moving in any locomotive yard, whether in steam or not.

13. All persons are specially warned that in no circumstances must they pass between the buffers of engines or other vehicles which are about to be brought together or are standing in close proximity, nor should anyone stand in front of a buffer when at work, and everyone concerned is hereby reminded of the necessity for the exercise of the greatest care in the performance of their duties to avoid injury to themselves or others. Any person exposing himself unnecessarily to danger will be liable to immediate dismissal from the company's service.

14. Engines must not be worked in a shed or shed yard without two men being in attendance, and when necessary the fireman or other appointed person must walk ahead of the engine to ascertain that everything is clear and to give warning.

15. Before any fire is put into a firebox, the gauge cocks must be tested to ascertain that there is water in the boiler, and any person having occasion to empty a boiler will be held responsible for placing a board on the front of the firebox indicating that the boiler is empty.

16. In cases where engines are left in the shed, with the tanks or tenders empty, a board must be placed indicating that this is the case, or the words "Tank Empty" written plainly in a conspicuous place on the tender, viz., on the black paint near the brake handle.

17. Workmen are forbidden to cross the lines, either running roads or sidings, more than is absolutely necessary, and when going to and from work they are to avoid sidings and running lines, and are instructed to use footbridges and subways where such are provided. Where routes are specially defined, only such authorised routes must be used.

18. Fouling points around engine turntables inside sheds have been marked on each stall road by means of white glazed brick, beyond which the buffers of engines or vehicles standing in the stalls must not project unless the turntable is first set for the stall in which the engine or vehicle is standing. In addition to this, the fireman or other responsible person must stand in such a position that he can take the necessary measures

to prevent the turntable being moved or an engine coming on to the turntable from the opposite stall so long as the white glazed bricks are fouled.

19. When coaling engines, care must be taken to trim the coal so as to prevent any falling to the ground.

20. All accidents causing personal injury to any person in the employment of the company must be reported immediately to the foreman on duty.

21. Disregard of any of these rules should be reported at once to the foreman on duty by the man in charge of the engine, or by any other servant of the company who may notice the irregularity.

By the time that the cleaner has thoroughly mastered the various details of his duties, he will have begun to learn the distinctive features of various types of engine, such as inside and outside cylinder engines, for instance.

Inside cylinder engines have the cylinders fixed inside the framing, immediately underneath the smokebox. Outside cylinder engines, as the name denotes, have the cylinders fixed outside the frame plates, and are coupled with rods direct to the driving wheels. In locomotives of the three and four cylinder types both positions are used, the inside and outside cylinders in most cases driving separate pairs of wheels, although in numerous designs they all drive the leading coupled wheels. Saddle-tank engines are used mostly for pilot work, and have the tank containing the feed water fixed saddlewise on the top of the boiler. Tender engines are those with tenders attached, and are used mostly for passenger and freight traffic on long journeys. Tank engines carry their water in tanks on each side of the boiler and the coal in bunkers on their own framing; they are used mostly for ordinary stopping trains or short journeys. The coal bunker behind the cab incorporates a supplementary tank for water.

LOCOMOTIVE CLASSIFICATION

A locomotive is classified, in the United Kingdom and America, according to the arrangement of its wheels, but on the Continent the axles are used. A simple system of numerals has taken the place of the unwieldly terms used previously. Thus, the former four-wheel coupled bogie engine is now a 4-4-0, or on the French system a 2-2-0, and on the German system a 2B (adopting the relative letter for coupled axles and omitting cyphers); and a six-wheel coupled bogie locomotive with trailing axle becomes a 4-6-2, or on the French system a 2-3-1, and the German a 2C. The centre numeral always refers to the number of driving (coupled) wheels and the first and last to the leading and trailing (uncoupled) wheels. Names are also used widely in the U.S.A., such as *Atlantic* (4-4-2), *Pacific* (4-6-2), *Mountain* (4-8-2), and *Mikado* (2-8-2). On the outbreak of war between the United States and Japan the name *Mikado* fell into some disfavour in the U.S.A. and the new name *MacArthur* was adopted for a time, but did not find general acceptance. The letter T is used after the classification when the engine is of the tank variety.

The system of classification by wheel arrangement was evolved by F. M. Whyte, an American engineer, at the beginning of this century; hence, it is now known in all English-speaking countries as Whyte's Notation. Railway officials in the U.S.A. had previously used names, all of which were quoted by an American author in *The Engineer* of August 27, 1897; curiously enough, that same issue described the 4-8-0 type as the *Mastodon* but subsequently the name has been applied generally to the 4-10-0.

The diagrams of wheel arrangements (Figs. 6 to 10) are intended to be of assistance as indicating the distinguishing features appertaining to the different types of coupled and non-coupled engines. The British, French, and German notations are given, together with the names usually applied to certain types.

These may be summarised as follow:—

(1) 2-2-0 type (now obsolete): Used on several early railways for hauling light loads.

(2) 2-2-2 type (now obsolete): In past years employed for high speeds with moderate train loads and used in the main for fast passenger work.

(3) 4-2-2 type (also obsolete): A development of the previous type with a leading bogie in place of the single leading axle; formerly used for express passenger service with moderate train loads. This type reached its highest development towards the end of the nineteenth century under Patrick Stirling, on the Great Northern Railway, with his famous "Eight-Foot-Single" express passenger engines.

(4) 0-4-0 type: Restricted to a few light tank engines working on dock railways and sidings.

(5) 0-4-2 type: For light branch trains, mainly "auto" or "rail motor" trains.

(6) 4-4-0 type: Used extensively for express and other passenger trains working on British and other railways; now superseded to a large extent by six-coupled designs for working the heaviest trains. Two locomotives of this wheel arrangement, built for the North Eastern Railway in 1896, had driving wheels 7 ft. 7¼ in. in diameter, believed to be the largest ever employed for a coupled engine in regular service.

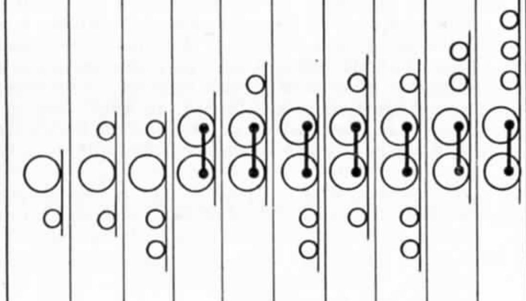
(7) 2-4-2 type: Used for tank engines working passenger trains in local and shorter-distance main-line traffic. Obsolete in modern practice. Originated in New Zealand in 1877; introduced to Great Britain in the 1890s.

(8) 4-4-2 type (*Atlantic*): A development of the 4-4-0 type, making possible a larger boiler and more extended weight distribution, but still having restricted adhesive qualities. Originated in America; first used in Great Britain, on the Great Northern Railway, in 1898.

(9) 0-4-4 type: Also a tank engine wheel arrangement for suburban trains of moderate loading. This wheel arrangement appears to have originated with the small, specially-designed locomotives of Matthias Nace Forney in the late 1870s for use on the elevated railways of New York, with their sharp curvature.

(10) 0-4-6 type (now obsolete): An American variation of the 0-4-4 type.

(11) 4-4-4 type (*Reading* or *Jubilee*): Identified solely with tank engine practice on British railways, and only in a moderate



NO.	WHEEL ARRANGEMENT	WHYTE'S NOTATION	FRENCH	GERMAN	NAME
1		2-2-0	1-1-0	1 A	Planet
2		2-2-2	1-1-1	1 A 1	Jenny Lind
3		4-2-2	2-1-1	2 A 1	Bicycle
4		0-4-0	0-2-0	B	Four-wheel switch
5		0-4-2	0-2-1	B 1	
6		4-4-0	2-2-0	2 B	American
7		2-4-2	1-2-1	1 B 1	Columbia
8		4-4-2	2-2-1	2 B 1	ATLANTIC
9		0-4-4	0-2-2	B 2	Forney four-coupled
10		0-4-6	0-2-3	B 3	Forney four-coupled

Fig. 6.—Wheel Arrangements of Engines (1 to 10).

degree. It is a somewhat more flexible wheel arrangement than the 4-4-2 type, but is fast becoming obsolete.

(12) 0-6-0 type (*Six-wheel Switch* or *Bourbonnais*): Employed widely for freight engines with tenders, and also in tank engine practice, usually in conjunction with inside cylinders. Used extensively for shunting (switching) duties in America; hence the name "Six-wheel Switch."

(13) 0-6-2 type: This wheel arrangement is used almost solely in tank engine practice, and for both passenger and freight service. The trailing wheels permit of a fairly large coal bunker, and give added support at the rear end.

(14) 2-6-0 type (*Mogul*): A natural development of the 0-6-0. It facilitates the use of a larger boiler, and, if required, larger cylinders. Is a useful type for mixed-traffic working. This type appears to have originated in America with a locomotive built by the Rogers Locomotive Works for the New Jersey Railroad, in 1863. It was introduced into Great Britain fifteen years later, when Neilson & Company built fifteen locomotives with this wheel arrangement for the Great Eastern Railway to the designs of William Adams, with modifications by his successor, Massey Bromley. Neither these engines, nor a large number of American-built 2-6-0s, imported by the Midland, Great Northern, and Great Central railways at the end of the nineteenth century, were successful, and several years elapsed before the popularity of this wheel arrangement was established.

(15) 4-6-0 type (*Ten-wheel*): One of the most useful and popular types on British and other railways for working heavy fast passenger trains, and to some degree also other classes of traffic. It was introduced into Great Britain by David Jones, who adapted the design for fifteen goods engines on the Highland Railway in 1893, but it did not become common on other railways until the early years of the present century.

(16) 2-6-2 type (*Prairie*): In British practice, this wheel arrangement has been adopted mainly for tank engines, but some tender engines of this type have been constructed for the L.N.E.R. in recent years. The wheel arrangement originated in America in 1878, and was introduced into Great Britain in the 1890s.

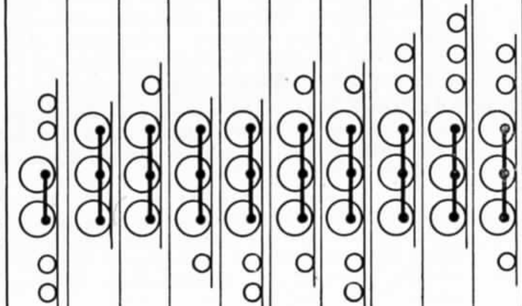
(17) 4-6-2 type (*Pacific*): A development of the 4-6-0 type, giving added support at the rear end and enabling a much larger boiler and firebox to be used. Engines of this class are working some of the fastest and heaviest trains, including those in the ultra-fast services of British railways. The type appears to have originated in the U.S.A. in 1886, and to have been adopted in New Zealand in 1901, but the locomotives designed by Baldwin's for the Missouri Pacific Railroad in 1903 fastened the now familiar name *Pacific* on to the design. The type owes its popularity in Great Britain to the designs of the late Sir Nigel Gresley for the L.N.E.R., although an experimental engine, *The Great Bear*, had been built for the G.W.R. in 1908.

(18) 0-6-4 type: This wheel arrangement is used almost solely for tank engines. The trailing bogie permits of a larger bunker than is possible with the 0-6-0 type.

(19) 0-6-6 type (now obsolete): An American variation of the 0-6-4.

(20) 2-6-4 type: This, so far, has been restricted to tank engine practice, and is a very popular wheel arrangement for engines of that kind, varying in size and power.

(21) 4-6-4 type (*Baltic* or *Hudson*): In Great Britain used for high-speed passenger tank engines. It is claimed to be a symmetrical



NO.	WHEEL ARRANGEMENT	WHYTE'S NOTATION	FRENCH	GERMAN	NAME
11		4 - 4 - 4	2 - 2 - 2	2 B 2	Reading or Jubilee
12		0 - 6 - 0	0 - 3 - 0	C	Six-wheel switch or Bourbonnais
13		0 - 6 - 2	0 - 3 - 1	C 1	
14		2 - 6 - 0	1 - 3 - 0	1 C	MOGUL
15		4 - 6 - 0	2 - 3 - 0	2 C	Ten-wheel
16		2 - 6 - 2	1 - 3 - 1	1 C 1	PRAIRIE
17		4 - 6 - 2	2 - 3 - 1	2 C 1	PACIFIC
18		0 - 6 - 4	0 - 3 - 2	C 2	Forney six-coupled
19		0 - 6 - 6	0 - 3 - 3	C 3	Forney six-coupled
20		2 - 6 - 4	1 - 3 - 2	1 C 2	Adriatic

Fig. 7.—Wheel Arrangements of Engines (11 to 20).

wheel arrangement providing for an amplitude of adhesion weight, and, at the same time, complete flexibility of the wheelbase. Relatively it has been used only to a moderate extent on British railways. The name *Hudson* originated in America, on the New York Central system, whose main line—the "Water Level Route"—skirts the Hudson River from New York to Albany, but the alternative name, *Baltic*, was adopted in Great Britain, and appears to be the only name of European origin.

(22) 0-8-0 type: Suitable for larger freight engines, and sharing with the 0-6-0 type the advantage of enabling the whole of the weight of the engine to be used for adhesion. Used mainly for engines with tenders, but also incorporated in tank engine design on various railways.

(23) 2-8-0 type (*Consolidation*): A development of the 0-8-0, the presence of the leading wheels improving the behaviour of the locomotive on curves and also providing independent support for the weight at the front end. This wheel arrangement originated in America, in 1866, with a locomotive built by Baldwin's for the Lehigh Valley Railroad.

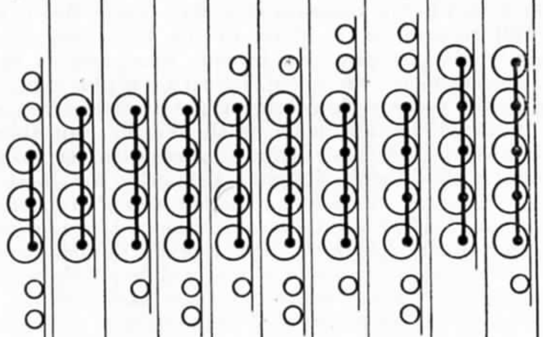
(24) 4-8-0 type: An enlargement of the 4-6-2 type, used on many overseas railways, but not widely favoured in Great Britain. The former American name, *Mastodon*, is now used to denote the 4-10-0 wheel arrangement.

(25) 2-8-2 type (*Mikado*): This is used on only one of the British railways, namely, the L.N.E.R., for heavy freight engines with tenders; it is incorporated in certain tank engine designs of powerful proportions. The prototype of this wheel arrangement was built by Baldwin's, in 1897, for service in Japan, which accounts for the name *Mikado*. The alternative name, *MacArthur*, originated during the 1939-1945 War, but did not come into common use.

(26 to 28) 4-8-2 (*Mountain* or *Mohawk*), 2-8-4 (*Berkshire*), and 4-8-4 (*Confederation*, *Northern*, or *Pocono*) types: Used on American and other overseas railways for hauling heavy loads on steeply-graded lines, but not used in Great Britain The names are of American origin. The first *Berkshire* was built for the Boston & Albany Railroad, which passes through the Berkshire Mountains of New England. Occasionally the 4-8-4 type is described in America as *Northern*, *Dixie*, or *Pocono*, instead of the more usual *Confederation*.

(29) 0-10-0: There is only one example of an engine having this wheel arrangement in Great Britain, namely, the four-cylinder engine with tender specially designed for banking service on the Lickey Incline, L.M.S.R. The name *Decapod*, used in America to denote the 2-10-0 wheel arrangement, has been applied in Great Britain to this banking engine on the Lickey Incline, and to the experimental tank engine designed for the Great Eastern Railway by James Holden, to apply steam traction (instead of electrification) to heavy suburban traffic.

(30) 2-10-0 type (*Decapod*): A development of the 0-10-0 type. The leading wheels assist the engine in negotiating curves, and provide additional support at the leading end. Locomotives of this type are used in several parts of the world for exceptionally heavy traffic, but the wheel arrangement was unknown in Great Britain until the "austerity" types were introduced during the 1939-1945 War.



NO.	WHEEL ARRANGEMENT	WHYTE'S NOTATION	FRENCH	GERMAN	NAME
21		4 - 6 - 4	2 - 3 - 2	2C2	BALTIC or HUDSON
22		0 - 8 - 0	0 - 4 - 0	D	Eight-wheel
23		2 - 8 - 0	1 - 4 - 0	1D	CONSOLIDATION
24		4 - 8 - 0	2 - 4 - 0	2D	Twelve-wheel (formerly called Mastodon)
25		2 - 8 - 2	1 - 4 - 1	1D1	MIKADO or MacArthur
26		4 - 8 - 2	2 - 4 - 1	2D1	MOUNTAIN or Mohawk
27		2 - 8 - 4	1 - 4 - 2	1D2	Berkshire
28		4 - 8 - 4	2 - 4 - 2	2D2	Confederation: Northern: Pocono
29		0 - 10 - 0	0 - 5 - 0	E	Ten-wheel switch
30		2 - 10 - 0	1 - 5 - 0	1E	DECAPOD

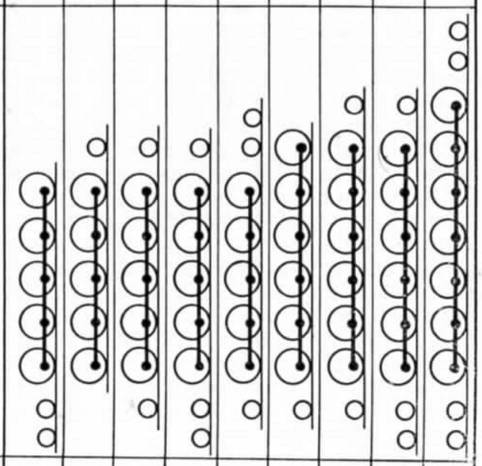
Fig. 8.—Wheel Arrangements of Engines (21 to 30).

(31 to 39) Locomotives with 10, 12, and 14 coupled wheels: Used in several parts of the world for exceptionally heavy traffic, but not introduced into Great Britain. In the main, the names used to denote these multi-wheel arrangements are confined to the U.S.A. Thus, *Santa Fe* for the 2-10-2, *Texas* for the 2-10-4, *Southern Pacific* for the 4-10-2, and *Union Pacific* for the 4-12-2 are all explained by the fact that the prototypes were built for the railways concerned (*Texas* is the Texas & Pacific). The names *Javanic* and *Soviet* are used to denote exceptionally powerful locomotives built for the railways of Java and the U.S.S.R. respectively.

Numerous other wheel arrangements are in use on railways in various parts of the world, incorporating the multiple wheel groupings forming part of articulated locomotive design. There are two examples of this practice in this country, namely, the 2-6-0+0-6-2 Beyer-Garratt locomotives of the L.M.S.R., and the single example on the L.N.E.R. of a similar engine but with the 2-8-0+0-8-2 wheel arrangement and six single-expansion cylinders (see pp. 224 and 447).

An articulated locomotive is one in which separate groups of wheels driven by independent cylinders are used. Each group of wheels, with its cylinders, forms a complete power unit by itself in the sense that it is not rigidly connected with the other group; it is virtually two engines in one. The steam pipes have spherical joints, and everything is arranged to allow of the locomotive accommodating itself readily to track variations and curvature. The weight of the locomotive is thus distributed over a large number of wheels, and, although the locomotive as a whole may be heavier, the strain on the track is reduced owing to the lower individual axle loadings. The Beyer-Garratt locomotive, built on this principle, has found wide application abroad for both passenger and freight service, and is also used for goods traffic on the L.N.E.R. and L.M.S.R. in this country, as mentioned above. Typical Beyer-Garratt locomotives, and their wheel notations, will be found in the diagram at p. 21. From this it will be seen that full recognition is given to the fact that an articulated locomotive is virtually two in one, inasmuch as two separate wheel arrangements are given, joined by a plus sign.

In earlier years various other types of articulated engine were used in Great Britain, such as the Fairlie, but these are now only of historical interest, and are not regarded as needing detailed description in a book designed primarily for those concerned with the cleaning, driving, and maintenance of existing engines. Because articulated locomotives of various types are used abroad (including many parts of the British Commonwealth) to a considerable extent, however, it is as well to outline a few principal characteristics. From what has been said already, it will be appreciated that an articulated locomotive is one in which some of the driving axles are able to take up positions where they do not remain parallel to the others, but may assume an angular relationship on curves. This provides greater flexibility, and mitigates the difficulties on curves of small radius resulting from large numbers of rigidly coupled axles. The origin of the principle of locomotive articulation is to be found in the Semmering locomotive trials of 1851, which were conducted by the Austrian



NO.	WHEEL ARRANGEMENT	WHYTE'S NOTATION	FRENCH	GERMAN	NAME
31		4 - 10 - 0	2 - 5 - 0	2 E	MASTODON
32		0 - 10 - 2	0 - 5 - 1	E 1	Union switch
33		2 - 10 - 2	1 - 5 - 1	1 E 1	SANTA FE
34		4 - 10 - 2	2 - 5 - 1	2 E 1	Southern Pacific: Super Mountain: Overland
35		2 - 10 - 4	1 - 5 - 2	1 E 2	Texas
36		2 - 12 - 0	1 - 6 - 0	1 F	Centipede
37		2 - 12 - 2	1 - 6 - 1	1 F 1	Javanic
38		4 - 12 - 2	2 - 6 - 1	2 F 1	Union Pacific
39		4 - 14 - 4	2 - 7 - 2	2 G 2	Soviet

Fig. 9.—Wheel Arrangements of Engines (31 to 39).

Government to secure suitable designs for the sharply curved Semmering Railway then being built, which was the first to cross the Alps, and, indeed, was the first mountain railway of any importance in Europe. Three of the competitors built locomotives of different kinds of articulation, of which two proved to be the prototypes of successful later designs. One had two groups of driving wheels and a single boiler, and was the forerunner of the Meyer locomotive (first built in 1868); the other had also two groups of driving wheels but also had two boilers, and was thus the prototype of the Fairlie design (first built in 1865).

The most widely used type of articulated locomotive, apart from the Beyer-Garratt, is the Mallet. Anatole Mallet (pronounced Mallay) patented the first articulated compound locomotive in 1885 in France, but the type has received its greatest development in the U.S.A. This uses a single boiler, and in general external appearance the engine closely conforms to the conventional non-articulated locomotive. Under the boiler, however, there are two sets of driving wheels. The rear one is an integral part of the locomotive as in ordinary engines, and has the usual cylinders, valve, gear, and motion. The leading set of wheels constitutes a Bissel truck with its separate cylinders, gear, and motion. The first Mallet built in the U.S.A. was constructed by the American Locomotive Works in 1904 for the Baltimore & Ohio Railroad, and since then a considerable number of Mallets has been built in that country for handling long freight trains over heavily-graded lines.

HEAD-LAMP CODES

After the types of engines, the cleaner should learn the method of classifying trains by their head lamps (Fig. 11). Early in the present century a standard code of headlamps was agreed between a number of British railway companies, and came generally into use on main lines, with the lamps used to indicate the class or category of each train. Some years later, in the interests of economy, by using fewer lamps and less oil, the code was revised in such a way that not more than two lamps are required for any indication, other than that of a royal train, for which four head lamps are used, one on every lamp-iron. These lamp-irons are arranged at both ends and in the centre of the platform above the engine buffer-beam, with the fourth position in front of the chimney, or in the case of many large-boilered modern locomotive types, on the upper part of the smokebox door.

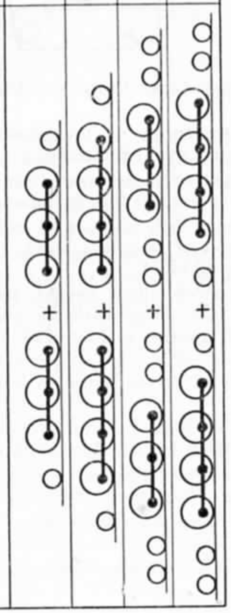
The lamps should be carried in the positions shown by day as well as by night and in most cases are white, but shunting engines in stations or sidings must carry one red head and tail light.

An engine without a train must, when on any running line, always carry a tail lamp in the rear. (Rule 122 (*a*).)

When two or more engines are coupled together without a train the last engine must have a tail lamp. (Rule 122 (*b*).)

An engine or engines drawing a train must not carry any lamp in the rear. (Rule 122 (*c*).)

An engine assisting a train in the rear must have a tail lamp attached; when more than one engine assists, the tail lamp must be carried on the last engine. (Rule 122 (*d*).)



TYPICAL BEYER—GARRATT LOCOMOTIVES	WHYTE'S NOTATION	FRENCH	GERMAN
	2-6-0+0-6-2	1-3-0+0-3-1	1C+C1
	2-8-0+0-8-2	1-4-1+1-4-1	1D+D1
	4-6-4+4-6-4	2-3-2+2-3-2	2C2+2C2
	4-8-2+2-8-4	2-4-1+1-4-1	2D1+1D2

Fig. 10.—Wheel Arrangements of Typical Beyer-Garratt Locomotives.

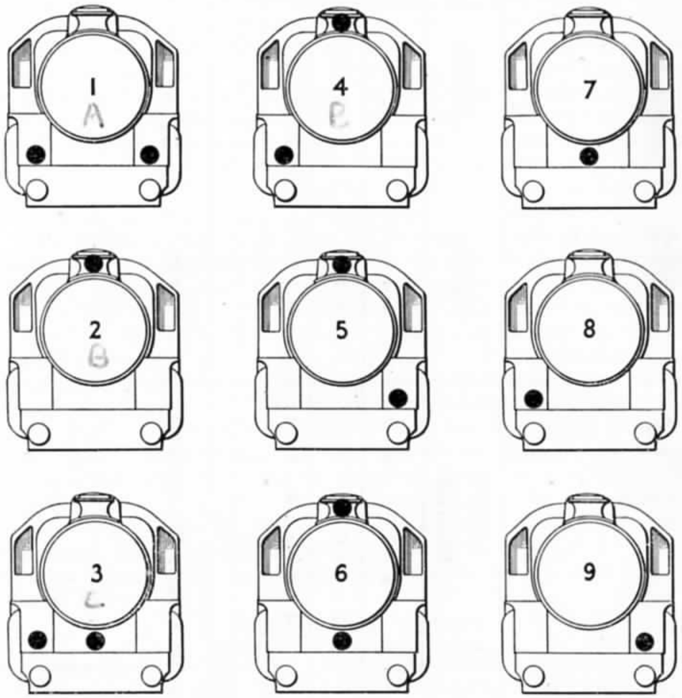


FIG. 11.—HEAD-LAMP CODE FOR CLASSIFYING TRAINS.

1. Express passenger train, or breakdown train going to clear the lines. (One lamp over each buffer.)
2. Ordinary passenger or motor train, also breakdown train returning to depot. (One lamp at foot of chimney.)
3. Parcels, newspapers, fish, print, milk, meat, horse, and "perishable" trains composed of coaching stock. (One lamp on right buffer and one in the middle.)
4. Empty coaching stock, fitted freight, fish, or cattle train, with not less than one-third fitted with the continuous brake. (One lamp on right buffer, another at foot of chimney.)
5. Express freight, or cattle train, fitted with less than one-third of the continuous brake. (One lamp on left buffer, another at foot of chimney.)
6. Through freight or ballast train. (One lamp in middle of buffer plank, and another lamp at foot of chimney.)
7. Light engine or engines coupled together, also engine with one or two brake vans. (One lamp in middle of buffer plank.)
8. Through mineral or empty wagon train. (One lamp over right-hand buffer.)
9. Freight or ballast train for short distances. (One lamp over left-hand buffer.)

When a train or portion of a train which has been left on any running line is propelled to the signal box in advance, or when the front portion of a divided train is being set back to the rear portion, a white headlight must be carried on the leading vehicle. (Rules 149 iii, 179 (*c*), 183 (*a*) i.)

When a train or portion of a train has to travel in the wrong direction to the signal box in the rear, in accordance with Rule 184, or where propelled in the wrong direction, a red headlight must be carried on the leading vehicle. (Rule 149 (iv).)

When the line is blocked and trains are worked to or from the point of obstruction, a red headlight must be carried on the leading vehicle. (Rule 149 (vi).)

When working a breakdown train in the right direction or proceeding from a signal box in advance to assist a disabled train, a white light must be carried on the leading vehicle. (Rule 149 (x).)

When working an officer's special train or when propelling the special coach in the right direction, a white headlight must be carried on the vehicle. (Rule 149 (ix).)

When a light engine is shunted into a siding for a train to pass, the driver must remove the tail light, so as not to exhibit a red light to a following train. (Rule 152 (*a*).)

When a train has been shunted from one running line to another on which trains approach from the opposite direction, the driver must exhibit a red headlight in front of the engine (or tender, if running tender first) and remove all other headlights. The red light must be exhibited until the whole of the shunted train has again been placed on its proper running line. (Rule 152 (*b*).)

When a train has been shunted on to the wrong line, and the engine has to be detached and the train left standing, the guard or shunter must place a red light on the front vehicle, and the driver must see that this is done before removing his engine from the train. (Rule 152 (*b*).)

Engines employed exclusively in shunting at station yards and sidings must, after sunset or during fog or falling snow, carry head and tail lamps both showing a red light or such other light as may be prescribed. (Rule 123.)

The national headcode is in general use on the Great Western Railway; on the London Midland & Scottish Railway except over the lines of the late Caledonian and Glasgow & South Western Railways in Scotland, and on the London & North Eastern Railway (except the London suburban lines of the late Great Eastern Railway radiating from Liverpool Street and Fenchurch Street); but it is not used at all on the Southern Railway. The meanings given above for the various combinations are supplemented by others, at the discretion of each railway, to suit circumstances from time to time, or the kind of traffic on specified sections of line, as laid down in special instructions. On the main and branch Great Eastern Section lines of the L.N.E.R. circular white discs replace the lamps in the daytime. Where the national code is not used the head signals generally indicate the route a train is to take and not its class. More than thirty different route combinations are in use on the S.R., where the lamps are also represented by day by circular white discs.

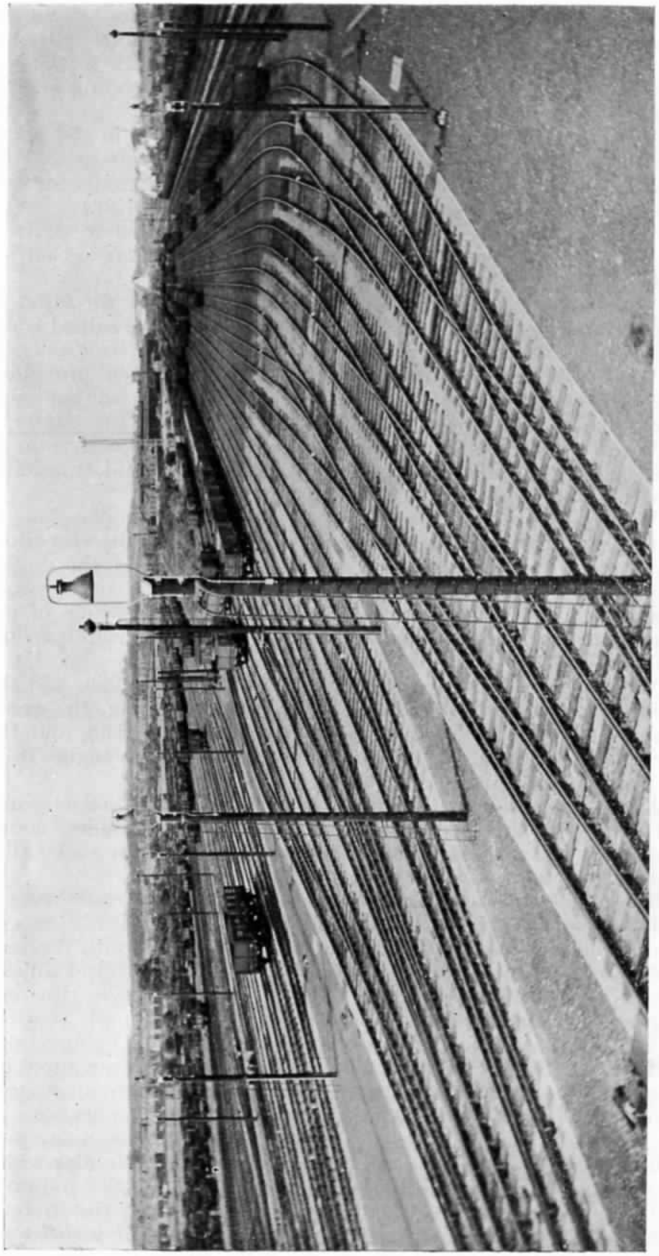


Fig. 12.—Toton Marshalling Yard, L.M.S.R., where Extensive Shunting Operations are Daily Carried Out.

Chapter 2

RULES FOR SIGNALS, SHUNTING, AND WORKING OF TRAINS

The cleaner, after having been in the shed for some time, will become somewhat familiar with the classification of the different engines and trains, and should prepare himself for the time when he will be called upon to act as a "spare fireman."

Some familiarity with the Railway Clearing House rules will therefore be essential, and the following rules relating to signals, shunting, etc., have been quoted as useful for the rising cleaner to learn. In this manner the "spare fireman" will be able to devote the whole of his attention to acquiring a knowledge of the practical part of his firing duties, and will be prepared to pass such examination as may be required by the particular railway company by whom he is employed. This examination usually includes a few questions appertaining to rules for signals and shunting; hence it may reasonably be assumed that a proper knowledge of these rules forms a very necessary part of a fireman's equipment.

RULE 34.—Fixed signals consist of distant, home, starting, advanced starting, calling-on, warning, draw-ahead, shunt-ahead, and shunting signals. In certain instances signals are repeated in rear, in which cases the additional signals are known as "repeating" signals. Automatic signals are signals controlled by the passage of trains and in addition can be controlled from a signal box or ground frame, being then called semi-automatic signals.

RULE 35.—(*a*) Except in case of automatic, or where otherwise authorised, the normal position of fixed signals is "Danger" or "Caution." Red is the signal of "Danger," yellow the signal of "Caution," and green the signal of "All Right."

(*b*) (i) Other types of signals include the three-position semaphore signals, the indications by day being arm in horizontal position with red light at night for "Danger." In the "Caution" position the arm is inclined diagonally upward with a yellow light by night, and in the "Clear" position the arm is vertically in the up-position with a green light by night.

(ii) Colour-light signals not provided with semaphore arms have the day and night indications given by means of lights only, *i.e.*, red for "Danger," yellow for "Caution," double yellow for "Attention," and green for "Clear."

(iii) Repeating signals of the banner type consisting of a black arm in a circular frame, illuminated by night.

(iv) Subsidiary signals in the form of disc signals, or of the banner type with red or yellow arm in a circular frame, or position-light signals, or semaphore signals with small arms. The normal indications are :—

By Day	*By Night*
Red disc.	Red light or white light.
Yellow disc.	Yellow light.
Red arm in horizontal position in a circular frame or on a white or black disc.	Red light, white light, or the day normal indications being illuminated.
Yellow arm in horizontal position in a circular frame or on a white disc.	Yellow light or the day normal indications being illuminated.
Position light signals with two white lights, or one red or yellow light on the left and one white light on the right, in horizontal position, or no lights.	Same as day.
Small red semaphore arm or small white semaphore arm with red stripes, in the horizontal position.	Red light, white light, or no light.
Small yellow semaphore arm in the horizontal position.	Yellow light.

The Proceed indication by day is given by the disc being turned off or the arm lowered or raised, or in the case of position light signals by two white lights at an angle of 45°, and by night by a green light or the day Proceed indication being illuminated, or in the case of position light signals by two white lights at an angle of 45°.

In some cases the signals are distinguished thus :—

Calling-on	By the letter C.
Warning	„ „ W.
Shunt-ahead	„ „ S.

In ground signals (colour-light), the normal indication is a yellow or red light and the Proceed indication a green light.

(*c*) Automatic stop signals are identified by a white plate with a horizontal black band. Semi-automatic stop signals are identified by a white plate bearing the word " Semi " above a horizontal black band.

(*d*) Back lights, where provided for fixed signals, show a white light to the signalman when the signals are at Danger, and are obscured when the signals are in the Clear position. In the case of position-light signals where back lights are provided, they are also exhibited in some cases when the signals are at Clear.

(*e*) Fixed signals, as a rule, are so placed as to indicate by their positions the lines to which they apply. Where more than one stop or subsidiary signal is fixed on the same side of a post, the top signal applies to the line on the extreme left, and the second signal to the line next in order from the left, and so on.

At some diverging points only one semaphore arm or colour-light signal is provided together with an indicator exhibiting a letter or number showing the line over which the train will run, or only one colour-light signal is provided together with a junction indicator exhibiting a line of white light or lights by day and by night, when a Proceed aspect is given for a diverging route. For

movements along the straight route, no junction indication is exhibited.

(*f*) Except in the case of automatic signals or where otherwise authorised, the normal position of fixed signals is Danger, or Caution in the case of distant signals.

(NOTE.—Additions to this rule are contained in separate publications issued by the companies concerned.)

RULE 36.—(*a*) Distant signals are placed at some distance in rear of home signals to which they apply, and where necessary below the home, starting, or advanced starting signal applicable to the same line of the signal box in rear.

(*b*) Where only one distant signal is provided for a diverging junction, such signal applies to all trains approaching it.

(*c*) The Caution position of a distant signal indicates to a driver that he must be prepared to stop at the home signal to which it applies.

RULE 80.—(*b*) Semaphore signals not in use are distinguished by two pieces of wood, nailed over each other in the form of a cross.

RULE 80.—(*c*) Disc signals not in use will not be fitted with discs or lamps.

RULE 43.—Where three-aspect signals are provided, the Caution aspect indicates to a driver that he must be prepared to stop at the next signal, and the Clear aspect indicates that he must be prepared to find the next signal showing either the Caution or Clear aspect.

Where colour-light signals having more than three aspects are provided, one yellow light indicates to a driver that he must be prepared to stop at the next signal, and two yellow lights indicate that he must be prepared to pass the next signal at restricted speed.

RULE 44.—(*a*) Calling-on signals, where provided, are placed below the signal controlling the entrance to the section ahead, and when lowered authorise the driver to proceed forward cautiously into the section ahead as far as the line is clear. The lowering of the calling-on signal does not authorise the next stop signal to be passed at Danger.

(*b*) Except where authorised, the calling-on signal must not be lowered until the train has been brought to a stand at it.

RULE 46.—Shunt-ahead signals, where provided, are placed below the signal controlling the entrance to the section ahead, and when lowered authorise the latter signal to be passed at Danger for shunting purposes only, and a train must not proceed on its journey until the signal controlling the entrance to the section has been lowered.

The following rules are specially applicable to hand signals :—

RULE 50.—(*a*) Hand signals will be made with flags by day, and with lamps by night, or in tunnels, or during fog or falling snow.

(*b*) A red hand signal indicates Danger, and, except as shown below, must be used only when it is necessary to stop a train. In the absence of a red light, any light waved violently denotes Danger.

Exceptions

*1. To indicate to driver and guard during fog or falling snow that a distant signal in which a red light is used is at Caution. (Rules 59, 91, and 194.)	Red hand signal held steadily by fog signalman.
*2. To indicate to driver that a distant signal in which a red light is used is defective and cannot be placed at Caution. (Rule 81.)	Red hand signal held steadily by hand signalman at distant signal.
3. To indicate to driver that single line working is in operation as per Rule 200.	Red hand signal held steadily by hand signalman at a distant signal in which a red light is used applicable to the line upon which single line working is in operation.

(* Applies to some lines in Ireland only.)

(*c*) A yellow hand signal indicates Caution and is used for the following purposes :—

1. To indicate to driver and guard during fog or falling snow that a distant signal in which a yellow light is used is at Caution. (Rules 59, 91, and 194.)	Yellow hand signal held steadily by fog signalman.
2. To indicate to driver that a distant signal in which a yellow light is used is defective and cannot be placed at Caution. (Rule 81.)	Yellow hand signal held steadily by a hand signalman at distant signal.
3. To indicate to driver that single line working is in operation. (Rule 200.)	Yellow hand signal held steadily by hand signalman at a distant signal in which a yellow light is used, applicable to the line upon which single line working is in operation.
4. To authorise driver to pass a multiple-aspect signal which is disconnected or out of order. (Rule 78.)	Yellow hand signal held steadily by hand signalman at the signal.
5. To indicate to driver and guard during fog or falling snow that a multiple-aspect signal is at Caution. (Rule 91.)	Yellow hand signal held steadily by fog signalman.

(*d*) The purposes for which a white hand signal is used are as follow :—

1. Move away from hand signal in shunting. (Rule 52.)	White light waved slowly up and down.
2. Move towards hand signal in shunting. (Rule 52.)	White light waved slowly from side to side across body.
3. To indicate to guard of passenger train that all is right for the train to proceed. (Rule 141.)	White light held steadily above the head by person in charge.

London Midland & Scottish Railway Company's addition :—

4. To indicate to guard whether driver of train is carrying train staff or ticket. (Regulations for working on single lines by train staff and ticket.)	White hand signal held steadily by the signalman.
5. To indicate to signalman that the points require to be turned. (Rule 69.)	White light moved quickly above the head by guard or shunter.

(*e*) The purposes for which a green hand signal is used are as follow :—

1. Move slowly away from hand signal in shunting. (Rule 52.)	Green light moved slowly up and down.
2. Move slowly towards hand signal in shunting. (Rule 52.)	Green light waved slowly from side to side across body.
3. Guard's signal to driver to start, and to indicate that guard or shunter has rejoined train. (Rules 55, 141, and 142.)	Green light held steadily above the head, or green flag (where used) waved above the head.
4. To indicate by night to fireman of goods train after starting that his train is complete. (Rule 142.)	Green light waved slowly from side to side by guard from his van.
5. To indicate to driver that train is divided. (Rule 182.)	Green hand signal waved slowly from side to side by signalman.
6. To give an All Right signal to driver where there is no starting signal. (Rules 37 and 38.)	Green hand signal held steadily by signalman.
7. To authorise driver to move after having been stopped at signal box. (Rule 54.)	Green hand signal held steadily by signalman.
8. To authorise driver to pass starting or advanced starting signal at Danger for shunting purposes. (Rule 38.)	Green hand signal held steadily by signalman.
9. To indicate to driver and guard during fog or falling snow that the signal is at Clear. (Rules 91 and 127 (xxii).)	Green hand signal held steadily by fog signalman.
10. To reduce speed for permanent way operations. (Rules 60, 127 (xxi), 217, and 218.)	Green hand signal waved slowly from side to side by hand signalman.
11. To give All Right signal to driver when fixed signal (other than a multiple aspect signal) is disconnected or out of order. (Rules 78 and 81.)	Green hand signal held steadily by hand signalman at the signal.
12. To authorise driver to draw forward to signal box when fixed signal is out of order before hand signalman has arrived. (Rule 81.)	Green hand signal held steadily by signalman at the box.
13. To indicate to driver that block section ahead is clear, but station or junction is blocked. (Rule 41.)	Green hand signal held steadily by signalman as train is approaching the box or after giving verbal warning.

14. To indicate to driver of goods train timed to stop at a station that there is nothing to pick up, and that if there is nothing to put off the train, it need not stop. (Rule 144.)	Green hand signal waved slowly up and down.
15. To indicate that catch points, spring points, or unworked trailing points are in right position for train to pass in facing direction. (Rule 196.)	Green hand signal held steadily by hand signalman at points.
16. To caution driver entering terminal station, or station worked under special instructions, if line is not clear. (Rule 96.)	Green hand signal held steadily by signalman after bringing train to a stand and giving verbal caution.
17. To caution driver of following train—"Regulations for working on goods lines where the Absolute Block System is not in operation, or where no special regulations are in force."	Green hand signal held steadily by signalman after bringing train to a stand and giving verbal warning.

Great Western Railway Company's addition :—

18. To indicate to signalman after sunset that points require to be turned.	Green hand signal held steadily in the hand by guard or shunter at knee level near the points.

London Midland & Scottish Railway Company's addition :—

19. To authorise driver to pass fixed signal at Danger when attaching, detaching, or removing vehicles. (Rule 116 (*b*).)	Green hand signal held steadily by signalman.

(NOTE.—Additions to this rule are contained in separate publications issued by the companies concerned.)

RULE 51.—In the absence of flags :—

(*a*) Both arms raised above the head denotes Danger or Stop. (NOTE.—When riding on or in a vehicle, either arm moved up and down denotes Stop.)

(*b*) Either arm held in a horizontal position and the hand moved up and down denotes Caution or Slow Down.

(*c*) Either arm held above the head denotes All Right.

(*d*) Either arm moved in a circular manner away from the body denotes Move Away from Hand Signal.

(*e*) Either arm moved across and towards the body at shoulder level denotes Move Towards Hand Signal.

RULE 52.—In shunting operations by night (see p. 32), or when necessary in foggy weather or during falling snow, a white light waved slowly up and down means "move forward," *i.e.*, go away from the person giving the signal. A white light waved slowly from side to side means "move back," *i.e.*, come towards the person giving the signal.

A green light used instead of a white light as above, means "move forward slowly" or "move back slowly."

RULE 53.—(*a*) Hand lamps and flags, when used as signals,

except where they are employed for the purpose of marking the actual point of obstruction, must always be held in the hand, and not placed upon or stuck into the ground, or fixed elsewhere.

(*b*) When a signalman gives a hand signal it must in all cases be exhibited outside the signal box.

RULE 54.—After a train has been brought to a stand by a hand Danger signal from a signal box, the driver must not move, although the hand Danger signal may have been withdrawn, until a green hand signal has been exhibited by the signalman. This All Right hand signal will not authorise the driver to pass a fixed signal at Danger unless he has been verbally instructed by the signalman to do so.

RULE 55 (*a*) to (*h*).—Signalman to be reminded by guard, shunter, or fireman when train is detained on running lines, and methods of procedure in normal and emergency conditions.

RULES 59 and 60.—The purpose and use of detonators at fixed signals, signal boxes, and other places.

RULE 117.—The standard code of audible signals by means of bell, gong, horn, whistle, or other appliance used for signalling to drivers engaged in shunting operations is as follows :—

Signal	*Indicates*
One	Go ahead
Two	Set back
Three	Stop
Four	Ease couplings

WHISTLE SIGNALS

In addition to the audible signals already mentioned, the cleaner is advised to gather such information as may be available with regard to the whistle signals in use under actual running conditions. Such information as he may obtain will be found useful immediately he begins his duties as a spare fireman. The importance of these whistle signals is more fully stressed in the next chapter, and the details there given should be sufficiently indicative of the necessity for the cleaner to familiarise himself at the earliest possible moment with the purpose and use of whistle signals when out on the road.

RULES 189 to 208.—These rules cover the working of the traffic of a double line over a single line of rails during repairs or the presence of an obstruction. Such working must be confined to the shortest length of line practicable. A competent person has to be appointed to act as pilotman, who must wear a red armlet bearing that title in white letters and he becomes responsible for controlling the movements of trains over the length of track concerned. Certain signals have to be maintained at Danger and may be passed only under the pilotman's authority. The detailed provisions of these rules should be studied very carefully. There are important differences between the practice on the different railways when a junction is involved in the single-line working.

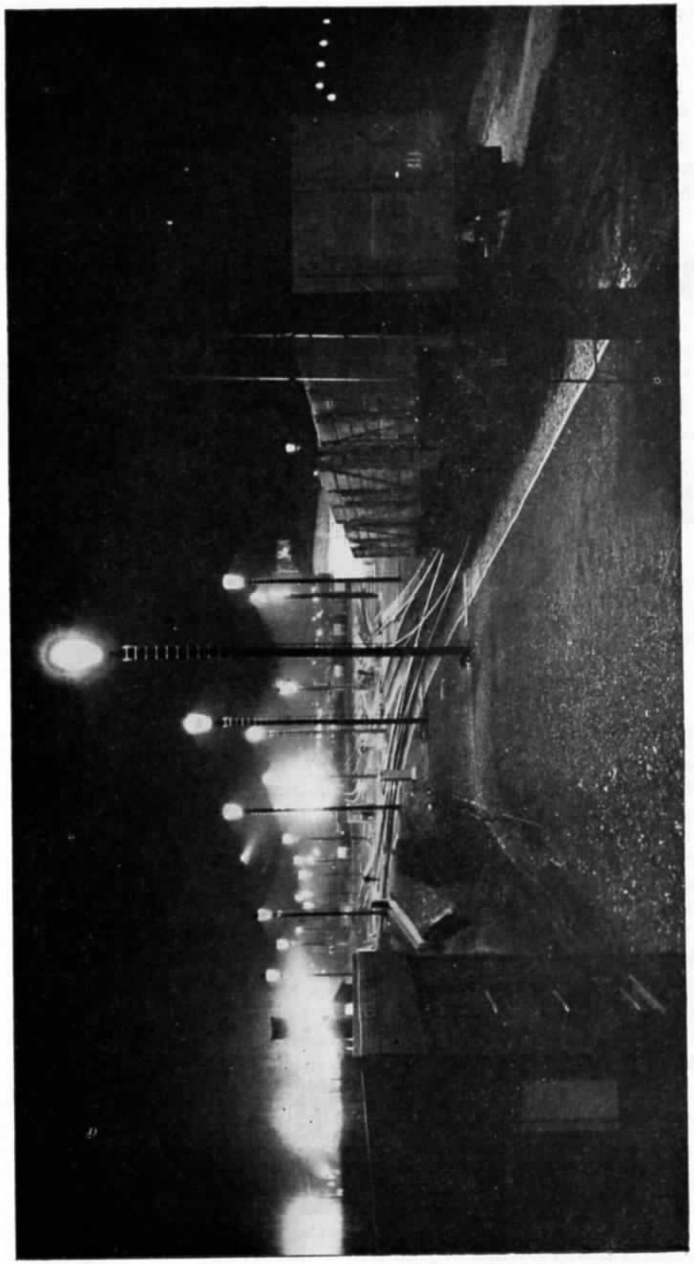


Fig. 13.—Night Shunting in Flood-Lit Concentration Yard. (*See p. 30, Rule 52.*)

Chapter 3

THE SPARE FIREMAN OR PASSED CLEANER

The spare fireman or passed cleaner will be booked out firing, and, on receiving his rule book, should immediately make himself familiar with those portions of it that affect his ordinary duties.

He will book on as required by the locomotive superintendent before being due to leave the shed, so that, after signing the Appearance Book, he will have time to look at the notice boards for any orders posted respecting water or repairs to the road on that portion of the line over which he is going to fire.

After obtaining his keys and lamps, he will usually find on arrival at the engine that there is but little steam up and only a small amount of fire on the firebars. The water-gauge cocks should first be tested to see that the water level in the boiler is at the right height. This is done by closing the water cock and opening the drain cock. After closing the drain and opening the water cock again, the water should return to the same level in the glass. The top cock should also be closed and the water cock opened for blowing through. This will also show there is no obstruction in the form of scale, etc., in the passages leading to the gauge glass.

The fire should then be levelled in such a manner that the whole is burned through without dead patches, thereby giving a good solid bottom fire to begin with.

With the fire going in this manner, steam will soon begin to rise, allowing the boiler to warm up gradually, and thus preventing undue strains on the tubeplate and firebox.

It will not be found necessary to make the fire very large until a short time before leaving the yard, and, when adding coal, the firehole door should be left open a little to prevent the formation of smoke.

There will be steam enough by this time to try the injectors, and these should be tested to see that they work properly, making sure that the water cock is opened before the steam cock.

If unable to get the injector working, the best method is to close the feed on the tender, open the drain cock to allow the water to drain thoroughly out of the feed pipes, then close the drain cock and open the tender feed. If the injector still refuses to work something is wrong with the cones or clack, and this should be attended to by the driver.

The tube ends and brick arch should be examined and raked down if found dirty.

A loose-fitting smokebox door will considerably impair the draught, so that it is important that this should be tightened home securely, and it must be seen to that the ashpan dampers are in working order.

It may be pointed out here that instances have occurred where trouble was caused through an imperfect and cursory examination of the ashpan and firebars. When a fireman has brought in an engine and thoroughly cleaned out the ashpan, he may naturally think there is no need to examine the firebars and ashpan before going out again. Between going off and coming on, however, the boilermaker has been and changed some ferrules, and in doing so has knocked down some portions of the brick arch and left the debris in the ashpan. Because of the engine steaming badly, the dart has been used, with the result that there has been fire above and below the firebars, burning the bars and framing down and causing trouble and loss of time.

Should the coal be of a bad quality or liable to clinker, a few bricks broken up to the size of a walnut, or a little wet sand spread evenly over the bars, will assist in keeping open the air spaces and prevent the bars from burning.

Before leaving the shed it must be seen to that there is a full set of fire-irons, shovel, tools, lamps, detonators, red flags, spanners, waste or cloths, oil-cans and feeders, and the necessary engine and lamp oils, etc. Be sure that the scoop or deflector is ready to hand.

It is a very good practice before starting out to throw a few bucketsful of water over the coals, both on tender and tank engines, to keep the dust down. This not only lays the dust but also prevents the fine coal from being drawn through the tubes before becoming ignited.

The mere fact of filling the bucket from the tank will tell how much water there is, and therefore be a very good check against going out with only a partly-filled tank. At the same time the fireman will get into the habit of noticing that the coal is stacked safely, for it will be understood readily how dangerous it is to platelayers and others working on the line should any coal be dislodged and fall off while the engine is in motion.

The fireman should follow out his driver's instructions with regard to oiling, and the methods of making trimmings, mops, and stringing corks, etc.

The foregoing will show that, from many points of view, a fireman's duties are as important and necessary as those of the driver, and, though this is not generally admitted, a fireman can, without doubt, establish for himself a reputation for the intelligent discharge of his duties, and a creditable reputation is a sound capital well invested with which to work in after-years.

It will be well to remember that on every ship there is only one captain, and this applies equally forcibly to a locomotive. The fireman should therefore strive to win the confidence of his driver by rendering him every possible assistance, and combining this with civility and strict attention to duty.

Firemen naturally expect a certain amount of assistance from their drivers in the acquisition of information relative to the raising of steam and the general running of an engine. By reason of their length of service and practical experience, drivers have a fund of information which, if properly imparted to a smart fireman, must be of invaluable assistance to him, especially during the earlier parts of his firing experiences on the road.

When the fireman is first put on the main line it will probably be on the night shift, so that it will take some time to learn which are the distant and which the home signals, where these are not differentiated by separately coloured glasses in the lamps, owing to invisibility of the swallow-tails on the arms in the dark.

With the assistance of his driver, these difficulties will soon be overcome, and he will quickly recognise localities by peculiarities of the landscape, or in a dense fog by simple things, such as gates and crossings. A special warning is given against lifting the fire-irons too far over the opposite running line. It is an easy matter, if care is not taken either before or after using, to put the dart through a coach window of a passing train.

Particular attention is also drawn to the number of lives that have been lost in the past because of the fireman forgetting the bridges when he mounts the tender or tank.

The fireman will discover quickly that he will be continually in hot water if too much smoke is turned out. This question of smoke is doubtless a serious one, and, along with that of combustion, has had the particular attention of our leading chemists, science professors, and engineers for many years. As long as coal is used there will be smoke ; but there is a vast difference between a chimney just showing signs of it and one belching out sufficient to blacken the whole countryside. It is an axiom that a smoky chimney is a wasteful one in many senses, and it is well to note that the coal consumption of every engine is subjected systematically to the keenest scrutiny by the various responsible heads of the departments. Economy or extravagance is immediately apparent on the coal sheets, and credit or blame is apportioned accordingly to the servant or servants concerned.

A brief and elementary consideration of some of the simpler laws of combustion will not be out of place here, and at the start the reader should impress it firmly on his mind that for every pound of coal burned a definite and known amount of energy can be evolved.

Broadly, in every 100 lb. of coal, 80 lb. is carbon, 5 lb. hydrogen, and the remainder is composed of oxygen, nitrogen, sulphur, and ash ; 1 lb. of average coal, properly consumed, gives out about 14,000 British Thermal Units (B.Th.U.).

When coal is fired it throws off various gases, each of which when properly combined with air will give off heat. This combination is known as combustion, and can be attained perfectly only by proper firebox temperature and proper admission of air. The various gases combining to make for good or bad combustion have their own individual characteristics, ignition temperatures, and heat values ; the temperature of the last is directly affected by the amount of oxygen supplied by the air through the means of the dampers or firehole door.

Coal itself is a great absorbent of heat, and when put into the firebox in large quantities will considerably reduce the firebox temperature.

The average ignition temperature of seven well-known classes of coal has been found to be about 807° F., which is much lower than 2,500° F. (approximately), the temperature at which carbonic acid gas, "the product of perfect combustion," is given off.

It will thus be seen that there is a wide difference between simply burning the coal and doing it efficiently and, therefore, economically. Other gases are liberated when combustion takes place, but these do not affect our purpose, the object of which is to present the facts from an elementary and practical standpoint.

The low ignition temperature of coal has been mentioned because smoke is mostly produced immediately the coal begins to burn. When ignition takes place, incandescent particles of carbon are given off. A proper supply of oxygen from the air is absolutely necessary for the complete combustion of these carbon particles, otherwise they will pass away unconsumed through the tubes and chimney in the form of black smoke, doing no useful work, and choking up the tubes, etc. A leaky smokebox door, by admitting oxygen, will cause the carbon particles to ignite in the smokebox in many instances, thereby giving fire at the wrong end of the tubes.

The remedy, therefore, for thick smoke is to fire in small quantities so that the firebox temperature is maintained, and to learn by practical observation the quantity of air required.

Although the amount of oxygen required for the consumption of a given amount of carbon is an exactly known quantity, the varying conditions and different qualities of the coal with which a fireman has to work make theoretical data of little value, the amount having to be determined by the conditions.

Carbon monoxide is another wasteful product of imperfect combustion. Its ignition temperature is about 1,210° F., and as a gas it is almost colourless and odourless, but poisonous. It is formed by an insufficiency of air or a lowering of the firebox temperature in conjunction with too thick a fire, and will pass away through the chimney unsuspected because it is not so patent to the sight as the darker carbon particles.

With proper firebox conditions this carbon monoxide is converted into carbonic acid gas, doing then its share of useful work in the economical production of steam. As an illustration of the losses due to the escape of flue gases in the form of carbon monoxide, it is necessary only to compare the 14,000 B.Th.U. given out by 1 lb. of carbon when burned to carbonic acid gas, with the 4,000 B.Th.U. produced when the same amount is burned to carbon monoxide, a distinct loss of 10,000 B.Th.U. These figures are a low estimate compared with some of the results for best classes of coal.

There are varieties of ways in which carbon monoxide is formed, perhaps the most common of which is the thick fire, a veritable hot-bed for the production of this gas. The burning coals will lie so closely together that the air is prevented from passing upwards through the firebars, and the air above the fire will pass through the firebox, coming in contact with only a small proportion of the burning coal. The fire is thus robbed of its due amount of oxygen, and the result is a distinct lowering of the firebox temperature, causing the finger of the pressure gauge soon to indicate a falling-off of steam.

It is a bad practice to stir up the fire with the dart too freely. The thick fire is always disposed to form dross and clinker, as its internal temperature is too low for their consumption.

When the dart is used, those portions of the fire liable to fuse will cling together, being brought into contact by the action of the dart, and together they will form a clinker, choking up the bars and thus further diminishing the supply of air.

In most cases when the fire requires stirring, a levelling up of the surface is all that is necessary.

It is a well-known fact that more firemen have come to grief through having too thick a fire than from having one too thin. The tubeplates become fouled, tube ends are choked up, and the firebars, by having the heat confined to their upper surface, will be burned away quickly.

It is an old axiom that the fire which makes the most steam will burn the least coal, comparatively.

Cleaning the fire, or dropping the fire, is an arduous duty under ordinary conditions of service where the amount of time allowed at the end of a trip for engine purposes is frequently very short. To meet this difficulty many locomotives are now fitted with a grate arranged so that one or both halves may be tilted in such a way that the clinker is dropped into the ashpan. The mechanism required for tilting is simple in action and is operated by a lever from the cab. This arrangement obviates the necessity of drawing out the clinker from the firehole as, when cleaning out becomes necessary, the good fire may be placed on one half of the grate with the refuse on the other half, and the refuse can then be tilted into the ashpan. After the grate has been returned to its normal position the live portion of the fuel may be respread over the whole surface of the grate, thus providing a good foundation for the rebuilding of the fire.

With ordinary firegrates, and unless very exceptional conditions prevail, the fire should never be more than 6 or 8 in. thick, according to the quality of coal, and should be 2 or 3 in. higher at the firebox sides and under the doorplate than in the middle and under the tubeplate.

This form and thickness of fire will give ample room for the proper combining of the gases and allow for a sufficient supply of air, and, with systematic and even firing, will produce steam and prevent the formation of smoke.

Firing with big lumps of coal is another fruitful source of carbonic oxide. When these are put into the firebox, bad places are made in the fire, the surrounding portions are consumed, and the bars are left bare. When this occurs, the cold air passes through the bars and reduces the firebox temperature to such an extent that the formation of carbonic acid is impossible, and the gases pass away in the form of carbonic oxide.

It is also a detrimental practice to fire with large lumps of coal, because the boiler has not yet been made that can long withstand the racking strains set up by this style of firing.

It is easy to imagine what takes place when lumps of coal are deposited against the firebox sides or pushed forward against the tubeplate. Bad places are formed, and the cold air plays upon the plates, setting up local contractions while the other parts of the firebox are under expansion owing to the heat of the fire, and this inequality will cause the tube ends to leak, and thick smoke will be given off.

For illustration, take an ordinary piece of wire, and it will be found that bending it backwards and forwards once or twice will do the wire very little harm, but if the bending be continued the wire will become distressed and ultimately break. There is a great similarity in the distressing effect on the metal by the bending of the wire and the unequal racking strains of the firebox. The lumps of coal therefore should be broken first into pieces not larger than half a brick. By this means a greater amount of coal surface is exposed to the action of the fire. The combustion in consequence will be much more rapid, as sufficient flame is given off immediately to keep up the temperature of the firebox and consume the carbon particles.

It will now be seen how necessary it is to fire "little and often," never more than 6 or 8 half-shovelsful at a time. This method is recommended because by it the fireman will learn to know exactly where the coal is needed in the firebox, and he will better be able to direct it to its proper place than if the shovel be heaped up.

This style of firing produces a fire full of energy, eager for combustion, and giving off such an intense heat that smoke, dross, and clinker will be nearly annihilated.

The loss of fuel and the risks of fire due to smoke and sparks from locomotives are now so generally acknowledged that any carefully-designed device for their abatement is worthy of serious consideration.

The importance of the proper regulation of the air supply must be remembered, because too much air is almost as bad as too little. This applies especially when fires are carried too thin. A very thin fire is apt to leave the bars bare, and will lift with the beats of the engine, allowing a superabundance of air to get into the firebox, and will sweep away the volatile gases before their heat is given out, or so dilute them that the temperature is lowered.

That large quantities of useful heat do escape by the chimney is an undoubted fact, and the whole art of firing should tend to the absorption of that heat before it is allowed to escape.

For this reason it is a bad practice to open the firehole door when the engine is starting after a stop, and no attempt at firing should be made until the reversing lever is notched back with the engine working at its normal amount of cut-off. If firing is begun too soon, with the engine working hard, large quantities of cold air will be drawn into the firebox, and its temperature will be lowered considerably.

It would be absurd to fix any limit as to how often and where firing should take place, as so much depends on the quality of the coal, the load, and the gradients. The fireman, however, will learn to arrange his firing so that he can be on the look-out for signals when going round a curve on which the driver cannot see ahead, and also arrange to get his fire into good form in ample time when approaching a stiff bank.

He will also learn that it is impossible to keep a steady head of steam unless the injectors are observed closely and the firing is done with care and judgment according to the rate at which the boiler is being fed.

In time the fireman will know how wasteful it is to have steam continually blowing off at the safety valves, and, by watching the gauge and regulator handle, will learn to check the tendency to blow off in good time by closing a damper or opening the firehole door a little.

He should also watch the driver, and, immediately before the regulator is closed, put on the jet, close the dampers, and open the firehole door slightly.

When standing or shunting, where it is a serious matter to make smoke, a good plan is to fire only one side of the firebox at a time so that the heat on the hotter side of the fire will assist in preventing the formation of smoke on the other.

While mastering the various details of the practical part of his work, the fireman will soon feel at home on the footplate, and, if he be smart, will begin to keep things in their proper place. Tools should not be thrown all over the box, but kept in perfect order, clean and ready to hand when needed, so that it will not take from five to ten minutes to find, say, a ¾-in. spanner, and then two or three patches of waste or cloths to clean the hands.

A good system is to have a piece of timber across the toolbox, putting the jaws of the large spanners on the right-hand side. This will keep them clean, and in case of urgency the fireman will be able to put his hand on the right spanner readily and quickly in the dark.

The head and gauge lamps should also be kept clean both inside and out, for nothing has a worse appearance than dirty lamps.

The handbrush should be plied assiduously to keep the footplate clear of coals and dust.

The screw of the handbrake should be kept clean so as to be ready for use always. It is bad policy on the part of a fireman not to use his handbrake when running into a station with a passenger train, and more especially into a terminus. There should be no need to point out how serious a matter it would be if anything went wrong, and it was proved that the fireman did not use his handbrake.

On returning to the shed the first duty will be to go to the coal siding and get a supply of coal, taking care to see that it is properly stacked, and then fill up the tank with water. After this the driver will take the engine over the ashpit for examination, finally setting both cranks near top centre for raking out the ashpan.

Before dropping the fire, the boiler should be filled, so that the tubeplates and firebox may cool gradually.

The dampers also should be closed, brakes put hard on, reversing lever placed in mid-gear, and cylinder drain cocks opened.

In cleaning out the smokebox, the handbrush should be well used, and the jet turned on only just sufficiently to keep the dust out of the eyes. If the jet be put on too hard, large quantities of air will rush through the tubes, setting up severe strains in the firebox and tubeplates because the boiler is cooled suddenly.

In railway practice one of the principal aims is to operate the locomotive stock of the company to the greatest advantage. Measures taken to reduce the number of engine classes, improve shed and yard facilities, and work the engines over much longer

FIG. 14.—MECHANICAL LOCOMOTIVE COALING PLANT AT PRESTON, L.M.S.R.

distances without change, have brought about considerable economies and have had a beneficial effect in other directions as well.

In many cases the track layouts at locomotive depots have been rearranged to allow of engines moving from point to point in the yards for coaling, watering, ash dumping, and so on, with greater freedom, and avoiding getting in one another's way when entering or leaving the shed in going on or off duty. The

coaling and watering arrangements have themselves been improved greatly, mechanical coaling plants and more efficient and easily handled water cranes being used. Power-operated turntables have been installed in a few cases so that the largest engines can be turned with greater facility. One ingenious method is that of using the brake power of the locomotive itself for

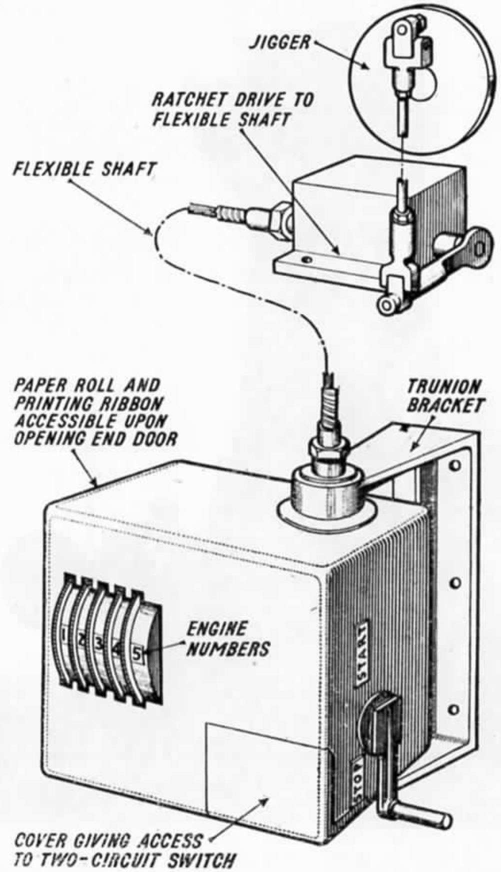


FIG. 15.—APPARATUS FOR RECORDING ENGINE NUMBER AND AMOUNT OF COAL DELIVERED TO TENDER.

operating a vacuum engine used for moving the turntable. This system was devised and patented by Cowans, Sheldon & Co. Ltd., of Carlisle.

With the mechanical coaling plants referred to above (one of which is shown in Fig. 14), railway wagons loaded with coal are raised from track level to the necessary height to enable them to be turned over, discharging their contents into bunkers, with which coal chutes are connected. By means of these, the coal is deposited on the tender of the locomotive standing below it. Electrical operation is used and the plants vary in size and capacity according to whether the running shed is large or small. The design also varies considerably in different plants, but the

FIG. 16.—NARROW-GAUGE TROLLEY FOR REMOVING ASHES FROM SMOKEBOX AND ASHPAN.

general purpose is that of expediting the handling and delivery of coal to the locomotives. In this way, a large locomotive tender can be loaded completely with coal in a very short time.

On the L.M.S.R., mechanism for recording the engine number and the amount of coal delivered on the tender has been installed at certain sheds, and an illustration of this appears in Fig. 15. The mechanism is controlled by the driver or fireman from an operating cabin on the platform of the coaling plant at about

FIG. 17.—COALING AND ASH PLANT AT KENTISH TOWN, L.M.S.R.

5 ft. from the rail level, so that, after the engine is set for taking coal, the operator can step off on to the platform at approximately the same level and enter the cabin, from which a clear sight of the tender is obtained, thus rendering it easy to regulate the mechanism for actuating the coal delivery. The control mechanism consists of a flap or outlet operating lever and the coal weight and engine number recorder. The procedure is that the operator sets the engine number on the dial of the recorder, then moves the operating lever for the flap to the required position, which automatically sets the water spray for the coal jigger into action, thus preventing dust during coaling operations, and finally moves the starting lever on the recorder. When sufficient coal is obtained, this lever is pulled back to the "stop" position, and the flap lever set to normal position which shuts off the water spray and moves the flap clear of the loading gauge. The weight of the coal put on to the tender, as well as the engine number, is recorded on a paper roll in the recorder itself.

Another time and labour-saving device adopted on the L.M.S.R. at certain large sheds is that illustrated in Figs. 16 and 17. Narrow-gauge tracks run along the bottom of the engine pits and also alongside them at rail level, and these are served by trucks having bottom-hoppered doors. The procedure is that, in dealing with the ashes from the ashpan, the truck is run under the ashpan, and after being filled is placed over a grid and the ashes deposited into the chutes. In the case of the paddled ashes, these are taken from the engine firebox through the firebox door, and then thrown from the footplate into the trolley on the track alongside the engine pit, and the ashes are disposed of similarly. The same procedure is adopted with smokebox ashes. Ample watering facilities are provided for efficiently quenching the ashes.

The practice of cleaning the boiler tubes themselves while running has now become almost universal. It has proved an excellent method of improving the steaming of an engine, especially when using dirty coal, and for making up lost time. The soot and ashes which block up the tubes and collect on the brick arch are all blown clean through with the ten-second steam blast of the soot blower, which should be used every hour. To prevent "birds-nesting" on the tube ends and tubeplate, the soot blower should be used ten minutes after lighting up fires and raising full steam; this prevents the ash building up. The tubes also should be blown through just before the locomotive returns to the running shed.

A good example of the kind of apparatus referred to, and one which is both simple and rapid in operation, is the Diamond blower, or cleaner, manufactured by the firm of that name, which incorporates what is called a snap-over valve action ensuring minimum steam consumption. When the steam supply to the cleaner is turned on, steam is admitted to the steamchest. The piston is slightly larger than the bore of the valve seat, so that steam pressure keeps the valve on its seat, and prevents any steam being used until the cleaner is operated. A sharp push on the handle is sufficient to carry the whole interior forward. No

steam is admitted to the shank and nozzle. The shank is slightly larger in diameter than the piston, so that steam pressure then causes the whole interior to snap forward into the operating

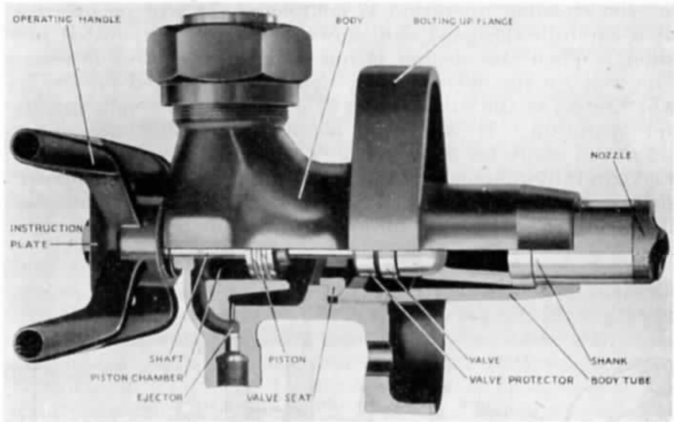


Fig. 18.—Diamond Soot Blower: Valve Open.

position. One full turn of the handle ensures that the whole tube bank is cleaned by the steam jets.

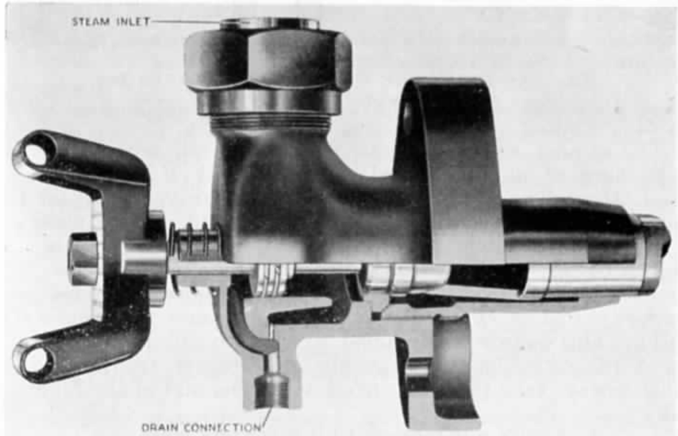


Fig. 19.—Diamond Soot Blower: Valve Closed.

A final sharp pull on the handle brings the valve protector back inside the valve seat. Immediately, steam pressure builds up and causes the valve to snap back on to its seat simultaneously shutting off the steam supply and withdrawing the nozzle inside the water-cooled housing tube. The Diamond snap-over valve action thus ensures that no steam is used until the nozzle is forward in its operating position, and that no steam is wasted after the cleaning operation is complete. It will be noted also that a carefully-designed shut-down valve is incorporated in the cleaner. When the cleaner is not in use, this valve is retained on its seat by the spring. The cleaner is mounted on the back of the firebox in the driver's cab at a convenient height for direct hand operation. It is readily accessible at all times and can be removed easily for inspection. The cleaner nozzle incorporates three carefully-machined cylindrical orifices, each designed to deflect a jet of steam positively to one zone of the tube bank. This positive deflection eliminates any danger of cutting the crown plate.

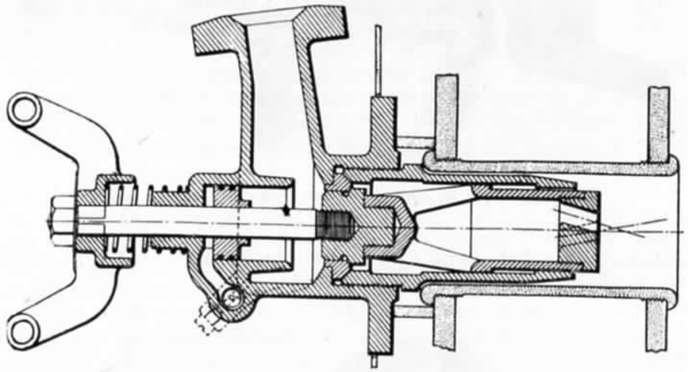


FIG. 20.—DETAILS OF DIAMOND SOOT BLOWER FOR LOCOMOTIVE BOILERS.

The cleaner can be operated easily in ten seconds by the single turn of a hand wheel. The method of cleaning is so simple that there is no temptation for the driver to avoid this important task. The illustrations, Figs. 18, 19, and 20, show the details of construction.

The Clyde soot blower manufactured by Clyde Blowers Ltd., Clydebank, is a standard fitting on many railways, having been supplied to more than fifty railway companies throughout the world. This blower is designed to operate automatically by a few turns of a hand wheel, the movements transmitted by which always take place in correct sequence, and in the following order :—

1. Nozzle advances until it leaves its housing.
2. Steam automatically admitted to nozzle.
3. Nozzle rocked to spread steam jet.

When the hand wheel is reversed the nozzle is retracted, housed, and protected, and steam is shut off from it automatically.

This description will be followed more easily if read in conjunction with the illustrations, Figs. 21, 22, and 23.

The application of the soot blower to the back plate of the locomotive boiler is effected by fitting a housing tube through the rear water space which gives access to the firebox. The blower is attached to the back plate by four $\frac{3}{8}$-in. diameter studs and nuts, and a steam connection is led from a stop valve on the boiler to the blower steam inlet and coupled to it by means of companion flanges or union nut and tail. A drain connection is led from the bottom of the blower steamchest.

The application of soot blowers to the sides of the firebox is desirable in certain circumstances. Sometimes the inclination of the brick arch and the arrangement of the arch tubes when fitted prohibit the application of a blower to the back plate, and the type of Clyde blower designed for fitting to the side of the firebox has operating mechanism which gives positive control from the cab. The operating hand wheel is situated in the cab and controls the advance of the nozzle and spread of the steam-jet, whilst in addition it admits and shuts off steam automatically.

An automatic drain valve is provided on the blower steam-chest and this valve remains open while the blower is in use, closing under steam pressure after all condensate has escaped.

The operation of the blower after the stop valve has been opened consists of turning the blower hand wheel several turns, first in one direction and then in another, whereby steam is automatically admitted to the nozzle and the jet discharged through each row of tubes in the nest. It is intended that the blower should be used with regularity every four hours, or as may be determined by experience.

An unique feature of the Clyde blower, and one of great importance, is that the steam spindle carrying the nozzle does not make complete rotation although the hand wheel does. Due to this fact, the nozzles are designed with two ports, discharging the steam at predetermined angles such as 5° on top and 25° on bottom.

As the housing tube is situated a few inches below the crown plate, it will be obvious that, were the steam spindle, carrying the nozzle, to make complete rotation with jet angles as stated, then the greater angle jet would strike the crown plate within a short distance of being discharged from the nozzle. Grooving of the crown plate in such circumstances would quickly develop. No grooving can take place with the Clyde soot blower nozzle design and part rotation of the steam spindle. By consulting illustration Fig. 23 this will be understood readily.

These remarks refer to the blowers fitted to the side of the firebox ; the standard type manufactured by Clyde Blowers Ltd. is arranged, as already indicated, for fitting to the back of the firebox.

Another apparatus designed and used for the purpose of keeping the boiler tubes and tubeplate clean is that known as the firebox sand gun. This is in the form of a fitting on the firebox back plate and by means of it small quantities of sand can be introduced into the firebox at intervals when the engine is working heavily. In the past it has been the practice of certain enginemen to spread a shovelful of sand over the top of the brick arch on heavy sections of the line, to prevent the tubes

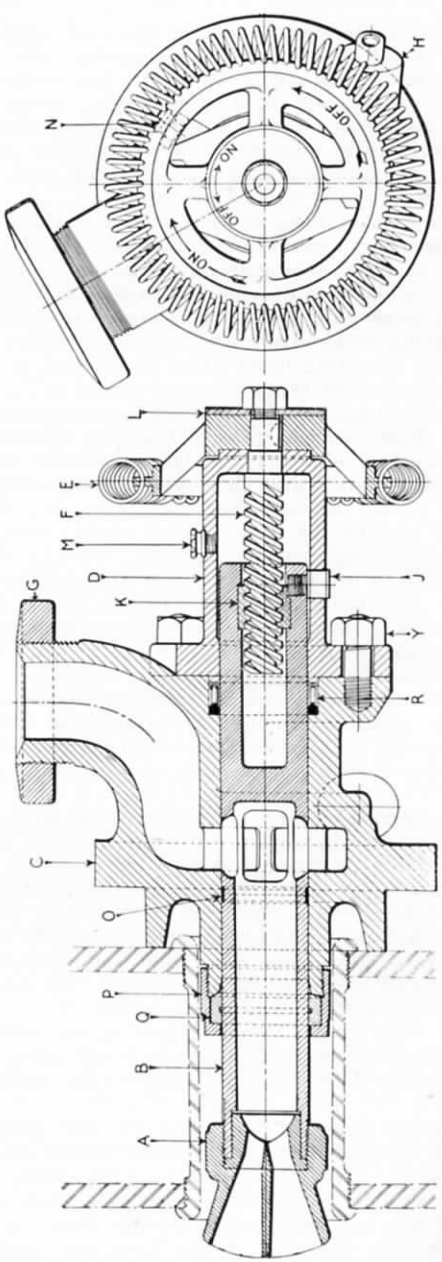


Fig. 21.—Clyde Patent Soot Blower for Locomotives, arranged for Fitting to Back of Firebox.

A, nozzle; B, steam spindle; C, steamchest; D, sleeve; E, hand wheel; F, triple screw; G, steam inlet flange; H, automatic drain valve; J, guide pin; K, triple nut; L, instruction plate; M, sleeve lubricator; N, chest lubricator; O, piston rings; P, cap nut; Q, bearing ring; R, packing rings; Y, studs and nuts.

from becoming furred, but this method of hand sanding is open to the serious objection that, should the regulator be closed during the process, some of the sand is liable to be sucked down the blast pipe and thus damage valves. The sand gun has been designed to be proof against such a possibility by making its action depend on steam taken from the steamchest, so that, as soon as the regulator is closed, it is put out of action automatically. The gun is arranged so that it introduces sand into the firebox from a point in the centre of the back plate immediately over the firehole door, and is thus discharged straight at the tubeplate over the top of the brick arch.

The apparatus illustrated in Fig. 24 consists essentially of a steam ejector taking steam as aforementioned from the steamchest, the steam jet entraining with it a supply of sand drawn through a pipe from a sand container situated in a suitable part of the engine cab. The mixture of steam and sand is discharged through a combining nozzle which enters the inner firebox through a short length of tube of about 5 in. diameter, screwed and expanded into the plates of the inner and outer fireboxes and beaded over at either end. In order that the whole area of the tubeplate may be covered, the combining nozzle is set at an angle and so mounted that it may be rotated by a hand wheel, thus causing the stream of sand to sweep round the tubeplate in a circular path so that all portions of it are subjected in turn to the scouring action of the sand blast.

After the smokebox is emptied, a good plan is to grease round the rim of the door, so that when screwed up tight a good joint is made and the drawing in of air prevented.

The fire can then be dropped and the ashes raked out. After locking up tools and lamps, and before leaving the engine, the fireman should assure himself that the jet and dampers are closed, handbrake hard on, cylinder drain cocks open, and reversing lever in mid-gear.

By this time the fireman will have had experience on pilot-engines and goods trains, and will have had an opportunity of becoming acquainted with the road, signals, and gradients. At the same time it should not be forgotten that the whistles for junctions and passing trains are described fully in the rules, and should be known.

In the early or probationary period of his firing experience, the spare fireman will have had many opportunities of noting the importance of whistle signals, and should therefore ascertain for himself the reasons for their use. Various forms of whistle signals are adopted on all railways, and are used according to circumstances, or location, as when passing through a junction, or a tunnel in which men may be working, etc. They may be used also for indicating to a signalman at a given point on route that a train is not stopping, or, on the other hand, is booked to stop at some particular station or siding.

By their use, whistle signals indicate to the signalman the line on which a train is coming, or, when approaching a junction, the driver, by giving the prearranged number and form of

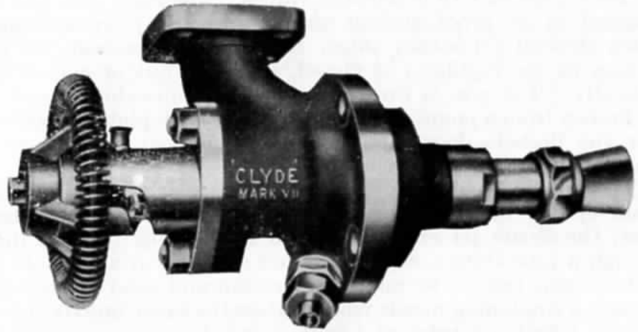


FIG. 22.—CLYDE BACK PLATE TYPE SOOT BLOWER.

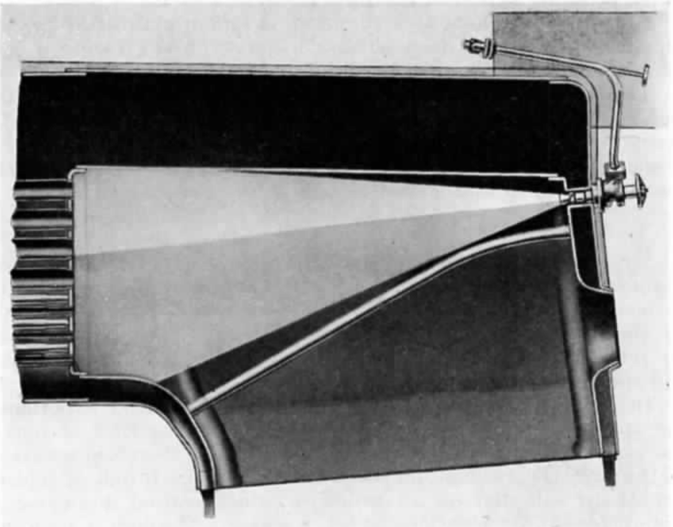


FIG. 23.—SECTIONAL VIEW OF A FIREBOX FITTED WITH CLYDE SOOT BLOWER ON THE BACK PLATE.

whistles, can indicate the particular line on which his train is intended to run. It will be seen thus that whistle signals have an important bearing on the time-keeping of the long-distance high-speed trains of today, since it is possible to inform the signalman that the train is booked to run through an important station or junction, and so on.

Then again, by reason of the failure of the water pick-up, or the absence of water in troughs, a driver may wish to stop at some convenient point for water, in which case the agreed code

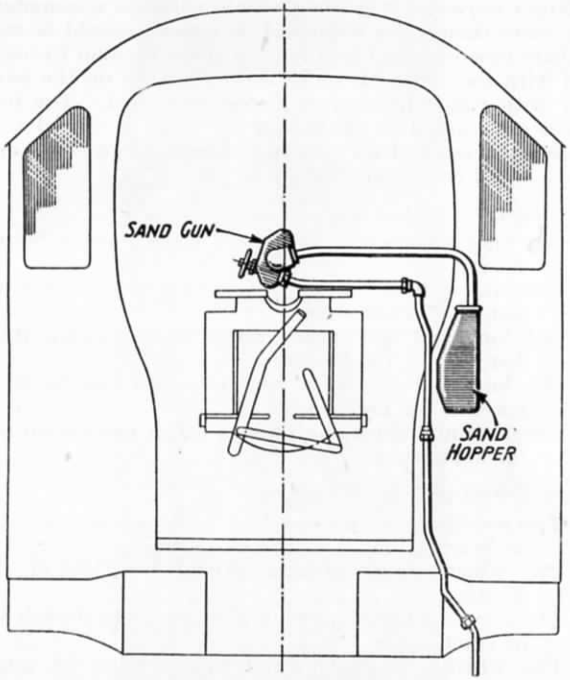


FIG. 24.—SAND GUN FITTINGS USED ON L.M.S.R. LOCOMOTIVES.

of whistles will be given. This applies also when there are vehicles to be detached at a station where the train is not timed to stop, and, in the event of a driver finding his engine, from any cause, unable to work his train to the next booked stopping point, he may give several "crow" whistles to attract the attention of the signalman at the next box the train has to pass. Having thus obtained the attention of the signalman, the driver, to indicate his difficulty, will signal to him as follows :—

By Night.—A white light shown to the signalman by the driver.
By Day.—A lamp held up by the driver toward the signalman.

The foregoing will be sufficient to indicate a few of the many purposes for which whistle signals may be used, and it will be seen that the meaning of the signal is determined by its form, which may be only a simple " crow," or two, three, or more short blasts according to the code adopted on the particular railway over which the engine is running. It will therefore be obvious that, to be of assistance as and when required, the spare fireman should make himself familiar not only with the various whistle codes in use on the railway with which he is concerned but also with the different points on route at which the signals are to be given.

Since the code of whistle signals may vary to a certain extent on different railways, it is not possible within a reasonable space to give more than a few examples, but these should be sufficient to indicate how essential it is for the spare fireman to familiarise himself with the codes in use in those districts on the particular railway with which he expects to be concerned. The following examples are quoted to show how the code is varied to suit a particular purpose; they are not, however, by any means a complete list of the whistle signals in use :—

Up Trains : Carlisle to Crewe (L.M.S.R.).

One long whistle and two crows when passing Southwaite station.

Two long whistles and two crows on slow line when wanting water at Penrith.

One long and one short whistle when passing Wigan on fast line for the South.

One long and two short whistles when passing Wigan on fast line for Liverpool.

One long and three short blasts when passing on fast line for Manchester.

Down Trains : Crewe to Carlisle.

Two whistles when passing Preston Brook and not stopping at Warrington.

One whistle when passing Wigan for Preston and the North.

Three crow whistles passing Milnthorpe to detach vehicles at Oxenholme.

Two whistles passing Clifton and Lowther for wagons to be detached at Penrith.

Three crows at Tebay No. 1 for passenger trains requiring a bank engine at Penrith when not timed to stop.

Up Trains : Crewe to London.

Two whistles passing Norton Bridge for running through Stafford and the South line, and two whistles and one crow for Wolverhampton and Birmingham.

Down Trains : London to Crewe.

Two whistles passing Welton for running through Rugby for Nuneaton and the North.

With the experience already gained, the fireman should be sufficiently advanced to be passed officially as a fireman, and will have begun to prepare himself for examination.

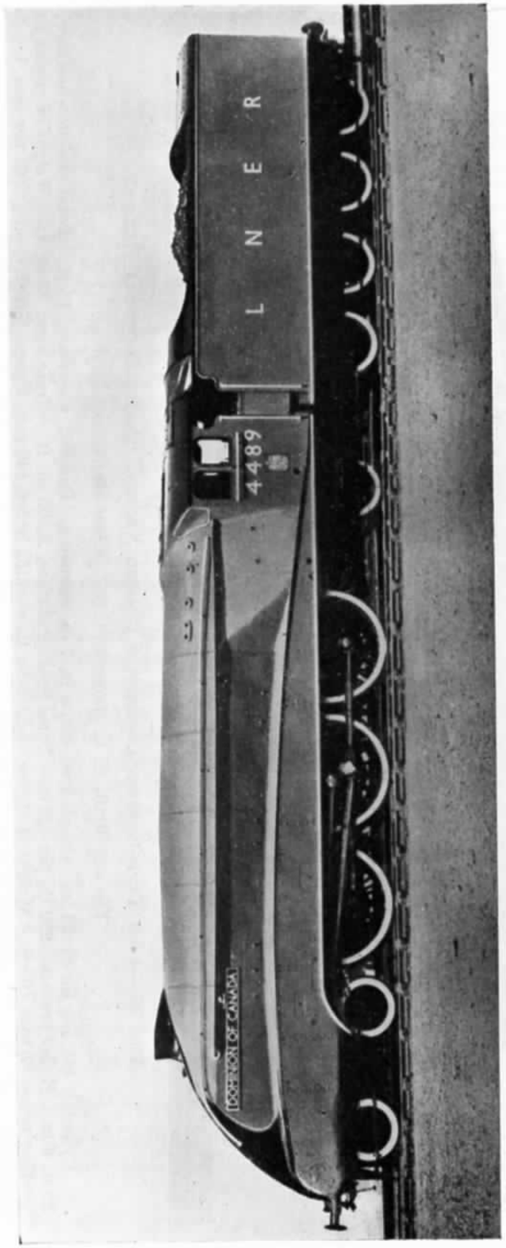


FIG. 25.—STREAMLINED 4-6-2 TYPE THREE-CYLINDER EXPRESS ENGINE, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 18½ in. by 26 in. Coupled wheels, 6 ft. 8 in. diameter. Coupled wheelbase, 14 ft. 6 in. Total engine wheelbase, 35 ft. 9 in. Boiler pressure, 250 lb. per sq. in. Total heating surface, 3,325·2 sq. ft. Grate area, 41·25 sq. ft. Weight of engine in working order, 102 tons 19 cwt. Weight of engine and tender in working order, 165 tons 7 cwt. Tractive effort (85 per cent. b.p.) 35,455 lb.

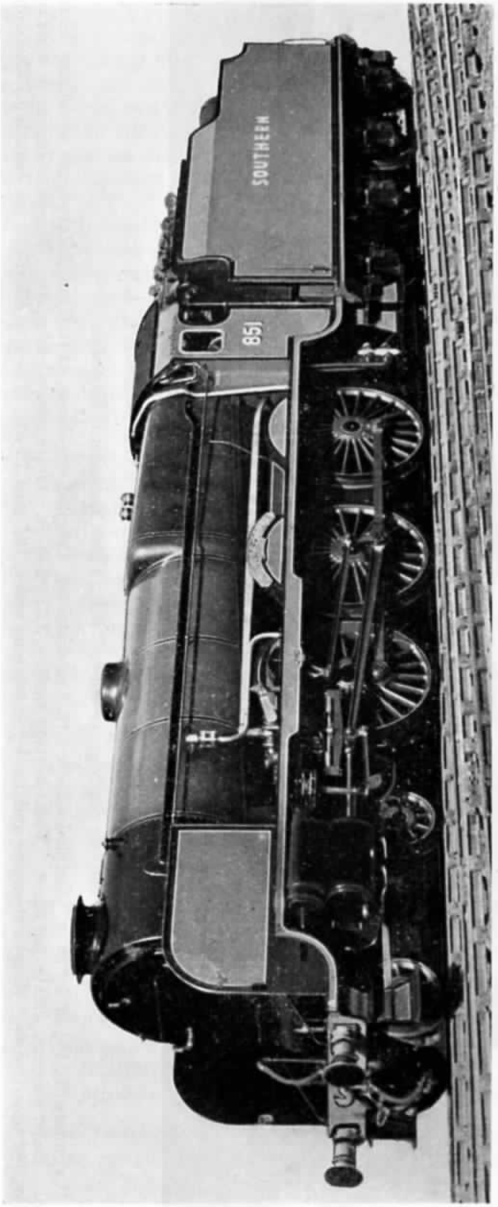


FIG. 26.—4-6-0 TYPE EXPRESS LOCOMOTIVE ("LORD NELSON" CLASS), SOUTHERN RAILWAY.

The late Mr R. E. L. Maunsell, C.B.E., Chief Mechanical Engineer.

Cylinders (4), 16½ in. by 26 in. Coupled wheels, 6 ft. 7 in. diameter. Coupled wheelbase, 15 ft. Total engine wheelbase, 29 ft. 6 in. Boiler pressure, 220 lb. per sq. in. Total heating surface, 2,365 sq. ft. Grate area, 33 sq. ft. Weight of engine in working order, 83 tons 10 cwt. Weight of engine and tender in working order, 140 tons 4 cwt. Tractive effort (85 per cent. b.p.), 33,500 lb.

CHAPTER 4

EXAMINATION FOR FIREMEN

THE technical examination for cleaners to act as firemen is an oral one, and the following subjects are usually included in the test of a candidate's knowledge :—

(*a*) General description of a locomotive, *i.e.*, names of the principal component parts.

(*b*) General knowledge of Rules and Regulations particularly applicable to :—

1. Hand and fixed signalling.
2. Protection of trains and opposite lines.
3. Locomotive equipment.
4. Methods of firing locomotives.

The official book of Rules and Regulations is supplied to all new entrants into the grade of engine cleaners.

1. *What would you do when first coming on duty ? Explain Rules affecting same.*

Sign on ; carry out Rule 126 (i) ; look at the notice boards, as per Rule 126 (ii), and see number of engine booked on sheet. Get the keys and lamps and see that there are two red shades, flags, and detonators. Examine water level in boiler, fire in firebox, smokebox door, ashpan, tube ends, brick arch, firebars, and try the injectors. See that there is a full set of fire-irons, comprising clinker shovel, dart, rake, pricker, pinch bar, set of tools, oil bottles, feeders, bucket, fire shovel, quarter hammer, handbrush, and scoop. Make the fire up, using some broken brick or wet sand to keep the bars from burning. Carry out Rules 127 (ii) and 126 (iii) and afterwards work to driver's instructions.

2. *What lamps would you carry on light engine to station goods yard or siding ?*

No. 7 headlight, viz., one white light on middle of leading buffer.

3. *How would you get the attention of a pilot in rear of train ?*

By giving two crow whistles, as per Rule 133 (*c*).

4. *What would you do first after starting away with a goods or coal train ?*

Carry out Rule 142.

5. *Explain what Rule you would use, if detained at a home signal?*

Rule 55 (*a*).

6. *What Rule applies to you if shunted across the road for a passenger or other important train to pass?*

Rule 55 (*b*).

7. *What should you expect to find in the case of all signals off and the signalman waving a green light from side to side?*

Train divided as per Rule 182.

8. *Explain what Rules are brought into use while running with a train.*

Rules 126 (iv), 126 (v), 127 (v), 127 (xvi), 132.

9. *What Rule would a fireman apply in case a vehicle caught fire on the train?*

Rule 188.

10. *If firing on a passenger train, explain what Rule you follow when leaving a station.*

Rules 126 (viii) and 143.

11. *What steps would you take in case your mate met with a serious accident?*

Bring the train to a stand at the first signal-box or station in order to obtain assistance.

12. *What methods of firing would you adopt to avoid making thick smoke?*

By firing often and in small quantities, and by closing the dampers, putting on the blower, and opening the firehole door immediately the regulator is closed.

13. *What would you expect to find if an insufficient amount of air was admitted to the firebox?*

Thick smoke issuing from the chimney.

14. *What are some of the results of admitting too much air?*

The hot gases are swept through the tubes before giving up their heat, and coal is wasted in heating up the surplus air.

15. *How would you find out that only just sufficient air was being used for complete combustion?*

By the appearance of smoke if the firehole door is closed a little.

16. *What would you assume if a larger amount of sparks than usual were being sent through the chimney?*

That the fire had got thin in places and cold air was being drawn at a great speed through the firebars.

17. *What methods would you adopt in order to restart a combination type of injector which had failed in its action?*

First shut injector steam cock, close feed on tender, and open drain cock to allow the water to be thoroughly drained. After draining the pipes, close drain cock and again open the tender feed.

18. *In case your engine was fitted with the old type of injector and clack box on side of boiler, what would denote that the clack valve was sticking or being held from its seat?*

A rush of steam or hot water through the overflow and back through the feed pipe to the tender.

19. *When this occurred, how would you proceed, in order to return the valve to its seat, before attempting to restart the injector?*

First close water plug and drain-pipe valve to avoid the back rush from the boiler, and then open steam supply cock to the injector. In this manner the pressure on both sides of the clack valve would be equalised, and any foreign substance between valve and seat would thus be released by the jolting or the sudden stoppage of the engine.

20. *How could you ascertain that the clack valve had been returned to its seat?*

By first closing the injector steam supply cock, and then opening the steam or water valves in order to see if the back rush from the boiler had ceased, in which case the clack would have been returned to its seat and would again be in working order.

21. *What would you do when running into a station or terminus?*

Use the handbrake and carry out as far as practicable Rules 127 (xiv), 127 (xix), and 128.

22. *Give the number and colours of the different wrong line order cards.*

Four cards as follows: Form A (Pink) issued by guard; form B (Green) issued by driver; form C (White) issued by guard, and form D (Yellow) issued by signalman and retained by driver after use.

23. *What Rule applies should an accident occur to a train and the opposite line is fouled?*

Rule 180.

24. *Should you break loose with your train, and had to set back on the facing line, what would be your duty and what Rule would you apply?*

Rule 183 (i).

25. *Should an accident occur to your train, and you were sent to the nearest signal box for an assistant engine or breakdown van, explain what would be your duty and give the Rule.*

Carry out Rule 183 (*f*).

26. *If it be necessary for a train, or portion of a train, to return on the wrong line to the signal box in the rear, how would you act?*

Obtain permission in writing from the signalman, as per Rules 184 and 185.

27. *Can you make a large end trimming, mop, and string a cork?*

Trimmings to be made in presence of examiner.

28. *What are the more important duties in putting an engine away?*

See that there is a proper supply of coal, water, and sand. Go with engine over the ashpit and fill up the boiler, before dropping the fire, to reduce excessive cooling stresses. Clean out the smokebox, with firehole door and dampers closed, using jet as little as possible, then drop the fire and clean out the ashpan. After arrival in shed, open the cylinder drain cocks; put the reversing lever in mid-gear; lock up tools, etc., and see that the handbrake is hard on.

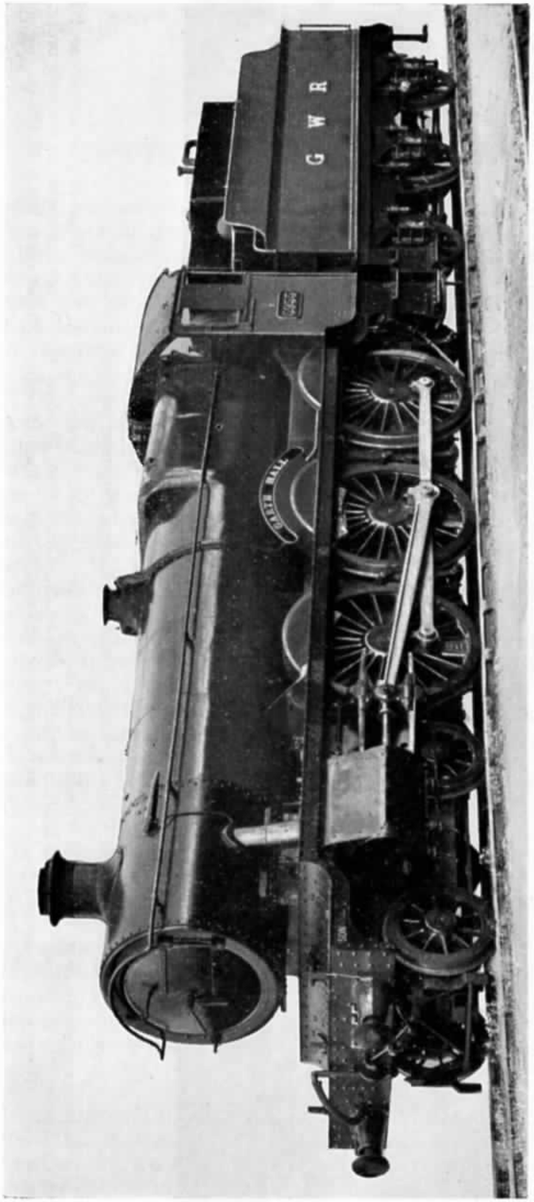


Fig. 27.—4-6-0 Locomotive No. 5955, "Garth Hall," G.W.R., Converted to Oil Burning. The Tanks for the Liquid Fuel can be seen on the Tender.

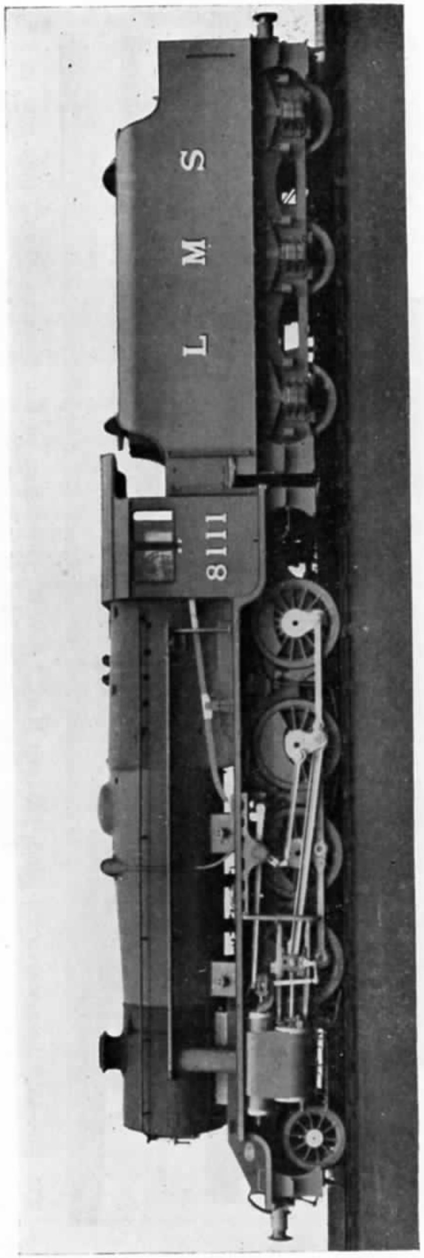


Fig. 28.—2-8-0 Type Freight Engine, L.M.S.R.

Sir William Stanier, Chief Mechanical Engineer (*retired*).

Cylinders, 18½ in. by 28 in. Coupled wheels, 4 ft. 8½ in. diameter. Coupled wheelbase, 17 ft. 3 in. Total engine wheelbase, 26 ft. Boiler pressure, 225 lb. per sq. in. Total heating surface, 1,865 sq. ft. Grate area, 28·65 sq. ft. Weight of engine in working order, 70 tons 10 cwt. Weight of engine and tender in working order, 125 tons 3 cwt. Tractive effort (85 per cent. b.p.), 32,438 lb.

Chapter 5

WATER, HEAT, AND STEAM

Hitherto the consumption of coal for steam-raising purposes and the principal details of the transference of the heat to the water have been chiefly described. Seeing that water is a vital necessity for the running of an engine, a few brief and elementary details of the properties of water, heat, and steam will not be out of place here.

Pure water is a chemical combination of hydrogen and oxygen. Steam is the vapour of water generated by the application of heat. The process of this production of aqueous vapour at the surface of the water is termed evaporation or vaporisation, the constituents of the water and vapour remaining the same, namely, 2 parts hydrogen to 1 part oxygen by volume.

Absolutely pure water can seldom be obtained for locomotive purposes, as there is always an admixture of impurities, varying in quantity and character with the locality from which it is procured.

The position of supply stations being determined by traffic requirements, railway companies, in many instances, are forced to use water of a very inferior quality for boiler-feed purposes.

A little knowledge of the supply districts will be useful to the driver, as it will enable him to a certain extent to know when and how to regulate his water level, so as to guard against priming and other boiler troubles.

It is sufficient for our purpose to say that water for all practical purposes is not compressible, although it readily expands when heated, and the density naturally decreases as expansion takes place.

It is this decrease of density, together with the rising steam bubbles, which sets up circulation in the boiler, the fluid next the firebox and tubes becomes heated and rises by its own buoyancy, while the colder portions fall by gravity to be warmed in turn, thereby setting up currents which in a well-designed boiler will keep all portions at a nearly uniform temperature. The efficiency and durability of a boiler depends very much on a proper and complete circulation.

When water is boiled in an open vessel at the sea level, the temperature of the water and of the steam rising from it remains at or near 212° F. If the same water could be taken to a great height, the upper air being rarefied and its pressure consequently less, ebullition or boiling would begin before 212° F. was reached, the decrease in weight of the atmosphere allowing the steam particles to escape earlier from the surface of the water. If the same experiment were tried far below the sea level, the pressure of air would be enhanced, and ebullition retarded, thus raising the boiling point above 212° F.

Similar action takes place in the boiler, the boiling point rising with the pressure, owing to the increased resistance offered to the release of the steam particles on the water surface. This increase of boiling temperature has been found to be approximately as follows :—

Pressure in barometer inches, 29·9.	Boiling point, 212° F.
„ „ „ 31·1.	„ „ 214° F.
„ „ „ 32·3.	„ „ 216° F.

An explanation of what 212° F. (Fahrenheit) means will not be out of place here. The thermometer invented by the scientist, Fahrenheit, and named after him, is the one mostly used in the British Isles, and consists of a glass tube with a small bore hole, one end of which is connected to a bulb containing mercury or spirits, the other end being closed. The expansion or contraction of the liquid by the variations of temperature is made the means of measuring by a scale the amount of heat or cold surrounding the thermometer.

When this thermometer was invented the greatest degree of cold supposed to be obtainable was marked 0° F. or " zero." Water was found to freeze at 32° F., and this was therefore termed " freezing point."

When ebullition commenced and steam was given off the mercury rose to 212°, and this was termed " boiling point."

The French use the Centigrade and the Russians the Réaumur. The principle is the same in all, and the only difference is in the marking of the scale of degrees.

All scientific work is conducted with a Centigrade thermometer. In it " zero " marks the freezing point and temperatures are measured by degrees above or below zero, the latter indicated by a minus (—) sign.

When steam is given off from water in an open vessel at 212° F. it has just sufficient elasticity to balance the pressure of the atmosphere, which at the sea level is 14·7 lb., or nearly 15 lb. to the square inch. Steam possesses remarkable expansive and compressible qualities. It is invisible and transparent until brought into contact with the colder air, by which it is partially condensed into moist particles. One cubic inch of water will produce 1 cub. ft. or 1,728 cub. in. of steam at atmospheric pressure.

This large volume decreases as the pressure increases, the steam becoming compressed, its density being made greater, and thus storing up its energy to be used as required. The relative decrease of volume with augmentation of pressure and density is known to be as follows :—

Pressure in Lb.	Temperature, ° F.	Density in Lb. of Cub. Ft.	Volume of 1 Lb. in Cub. Ft.
20	227	0·05	19·9
40	267	0·09	10·3
80	311	0·18	5·4
160	363	0·35	2·8

From the foregoing it will be seen that when steam is generated in a boiler and not allowed to escape during the addition of further heat, the density, and therefore the elasticity of it, is increased, the temperature and density always corresponding with the pressure shown by the gauge, as long as the steam remains in contact with the boiling water.

After the boiling point has been reached, and the temperature begins to further increase, less coal is required for a given amount of steam than at the lower temperatures. This is accounted for by the water lying almost dead during the heating-up process. Immediately steam begins to form, the bubbles rise from the heating surfaces to the top of the water and quicker circulation follows, the interchange of hot and cold particles becoming more rapid.

It is during this process of evaporation that the impurities in the feed water, if of sufficient density, are deposited on the boiler surfaces.

If, on the other hand, the impurities be of a buoyant nature, they are carried to the surface, and, if present in any appreciable quantity, foaming or priming begins to take place.

Water used for locomotive purposes may be classed as follows :—

1. Surface drainage, *i.e.*, from reservoirs.
2. River or flowing water.
3. Well water.

The first is really impounded rainwater, and is the best for boilers. Its impurities have been absorbed according as the district has been one of limestone or chalk, etc., and settle in the form of scale, which can be removed by an efficient method of washing out and by periodical " scaling."

It is of the utmost importance that this scaling should be done very thoroughly, otherwise the water is prevented from getting into close contact with the heating surfaces of the tubes and plates, and, the heat being confined locally by the scale, burning of the plate or tube is likely to result.

If this deposit be allowed to remain, the effective work of the boiler is greatly impaired, the loss due to a scale $\frac{1}{8}$ in. thick being computed to be as much as 25 per cent.

The firebox, when clean, is an excellent medium for transmission of heat, the approximate relative conductivity of copper being 100, brass 30, iron 16, and water 0·2. As already mentioned, it is a fact that copper when coated is little, if any, better than other metals, the great loss due to thick scale is therefore self-evident from the above figures.

River water is not as suitable as surface-drained water. The characteristics of the impurities will be influenced by the gathering grounds, and the districts through which the river flows. Manufactories, whether they be chemical or iron works, contribute their quota of matter detrimental to the water if employed for boiler-feed purposes. Most rivers also contain a large amount of suspended matter, which may be of an acidulous character, or organic substances, sewage, etc.

Acids attack the plates and heating surfaces, setting up pitting and corrosion, which, when once started, is difficult to arrest. Organic matter, sewage, etc., are the most frequent causes of priming, the worst feature of which is that it is both dangerous and wasteful, water upon which a certain amount of coal has been expended in heating being wasted.

Little need be said about water from wells. Because of their varied environments and totally different localities, no classification of wells can be made that would bear on the present subject; wells usually contain more foreign matter than either of the other sources of locomotive water supply.

The question of impurities in feed water is of the greatest importance to steam users, and many devices and patents have been put on the market for the purification of water by filtration, sedimentation, distillation, and the addition of chemical reagents.

A few of the more common impurities, the trouble they cause, and the remedies usually adopted are given below :—

Impurity	*Trouble*	*Remedy*
Sediment, mud, and clay.	Incrustation.	Filtration and blowing off.
Magnesia and iron.	Incrustation.	Caustic soda.
Acid in mine waters.	Corrosion.	Alkali.
Organic matter, sewage, etc.	Priming.	Precipitate with alum and filter.
Carbonate of soda in large quantities.	Priming.	Add barium chloride.

The treatment of boiler-feed water, either by the use of chemical reagents added to the water already in the boiler, or externally in water-softening plants prior to its being supplied to the tender or tank, has during the past several years been a growing practice rendered necessary in the interests of boiler performance and maintenance. On British railways the external method is generally preferred.

A plant of the lime-soda type was supplied by the Permutit Co. Ltd. and installed at Spitalfields in the vicinity of Liverpool Street Station, London (L.N.E.R.). The plant is of the cylindrical type, built for a continuous hourly capacity of 40,000 gal. The raw water is drawn from the Metropolitan Water Board's mains, and the initial hardness of 16° to 18° (Clark) can readily be reduced to 3° or less by the softening process. The settling tank is of riveted mild steel construction, with dimensions of 36 ft. diameter by 46 ft. 9 in. high, allowing a total settling time of four hours; the tank is erected on a reinforced concrete structure so that the tank base coincides with rail level, and the Permutit P.M. type ground-operated lime and soda measuring apparatus is housed in an arch below the track. This is arranged to give a proportionate dosing of lime and soda at all rates of flow by the use of a special contracting water meter fitted in the pipeline, which carries the hard water to the inlet point on the settling tank.

The lime and soda emulsion is stored in a cylindrical mild-steel tank measuring 9 ft. diameter by 5 ft. 6 in. deep, and the emulsion is kept permanently in an evenly mixed condition by means of a motor-driven agitator. At the base of the tank there is a valve box housing the positive type discharge valve, which is actuated by a powerful solenoid attached to a bracket at the top of the tank. The solenoid is wired up with the electrical contacting meter on the crude water inlet pipe, and the arrangement of the meter is such that the contacts close after the passage of a unit number of gallons. At each contact the solenoid is energised, thereby opening the valve, and the discharge of lime and soda takes place into a dilution tank fitted below. The measured lime and soda emulsion is diluted in this tank by soft water, and the diluted mixture is pumped continuously to the raw water inlet point on top of the softener by means of a specially constructed reciprocating pump mounted on the side of the lime and soda tank.

The arrangement of this measuring gear is such that dosage is always proportionate, since if the flow of water to the plant diminishes, a reduction occurs in the number of meter contacts, and consequently the number of valve discharges is correspondingly reduced. Conversely, if an increase in flow occurs the valve is opened more frequently to cope with the increase. Alongside the lime and soda storage tank there is mounted a lime-slaking tank measuring 9 ft. diameter by 3 ft. 9 in. deep, and an auxiliary measuring equipment is also provided for the addition of a coagulant, sodium aluminate. The hard water and the measured chemicals enter the settling tank by way of the downtake pipe, which reaches from the top of the settling tank to a point within the sludge collecting cone at the base of the tank, and agitating gear is fitted to ensure even mixing and to accelerate "floc" formation. On reaching the base of the downtake, the water begins to rise slowly in the tank towards a wood-wool filter. The filter effects final clarification, and the accumulated sludge in the sedimentation tank is discharged from the cone bottom at the required periods.

Beneath the base of the settling tank there is provided a reinforced concrete sludge pit into which the sludge is discharged and settled, and a floating arm is arranged for the draw-off of the resulting clear water. The thickened sludge is pumped through a filter-press which normally is installed within a separate housing arranged alongside the settling tank. The use of the filter-press considerably simplifies the disposal of the sludge, since by its use the liquid sludge is converted into sludge cakes which can be handled and transported readily.

The water-softening plant shown in the diagrammatic illustration (Fig. 29) is installed at Eccles (L.M.S.R.) to soften water of the following composition :—

	Grains per Gallon
Calcium carbonate	12·8
Magnesium carbonate	0·97
,, sulphate	5·99
,, chloride	1·12
Sodium chloride	1·25
Silica	1·15
Oxide of iron and alumina	0·31

This water is not only very hard and scale forming, but is at the same time corrosive.

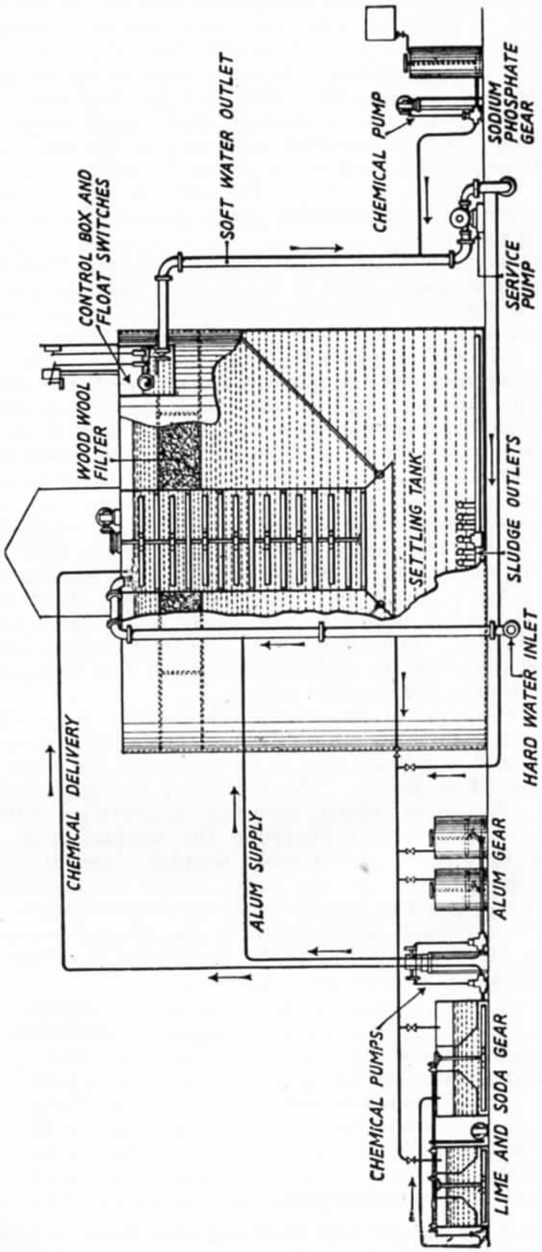


Fig. 29.—Kennicott Water-Softening Plant at Eccles, L.M.S.R.

The plant, installed by John Thompson (Kennicott Water Softeners) Ltd., has a capacity of 30,000 gal. per hr. and consists of a reaction tank, 30 ft. high by 36 ft. diameter, fitted with a mixing chamber allowing a full fifteen minutes' contact time, an agitator extending the whole length of this mixing chamber. Suitable sludge gear is provided at the bottom of the reaction chamber, and a wood-wool filter is fitted at the top of the reaction tank. The chemical proportioning gear is provided at ground level for adding lime, soda, and sulphate of alumina or sodium aluminate. Chemical pumps with adjustable strokes are used for pumping the chemicals to the top of the reaction tank where the water enters.

Immediately the chemicals come into contact with the water the whole is subjected to a thorough mechanical agitation, thus ensuring complete intimate admixture of chemicals and water and the formation of a suitable floc in order to ensure rapid settlement of the precipitated hardening salts. The size of the reaction tank is such as to allow a full six-hour reaction period. From the filter the water flows into a control box where the outlet is controlled so as to ensure that air does not enter into the outlet pipe, which is connected to a pump for delivering to the various storage tanks. In order to finally condition the water a special sodium phosphate gear is provided for dosing the water with this chemical on the suction side of the service pump. The proportioning gear is suitably housed in a brick building, and storage space is provided for the storage of chemicals.

On account of the necessarily restricted water space compared with that of a stationary boiler a locomotive boiler requires the most careful handling and alertness on the part of a driver or fireman, the water evaporated on a run of any considerable length being many times the volumetric capacity of the boiler. This rapid change of water into steam and the various sources from which the water is obtained make the question of incrustation, corrosion, and foaming, or priming, a very complex one in locomotive practice.

The use of softened water, for instance, in boilers of high steaming capacity, in conjunction with a comparatively restricted water space, necessitates frequent blowing down, otherwise the rapid concentration of the alkali which occurs during evaporation would result in dangerous and wasteful priming. An illustration and description of an efficient form of boiler blowdown valve appears on p. 89 (Fig. 43), Chapter 6.

The usual method of delivering the feed water in a locomotive boiler is by means of internal pipes connected to the injectors at the back plate, these few connections terminating about the middle or in the front portion of the boiler, in order that the comparatively cold entering feed may be directed into the lower front end, with a view to discharging the water at the coolest portion of the boiler. The delivery of the water into this particular portion of the boiler is, however, known to bring about local or unequal expansion and contraction, with the result that there is a liability to grooving at the junction of the front tubeplate and the barrel, in addition to the breakage of stays in the locality of the throat plate.

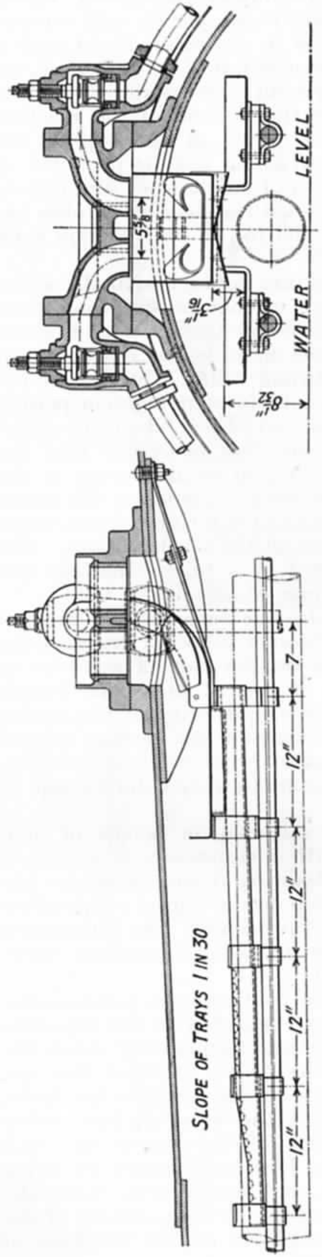


FIG. 30.—BOILER TOP-FEED ARRANGEMENT, G.W.R.

THE CHURCHWARD "TOP-FEED"

The illustration (Fig. 30) shows the "Top-Feed" arrangement designed by the late G. J. Churchward, when Chief Mechanical Engineer of the Great Western Railway.

With this apparatus in use, the water is delivered through feed pipes which are carried round and up outside the boiler barrel, as shown. These pipes are connected to clack boxes fitted with valves, through which the feed water is discharged into a shoot and thence into trays, which are supported by clips fixed to the longitudinal stays. The trays are notched at the sides, and the water is thus finally delivered in the form of a number of very fine streams which drop through the steam space to the water below. In this manner the temperature of the whole of the water in the boiler is equalised and the entering feed is heated thoroughly before it is brought into contact with the metallic surfaces forming the boiler.

The heating of the water in the trays, of course, brings about the deposition of much of the scale-forming impurities, but since the trays can be removed readily, it will be obvious that these can much more easily be maintained clean and free from furry or scaly deposits than is the case with the usual form of internal feed delivery pipe. The retention of these deposits by the trays must also necessarily result in a reduction of the total amount of scaly or sedimentary impurity in

contact with the heating surfaces, thereby maintaining the boiler at its maximum evaporative capacity for a correspondingly longer period.

The "Top-Feed" apparatus has been proved, by lengthy and carefully conducted trials, not only to reduce considerably the wear and tear of the boiler, but also to be economical from the coal consumption point of view.

The method of transmission or conduction of the heat from the firebox to the water in the boiler is of great importance, and it is with this end in view, with due regard to safety, that the whole science of boilermaking has been brought to bear not only on the materials used, but also on directing the path of the hot gases from the fire, so that as much heat as possible may be transferred through the heating surfaces to the water.

Many devices have been tried for the complete abstraction of this heat, such as corrugated tubes, and tubes ribbed on their inner surface to split up the gases. On account, however, of cleaning and other troubles, these have not as yet met with universal favour.

It was this demand for a large amount of heating surface, combined with compactness, that influenced the earlier designers in producing a locomotive boiler practically as we see it today. The hot gases from the fire are split up and passed through a number of tubes, which run the full length of the boiler from the firebox to the smokebox. The tubes are completely surrounded by water, their function being to use as much as possible of the heat generated by the fuel in the firebox, abstracting it from the gases, so that there may be as little waste as possible. In this connection the reader may be advised to study with care the details of construction referred to and in some cases illustrated in Chapter 6, "The Locomotive Boiler."

Thus it will be seen that our previous remarks on the development of a large initial heat in the firebox have a direct bearing on the efficient use of the great amount of heating surface, especially when the admittance of air has to be regulated judiciously, so that the gases may leave the tubes at a comparatively low temperature.

It is well known that a specific amount of energy can be evolved for every pound of coal consumed, and this can be measured and its mechanical equivalent ascertained.

By way of illustration take the British Thermal Unit. One unit is the heat required to raise the temperature of 1 lb. of water 1° F. when the said water is at its greatest density, namely, 39·1° F. The energy contained in one unit of heat has been found to have its mechanical equivalent, known as Joule's, and is expressed as 778 ft.-lb.; a foot-pound is the amount of work done in raising 1 lb. through a distance of 1 ft.

These very elementary details of the known mechanical properties of heat are given to remind the rising fireman that a known power for every pound of coal consumed may be evolved, and that only by the proper application of an efficient method of working can the best results be obtained.

These methods should include making full use of a knowledge of what is taking place in the firebox, combined with an appreciation of the expansive possibilities of steam, remembering that it is its pressure-resisting and elastic quality that makes it so adaptable for the conversion of heat transmitted by the fire into mechanical energy.

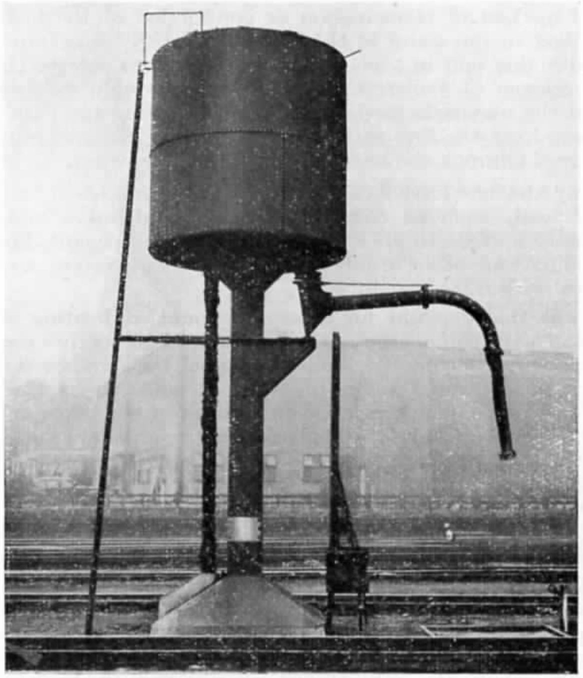


Fig. 31.—A Type of Water Column Installed on the Southern Railway.

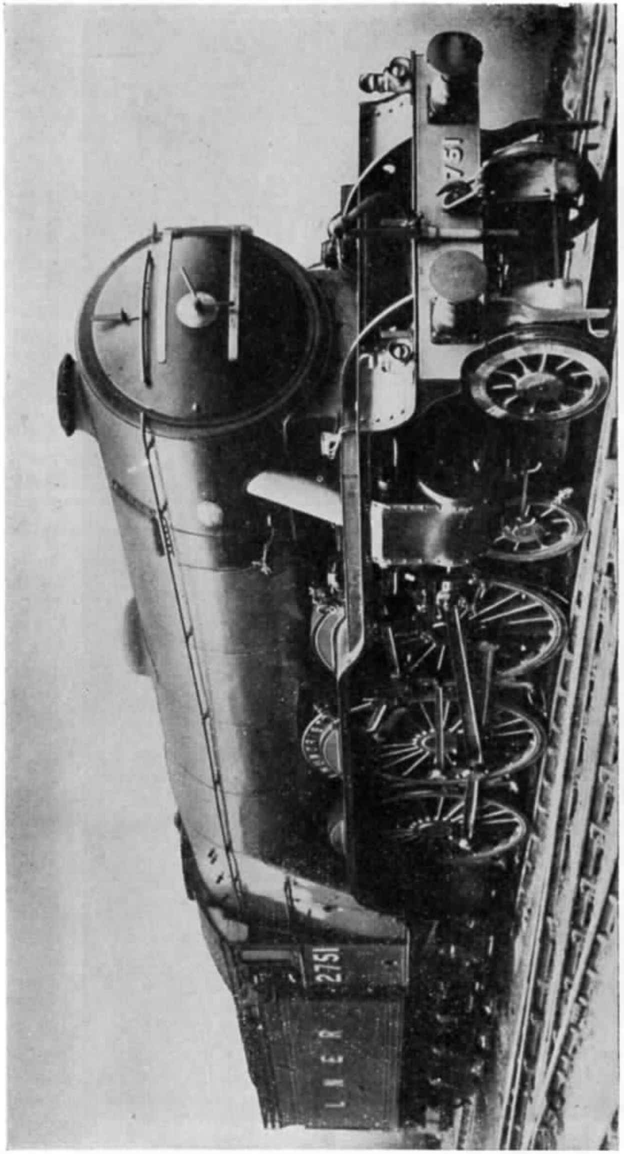


Fig. 32.—4-6-2 Type Express Locomotive, L.N.E.R.
The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 19 in. by 26 in. Coupled wheels, 6 ft. 8 in. diameter. Coupled wheelbase, 14 ft. 6 in. Total engine wheelbase, 35 ft. 9 in. Boiler pressure, 220 lb. per sq. in. Total heating surface, 3,397·84 sq. ft. Grate area, 41·25 sq. ft. Weight of engine in working order, 96 tons 5 cwt. Weight of engine and tender in working order, 152 tons 11 cwt. Tractive effort (at 85 per cent. b.p.), 32,909 lb.

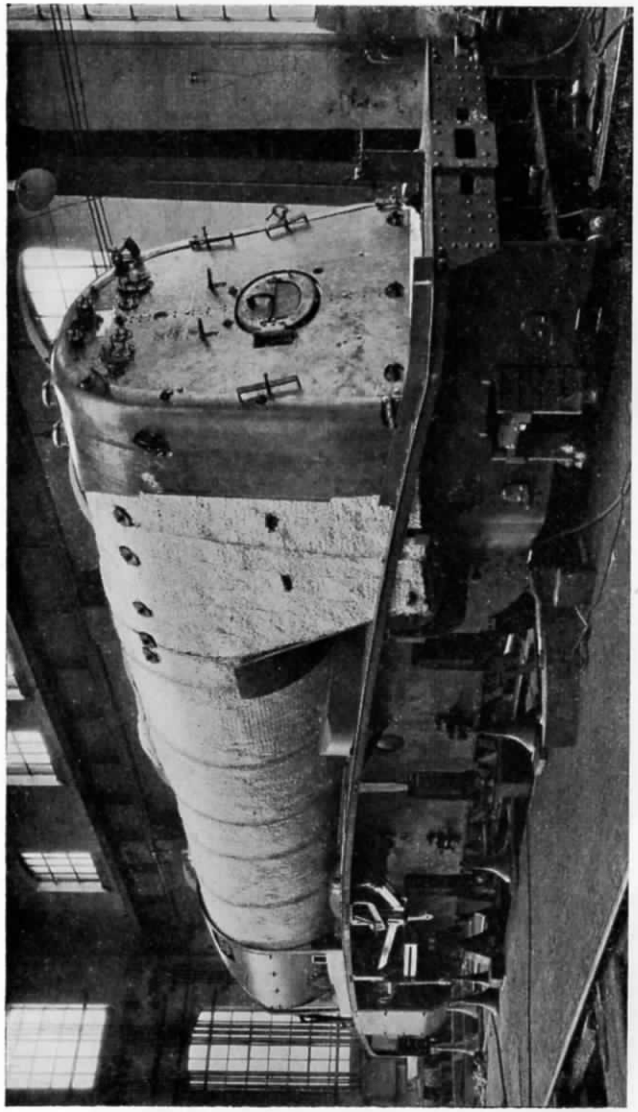


Fig. 33.—Locomotive Boiler Lagged with "Alfol" Insulating Material.

Chapter 6

THE LOCOMOTIVE BOILER

The requirements of a modern locomotive boiler are exacting, as the boiler has to withstand high steam pressures with a large margin of safety, combined with efficiency and economy of space. The restricted space at the disposal of the designers, and the large area of heating surface required, together with the production of a sufficiently strong draught, have determined the form of the boiler, and, although the form is suitable for the purpose to which it is put, a locomotive boiler necessitates more careful handling than the majority of other types.

The efficiency of a boiler is measured by the amount of water that can be evaporated per lb. of coal, and this depends on the quantity of coal that can be consumed efficiently on the firegrate. For the economical production of steam, therefore, a boiler must be well designed for its work and must be handled with intelligence.

Because of the considerable increase of working pressures, improvements are being made constantly in the methods of boiler construction. Rivet holes, which were formerly punched, are now drilled, and in most cases specially designed machines are used, so that the boiler shells, etc., can be drilled after being rolled or pressed into shape. By these means the holes in the plates are made to correspond with each other very exactly and the rivets a much better fit than they were by the old methods. The liability to damage the texture of the boiler plates was formerly much greater than it is now. A drilled plate is 10 per cent. stronger than a punched plate.

The old-fashioned riveting and caulking by hand is superseded by the employment of hydraulic and pneumatic tools. The hydraulic riveter will give a pressure of about 100 tons per sq. in. on the rivet head. This great force ensures the complete filling up of the hole and bringing the plates close together in a manner that was almost impossible with the hand hammer. Many other new methods have been introduced which, combined with improvements in the materials used, allow of much higher steam pressures than were dreamed of formerly, and have increased the efficiency of locomotives.

In modern practice welding is resorted to in boiler construction to an increasing extent, taking the place of riveting and having the advantage of dispensing with drilling holes and keeping rivets tight, and also effecting a saving in weight. This practice is extended to other structural parts of locomotive construction, and there are cases in which the cylinders, instead of being cast, are fabricated, that is, built up of welded metal instead of taking the form of castings.

For our purpose we may say that the locomotive boiler can be divided into five parts, as follow :—

1. The barrel containing the tubes and superheater flue tubes, which are held in position by the tubeplate at the firebox end, and by the corresponding tubeplate at the smokebox end of the boiler. The smoke tubes, usually about 2 in. diameter, conduct the products of combustion from the firebox to the smokebox, thus exposing a large amount of heating surface to the surrounding water for evaporating purposes.
2. The firebox outer shell forming the outer casing for the water space surrounding the inner firebox.
3. The inner firebox containing the firegrate, brick arch, etc., and providing room for burning the fuel.
4. Smokebox containing blast-pipe, main steam pipes, etc., and supporting the chimney.
5. Chimney for conveying the smoke, etc., above the train level, and for producing, in conjunction with the blast, a strong draught for the proper combustion of the fuel.

The joining together of these parts and the choice of materials call for the highest engineering skill.

The boiler-shell or barrel is made up from flat mild steel plates about ½ to ¾ in. thick and about 3 to 6 ft. wide. These flat plates are rolled into circular rings of the required diameter, and jointed by longitudinal seams, which are usually " butted " and riveted together by means of covering plates, inside and out, secured by double rows of rivets. Three or four of these rings are then joined together to form the barrel. The ring joints are generally of the " lapped " type with about 4½ in. of lap. This transverse joint is secured by double rows of rivets.

On certain railways, notably the G.W.R. and L.M.S.R. in this country, the boiler barrel of the locomotive is of tapered formation instead of in parallel rings or sections. It is claimed that adopting this method the greatest cross-sectional area is obtained next the firebox where the heat value is at its greatest, while there is the added advantage of increasing the space in the upper part of the barrel available for the collection of steam. The underside of the barrel is usually kept horizontal, and the forward part of the boiler is lighter. The distance from the rail to the top of the smokebox is reduced, giving an opportunity of increasing the length of the chimney.

The wrapper or outer firebox plate is shaped to various designs, and is made from one plate forming the top and sides and secured to a foundation ring by hot rivets made from the best iron or mild steel, about ⅞ in. diameter, and pressed up securely by hydraulic pressure.

The firebox front or doorplate is fitted into the firebox outer shell and forms the end of the boiler. This plate, made from mild steel about ½ to ¾ in. thick, is deeply flanged, and is pressed into shape by hydraulic pressure, with the flanges turned at a large radius to give strength and elasticity. The outer firebox shell is riveted to this flanged plate on the two sides and top, the bottom being secured to the foundation ring.

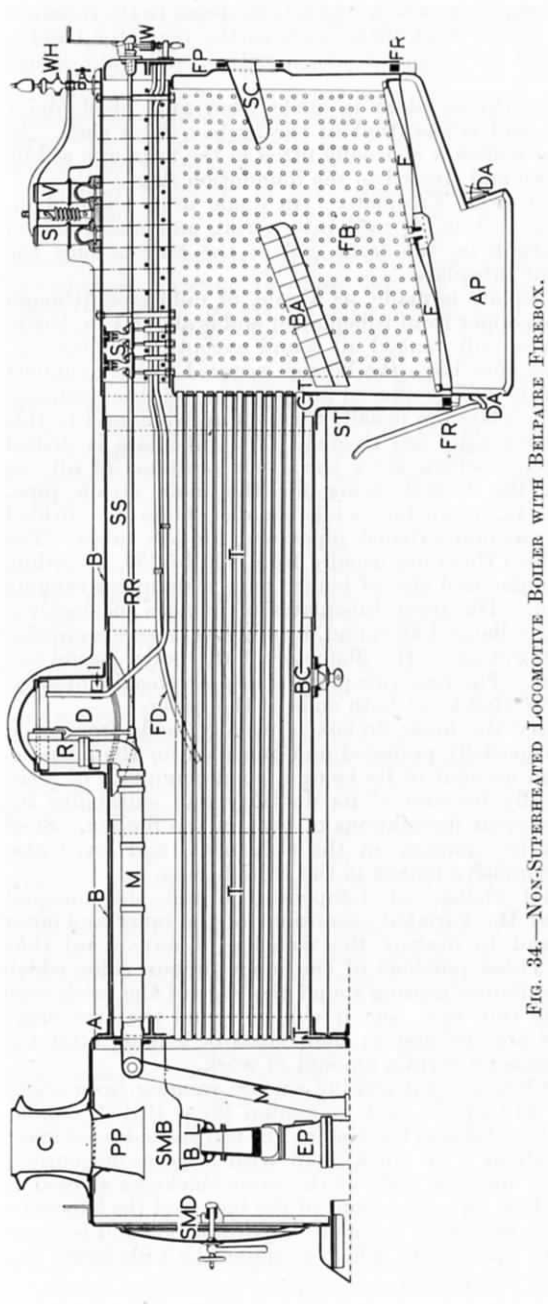


FIG. 34.—NON-SUPERHEATED LOCOMOTIVE BOILER WITH BELPAIRE FIREBOX.

B, barrel; FR, foundation ring; FP, front plate; ST, saddle or throat plate; A, angle iron for front tubeplate; IT, steel tubeplate; FB, firebox; S, stays; D, dome; R, regulator; I, method of fixing steam supply pipes for injectors, steam sanding, jet, vacuum ejector and steam brake; SV, safety valves; WH, whistle; SMB, smokebox; M, main steam pipes; EP, exhaust or blast-pipe; PP, petticoat pipe or cowl; BA, brick arch; F, firebars; AP, ashpan; DA, dampers; FD, feed delivery pipe; RR, regulator rod; C, chimney; SMD, smokebox door; BL, blower or jet; SC, scoop or deflector; W, water gauge; T, tubes; CT, copper tube plate; SS, steam space; BC, blow-off cock.

(For illustrations of boiler fitted with superheating apparatus see pp. 256 and 259).

The various mountings which control the steam to the different parts are fitted to the front plate, such as the regulator handle, steam sanding and jet arrangements, injectors, and water-gauge fittings, etc.

The saddle or throat plate is made from mild steel about $\frac{1}{2}$ to $\frac{3}{4}$ in. thick, and is the front of the firebox outer shell. In the older types of boilers it is usually fitted in the form of a saddle to the boiler barrel and riveted to the foundation ring.

Angle iron for front tubeplate. An angle iron, about 6 in. by 6 in. by 1 in. section, formed into a ring and machined on its faces and shrunk on the front end of the barrel, joins the barrel to the front tubeplate.

The front tubeplate is made, as a rule, of mild steel (though some boilers have copper front tubeplates) and is about 1 in. thick. It is in many cases still flanged all round except at the bottom. Inside cylinder engines have the bottom secured to the cylinders when the boiler is finally placed in position on the framing. The flanges on the plate are usually about 3 in. wide, and to this plate the smokebox sides are riveted. The tubeplate is drilled through a template, which gives the exact positions of all the necessary holes, the largest being for the main steam pipe, usually about 5 in. diameter, while smaller holes are drilled for the jet and vacuum exhaust pipes and for the tubes. The tube holes, of which there are usually from 100 to 250, according to the class of engine and size of boiler, have a diameter ranging from $1\frac{5}{8}$ to $2\frac{1}{4}$ in. The front tubeplates of modern locomotives are very frequently flanged all round, forming as it were a circular dished plate conforming to the diameter of the boiler barrel and recessed within it. The rear tubeplate is also arranged similarly, and riveting is resorted to at both ends of the boiler.

In this country the inner firebox is usually made from good copper, which is specially prepared and annealed for the purpose. Copper is used on account of its being a good conductor of heat, but more especially because of its ductility and suitability for withstanding the great fluctuations of heat in the firebox. Steel fireboxes are fairly common on the Continent, and have also been fitted to locomotive boilers in the British Isles.

The continual change of temperatures and the unequal stresses set up by the variable expansions of the inner and outer firebox shells tend to destroy the tenacity of any metal that may be used. Those portions of the inner firebox sides which are licked by the flames passing round the edge of the brick arch generally become thin first, and it will be found that the stays near these parts are the first to show signs of leaking after the engine has performed a certain amount of work.

The inner firebox gives a heating surface ranging from about 100 (or less) to 240 sq. ft. as a maximum for a British engine, again according to the size of the boiler. The top and sides are made from one piece about $\frac{1}{2}$ in. thick, bent with large round corners to give strength; another plate of the same thickness shaped to suit the firebox door forms the front of the box, and the tubeplate the back. This tubeplate is the more important one and is about 1 in. thick in the upper part, which contains the tube holes, and $\frac{1}{2}$ in. thick at the lower part.

The width of the foundation ring defines the minimum water space, which is usually from $2\frac{1}{2}$ to $4\frac{1}{2}$ in. The ring, which is made of steel, extends round the bottom of the inner box and is secured between the inner and the outer shells by rivets passing through the two shells and the ring. A similar ring forms the firehole mouthpiece, or the plates are flanged to meet and riveted together.

The large amount of flat surface which the inner and outer firebox contain, and the varying stresses set up between them, make the staying of these parts an exceedingly important matter. The circular parts of the boiler can easily withstand the internal bursting pressure, but the flat surfaces would immediately bulge unless an effective method of staying were adopted. The inner box is usually tied to the outer shell by copper stays about $\frac{15}{16}$ in. diameter, screwed with ten or eleven threads per inch. These stays are pitched about 4 in. apart and are fitted through threaded holes in the inner and outer shells, after which they are riveted over on the inner and outer sides.

The crown of the box was formerly in general practice supported by girder stays, but nowadays direct stays passing through threaded holes in the crown and outer shell are mostly adopted. The top of the box is usually flat, and it is on this part that the most rapid evaporation takes place, 1 sq. ft. on the top of the box having been found to evaporate from six to ten times the amount of water that 1 sq. ft. of average tube surface will evaporate. It is essential, therefore, that the circulation over the crown should be as free as possible, so that the heated water and steam can be replaced by the colder portions of water rapidly. This is taken into consideration when adopting any method of staying the top of the box. When girder stays are used, they pass immediately over the top of the inner box, and are said by many to interfere somewhat with the circulation, obstructing the hot water or steam bubbles as they tend to rise to the water surface.

The girder stays also make the washing out or scaling of the top of the box more difficult, which is an important matter when it is considered that the heat-conducting properties of copper are little better than that of other metals if the copper is allowed to become coated or heavily scaled.

For these and various other reasons the "Belpaire" shape of firebox is now adopted extensively. In this type direct stays can be used, as the outer shell or wrapper plate is made flat on the top. The stay holes are threaded, and the stays screwed in from the top and through the inner box at the same time, after which a nut is screwed tight up to copper washers inside and out, thereby ensuring that the stays are steamtight. Flexible stays are sometimes used in what is known as the "breaking zone" at the forward extremity of the interior box where the effect of expansion and contraction is felt most severely (see Fig. 34, p. 75).

The tubeplates are generally stayed by longitudinal stay bolts or bracing stays, which pass from the firebox to the smokebox. These stays have little work to do, the tubes, when expanded in position, acting as stays themselves. Longitudinal stays, ordinarily five in number, also pass from the frontplate immediately over the top of the inner firebox to the smokebox tubeplate with a view to strengthening the flat surfaces of the frontplate.

The bottom of the inner firebox is formed by the firegrate, which is made with bars of a suitable shape to admit the air necessary for the burning coal. In most cases two bars are used to make up the full length of the firegrate, thereby obtaining a bar that is conveniently handled and costs less to renew.

These bars are placed side by side and lengthways with the firebox, the ends being supported by a frame or stretchers fixed across the bottom of the box. Rolled iron or steel bars are sometimes used, although they are mostly made in the form of a tapered iron casting, wider at the top edge than the bottom, and cast with facings to keep them a suitable distance apart, so that the air can pass freely between them to the fire. They incline towards the tubeplate, the motion of the engine thereby gradually working the fuel forward and assisting in a proper distribution of the fire over the grate area.

An arch made from firebrick or fireclay lumps is erected inside the firebox immediately underneath the bottom row of tubes. It is built in the form of an arch so as to be self-supporting, and is erected from side to side of the firebox, with the two ends resting on brackets or studs, so that the sides of the box act as abutments for its support.

Special firebricks and studs are usually inserted at intervals between the brick arch and tubeplate, so that there is a small space between the face of the tubeplate and the back of the arch. It has been found in practice that a boiler steams better with this space—so long as it is kept within certain limits. The space is also useful for keeping the top of the arch clear of debris or any dirt that may fall when raking down the tubes, etc.

The arch, which extends diagonally upwards towards the firehole door, acts as a baffle, and has a very important duty to perform, particularly with regard to the prevention of smoke and the proper combining of the volatile gases.

The grate area of a modern British locomotive boiler ranges between 26 and 50 sq. ft. Its further capacity is restricted by the rails or gauge, and it is only by the employment of an intensely strong draught that sufficient fuel can be burned to meet the heavy demand for steam. If unretarded, this strong draught would carry forward the products of the fire before their hea had been given up. These hot gases would escape by the lower rows of tubes and the cold air would be drawn from the firehole door over the top of the fire to the detriment of the tubeplate, tube ends, and steam pressure.

The scoop or deflector, which is fitted in the firehole door, is made to point downwards, so that the entering cold air is directed toward the hot gases and flame passing over the edge of the brick arch, the scoop and arch acting in conjunction for the proper mixing of the hot gases and the incoming air.

The ashpan is fixed below the firegrate in the form of a box or receptacle for retaining the ashes that fall from the fire. It is made from wrought iron or mild steel sheets about ¼ in.

thick, and completely encloses the underside of the firebars, so that the air admitted to the fire is under the control of the fireman, and can be regulated by means of the dampers, which are usually fitted before and behind the ashpan in the form of swinging doors, which can be moved by means of rods and levers held in position by catches on the footplate.

In the larger locomotive boilers it is not an uncommon practice nowadays to provide a combustion chamber in which the gases from the firebox can commingle before passing on through the tubes, thus bringing about more complete combustion of the fuel. This chamber is as a rule formed as an extension of the interior firebox, to the heating surface of which it adds a fairly considerable area.

Fig. 35 illustrates a modern example of firebox construction incorporating a combustion chamber. The chain dotted lines indicate where welding was resorted to. Fig. 36 shows the interior firebox of a 4-6-2 type express locomotive with riveted combustion chamber.

The amount of steam space above the working water level in a locomotive boiler is necessarily restricted, by reason of the demand for compactness to suit the road and bridge levels. The limitations of the steam space, together with the violence of ebullition due to rapid evaporation and the motion of the engine, make the question of priming and the collection of dry steam of the utmost importance. To overcome these difficulties a kind of collecting chamber or dome is fitted above the steam space. It is usually placed on the second ring from the firebox. When the engine is running forward or backward the water will rise somewhat at the boiler ends, and this is taken into account in determining the position of the dome on the barrel. Of late years boilers have been increased so largely in size and height that domes have become small in order to keep within the limits imposed by the loading gauge.

Although some engineers have designed locomotives without domes, many reasons can be urged to prove that the steam from a dome is much drier and the chances of priming considerably reduced. A ready means of access is also afforded for dealing with the pipes and connections which lead to the various fittings on the different parts of the boiler.

The principal connection coming from the dome is the main steam pipe, which passes through the boiler direct to the front tubeplate, to which is connected a cast-iron elbow in the case of engines fitted with inside cylinders, and a cast-iron tee-piece to those engines fitted with outside cylinders. In locomotives using saturated steam, copper pipes conduct the steam from these castings through the smokebox to the cylinders below.

A cast-iron connection to which the regulator is fixed reaches up into the dome. There are various forms of regulators, some of the sliding type, which move over port-holes in the casting, and others of the equilibrium or double-beat type of valve.

The illustration (Fig. 37) shows an efficient type of double-ported steam regulator. Steam is admitted to the main pipe through the ported slide, which is actuated at the elongated hole by the pin in the end of the forked connecting link. A slide

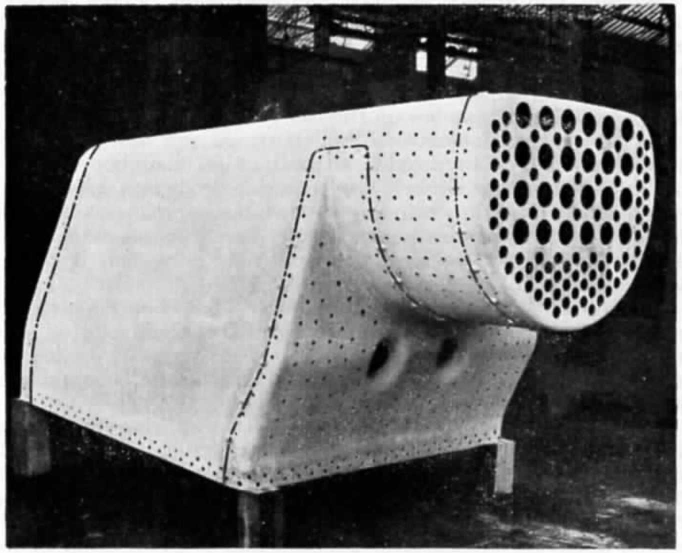


Fig. 35.—Welded Firebox with Combustion Chamber (Vulcan Foundry).

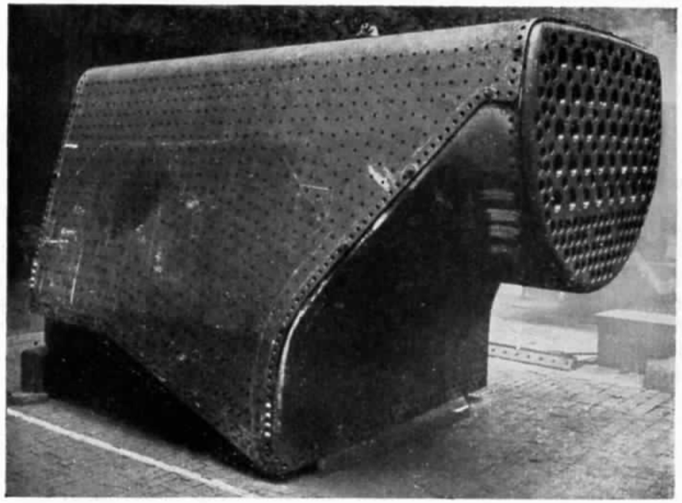


Fig. 36.—Combustion Chamber Firebox, 4-6-2 Type Engine, L.M.S.R.

containing smaller pilot port-holes is fitted on the back of the main slide, and is also actuated by the before-mentioned pin in the end of the connecting link. The latter slide is made a good fit on the pin, and is therefore the first to open the small ports to steam thus, by the gradual admission of steam, placing the main slide in equilibrium and avoiding a sudden rush of steam and the accompanying priming as far as possible. After the small pilot ports have been fully opened the pin will have travelled the full depth of the elongated hole in the main slide, and the larger ports then begin to open for the maximum admission of steam to the engine cylinders.

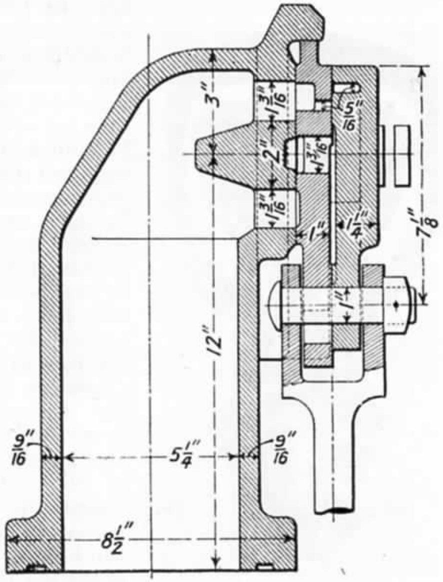


Fig. 37.—Double-Ported, Flat Type Regulator Valve.

The regulator is controlled by a long rod, about $1\frac{1}{4}$ in. diameter, reaching from the dome through the back or door plate, and maintained steamtight by a gland and stuffing-box fitted to the plate. The regulator lever is fitted to the projecting end of this rod, and is guided by a quadrant which is usually fixed in the centre of the boiler back for the convenience of the driver; this is essential as it is the means by which power is given to the engine.

In many cases the slide and ported type of steam regulator has been abandoned in favour of the double-beat or equilibrium type, so that the effort required for opening and closing may be reduced to a minimum.

The " Joco " combined regulator and drifting valve (Fig. 38), one of several types made by the firm of Wota Ltd., comprises a valve body and three circular, single-beat, mitred valves mounted concentrically on a spindle, and can be operated by the usual crank rod or lever in conjunction with a lifting fork and bridle. The valve body is of half-spherical formation and has a mitred seat at the top. Within the body is the largest of the three valves, with ribs at the top and an extension at the bottom fitting into a guide formed inside the body. The large valve contains a second valve, which is guided by ribs at the top and a piston-like portion at the bottom. Within this second valve is a third valve, also guided by ribs. Passing through the third valve is a spindle on which is also mounted a distance piece and nut secured by a split pin. The top of the spindle is connected to the bridle by means of a pin.

In operating the valve, the first movement of the regulator handle opens the small valve to steam, which enters the chamber formed between the underside of the piston portion of the second valve and the inside of the large valve, and then passes between ribs formed on the outside of the distance piece to the inside of the valve body, and thence to the valve chests and cylinders.

When the small valve is fully open the steam passing between the ribs on the outside of the distance piece is of the requisite amount for admission to the valve chests and cylinders when the engine is drifting, *i.e.*, coasting, and this is, therefore, the drifting position of the regulator valve. In this position the area of opening of the small valve is sufficient not only to pass the required amount of steam for drifting purposes but to ensure that the pressure in the chamber below the second valve is maintained at approximately the same pressure as in the boiler. The second valve is therefore balanced, and can be opened by a further movement of the regulator handle.

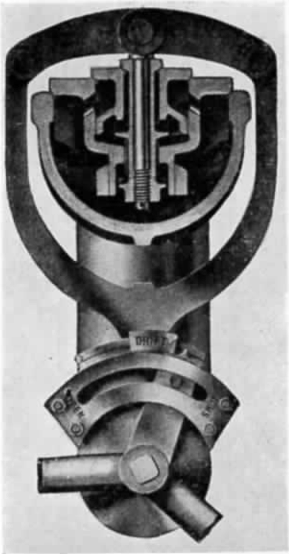


Fig. 38.—The "Joco" Combined Regulator and Drifting Valve.

Steam flowing under the mitre of the second valve passes through ports formed in the side walls of the largest valve to the underside of the valve body, and fills the steam pipe and valve chests, thus balancing the larger valve, which can now be opened. In the opening operation the distance piece lifts the second valve, and the nut performs the same duty for the large valve. The opening of each valve is therefore positive. In closing, the large valve shuts first, then the second valve, and finally the third valve is returned to its seat, all under the control of the regulator handle in the cab.

The drift position indicator is incorporated in the stuffing-box quadrant, and a friction pad, also on the stuffing-box quadrant, holds the valve in any set position. This combined regulator and drifting valve is absolutely steamtight. Being practically balanced, it is very easy to operate, and when closed the steam pressure seals the valve and prevents inadvertent opening.

Another type of regulator for locomotives, of which large numbers have been fitted, is the "Servo," illustrated in Fig. 39. This regulator consists of a single-seated main valve C formed with a cylindrical throttle extension D on its outlet side, and a piston on its steam side containing an auxiliary pilot or balancing valve K which terminates in a fine-pointed cone and is attached

to the valve spindle E. There is no direct connection between the valve spindle carrying the pilot valve and the main valve.

The piston, which is packed with an ordinary piston ring, works in a bored cylindrical extension of the valve casing and forms with it a balancing chamber A. This is in permanent communication with the boiler by means of the annular inlet P, and is thus kept under steam pressure which, so long as the pilot valve K remains closed, presses the main valve firmly against its seat S.

The regulator is opened by drawing the pilot valve K from its seat within the main valve and allowing the steam from the

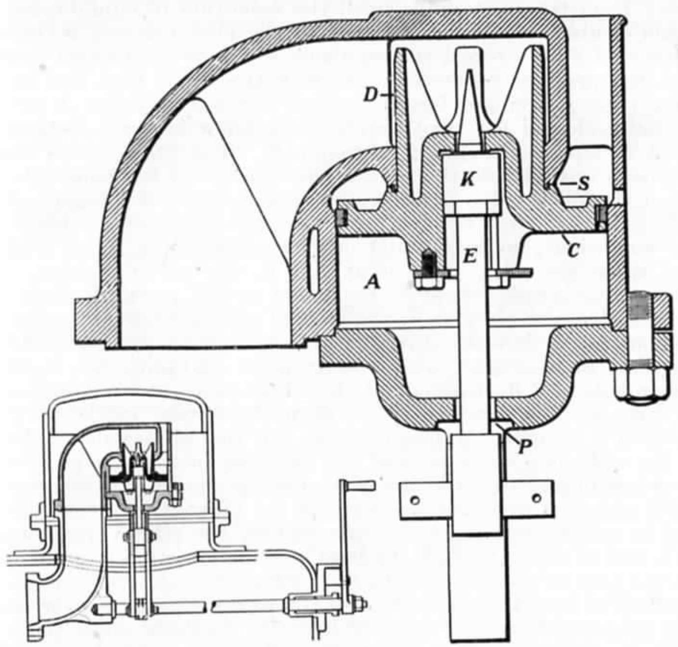


Fig. 39.—Details of the "Servo" Regulator Valve for Locomotives.

balancing chamber A to escape past its conical point until the rate of flow out of the chamber past the pilot valve K is in excess of the steam supply to it through the inlet P, and the pressure in A is thereby reduced. A point is thus reached at which the pressure in A is insufficient to keep the main valve closed against the steam pressure constantly exerted in an opposite direction on the annular surface of the other or valve side of the piston, and the piston is forced inwards into its cylinder (the balancing chamber A) and draws with it the main valve from its seat.

The main valve now takes up a certain definite position in relation to the pilot valve and so adjusts itself with regard to it that the outflow of steam from A past the pilot valve K exactly equals the supply admitted through the inlet P, which is in permanent communication with the boiler.

It will be seen that, when these conditions have been established, there is no tendency in A for the steam pressure to either increase or diminish, and that the piston is thus in a state of equilibrium. The main valve, in fact, may now be said to float upon the steam, and in this condition is highly sensitive to changes of pressure in the balancing chamber A ; if the pilot valve K is made to approach its seat, the outflow of steam past it is at once restricted, with the result that the pressure in A rises and instantly forces the main valve and piston outwards in the cylinder and away from the pilot valve until the condition of equilibrium is again established, and, conversely, if the pilot valve K is drawn back and thus opened wider, more steam is discharged from, and the pressure reduced in, A, with the result that the main valve and piston are forced further into the cylinder A until, partially closing the pilot valve, the outflow is again restricted until it equals the inflow through P. The main valve thus responds instantly to the slightest movement of the pilot valve ; when the pilot valve is advanced or withdrawn the main valve follows it as though the two were one, automatically establishing the condition that inflow and outflow of steam in A are equal, and when the pilot valve is at rest in any given position the main valve is rigidly held by the steam in that position. Indeed, so sensitive and absolute is the control afforded that it has been demonstrated that the driver is able to increase his steamchest pressure at will and with the greatest certainty by regular increments of 2 lb. throughout the whole range at his command.

The effort required to work even the largest valves on the " Servo " principle is insignificant, for the pilot valve, which is the only one to be moved by hand against steam pressure, does not in any case much exceed 1 in. in diameter ; the steam itself provides the necessary power to move the main valve, and is set in operation and controlled by the pilot valve acting as a sort of relay, so that the least possible exertion is necessary on the part of the driver. In fact, when the pilot valve is once opened, he has only the friction of the working parts to overcome and thus is able with a touch to keep his regulator under perfect control. It is important to note that the main valve does not in any position exert the slightest pull on the regulator handle, there being no mechanical connection between the two.

The regulator valve and operating mechanism (Fig. 40) is employed on the 4-6-2 (A4 class) and other locomotives of the L.N.E.R. The valve is of the cylindrical balanced type and is made in two parts with seatings at top and bottom. The illustration shows it closed. The open position is obtained when the bell crank, operated by the rod (indicated in the drawing by a horizontal dotted line) from the cab, is moved to the other centre seen in the drawing. The loose top seating avoids the necessity of providing a door in the body of the castings for assembling the valve. This is considered advantageous, as it obviates uneven distortion of the casting. The loose seating is secured in place by means of a number of set screws.

All the latest taper boiler locomotives on the L.M.S.R. are

fitted with a steam dome for housing the regulator valve, differing in this respect from the earlier engines of Stanier's design, which had no dome and carried the regulator valve in the smokebox, where it was enclosed in the superheater header. The drawing (Fig. 41) shows that as far as possible the design of the main valve and starting valve has remained unaltered, and that these still work laterally across the port faces. The chief difference lies in the form of the regulator head and connection to the main steam pipe, together with the operating levers.

The regulator head is built up in two parts, the top part 14 and the bottom casting 15. The bottom portion embodies the elbow and connection to the internal main steam pipe and the front bearing for the regulator rod 1 from the cab. This portion

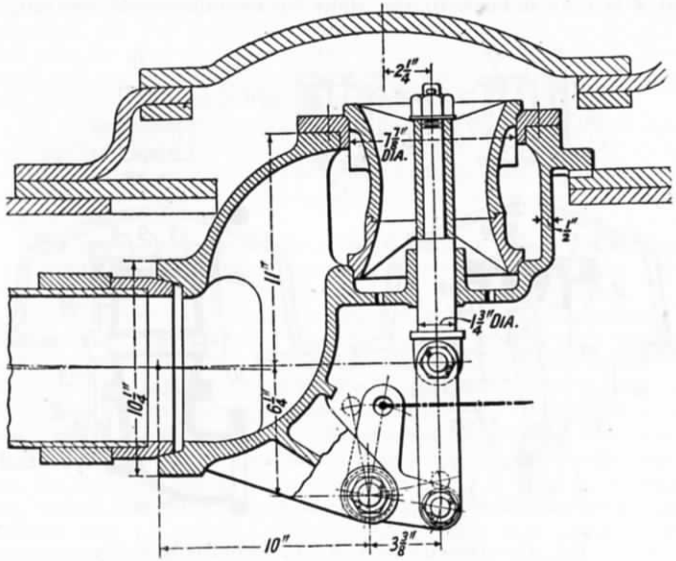


Fig. 40.—L.N.E.R. Balanced Regulator Valve.

also carries the brackets 18 which secure the whole regulator assembly to the boiler shell. The top casting which carries the fulcrum pin 10 for the valve-actuating levers has three ports 11, 12, and 13 machined on the top surface. The main valve rests directly on the port face and is a flat slide valve of bronze having a series of ports, 6, 7, 11A, and 12A, each of which appear in groups of three, are so arranged to give additional strength to the casting. The two narrow ports, 6 and 7, are known as the starting ports, and are covered by a cast-iron starting valve when the valve is shut. The starting valve takes the form of a rectangular frame with projecting sides provided with slots 16 for engagement with the actuating rod 4. In a similar manner the sides of the main valve are extended and provided with slots 17, but in this case the slots are wider than in the starting valve, the difference in width being equal to the travel of the latter valve.

To open the regulator, the rod 1 is rotated in a clockwise direction by means of the regulator handle, which moves the short crank arm 2 and the lower end of the actuating lever 3 to the right. The top of the actuating lever which works about the fulcrum pin 10 then moves to the left, causing the starting valve 5 to move in the same direction, so that the starting ports 6 and 7 are uncovered in that order. When the starting ports are fully opened, the actuating rod will have moved over sufficiently far to make contact with the left-hand side of the slots 17 in the main valve 8. Further movement of the regulator handle then moves both valves together, the main valve opening the three main ports in the valve seating as it does so.

The action in closing is the reverse of the above. The actuating rod 4 is moved back to the right by anti-clockwise rotation of

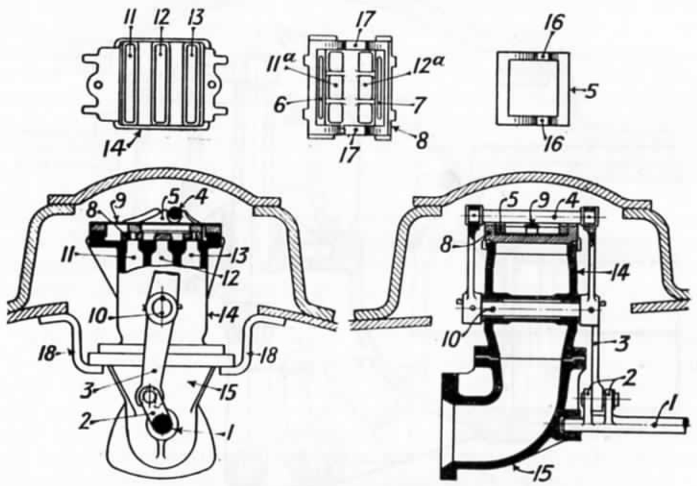


FIG. 41.—DETAILS OF L.M.S.R. REGULATOR VALVE AND FITTINGS IN DOME.

the regulator rod. The starting valve is first moved back over the starting ports 6 and 7, and finally both valves are moved over into the closed position as shown in the drawing. A flat steel spring 9 secured to the regulator head presses the starting valve down upon the upper face of the main valve, and by keeping the working faces in contact serves to prevent foreign matter from working between them whilst the boiler is out of steam. A spring-loaded catch is now being fitted to the regulator handle which gives a positive location for the regulator in the drifting position. Drivers should find this fitting a great convenience on the road, as it saves juggling with the regulator to obtain a breath of steam for coasting purposes.

As is explained in Chapter 11, which deals with superheated steam, the practice in some cases is to locate the regulator in the superheater header instead of in the steam dome on the boiler

barrel. The type known as the multiple valve regulator is incorporated, and particulars of this are given on p. 261.

Another system of steam collection has been applied to certain classes of engines on the L.N.E.R. On the top of the boiler barrel there is a steam collector formed integrally with the dome. This is produced as a steel pressing riveted to the top of the boiler on the outside. Steam is admitted to the collector by a number of slots in the top of the boiler barrel, the object being to prevent water combining with the steam on the way to the regulator valve, which, together with the steam pipes, is of extra large size to ensure that the boiler pressure can be maintained in the steamchests. Fig. 42 illustrates the fitting referred to.

The other pipes which are placed high in the dome for dry steam are five in number, namely, two for steam supply to the injectors, one for the steam sanding cock, one for the jet cock, and one for the vacuum ejector or steam brake valve. These pipes are mostly made of copper, and are expanded or ferruled into the frontplate and secured by clips in the dome.

In many cases it is usual to fit perforated plates about half-way up the dome immediately underneath the regulator valve, with a view to preventing the water from getting into the steam pipes when the engine is in rough motion or the water in a violent state of ebullition.

The cover or dome top is secured in position by bolts about $\frac{7}{8}$ in. diameter, and the joint usually is made with asbestos. This cover is easily removed for repairing the various pipes, etc.

When boiler feed water is treated chemically to reduce its scale-forming and corrosive properties, some trouble with priming is liable to occur. Stopping the engine for washing out at frequent intervals is one method of overcoming the trouble, but this has the disadvantage that the engine has to be withdrawn from traffic for this purpose. An alternative method is to use a continuous blowdown apparatus, and with this in use an engine can be steamed for greatly increased periods without washing out, and at the same time more fully softened water can be used without fear of priming. Reference to this was made in the preceding chapter.

The apparatus, as fitted on the L.M.S.R., consists of an automatic water valve and a main stop-plug mounted together in a casting secured to the back of the boiler, together with the necessary piping and connections to carry away the discharged water. Its purpose is to allow a definite but limited quantity of water to be blown out of the boiler continuously so long as the regulator is open. This water is discharged on to the ballast through a cooling coil immersed in the tender tank.

The apparatus is very simple, the outlet pipe from the boiler being brought to a port in the blowdown valve casing. This port can be closed by a main stop-plug so that the whole apparatus can be shut down if necessity arises. Normally, this stop-valve is sealed in the "open" position and the hot water passes through the automatic blowdown valve which is controlled by a piston, to the underside of which steam from the steam-chest is led. The valve is thus open only when the main regulator is open and the engine is working; at all other times the valve is returned to its seat by means of the return spring. Fig. 43 illustrates the apparatus.

The safety valve, familiar to all on account of its simplicity of action, is a very important adjunct to the boiler. The most common type of locomotive safety valve is the one known as the Ramsbottom. The design is so simple that any attempt at tampering is at once apparent. The valves are generally fixed in the centre of the firebox outer shell, and well away from the dome, so that the regulator is clear of any water that may lift when steam is blowing off violently. The base is usually made in the form of an iron casting with pillars, fitted with circular brass valves of the winged pattern, about 3½ in. diameter

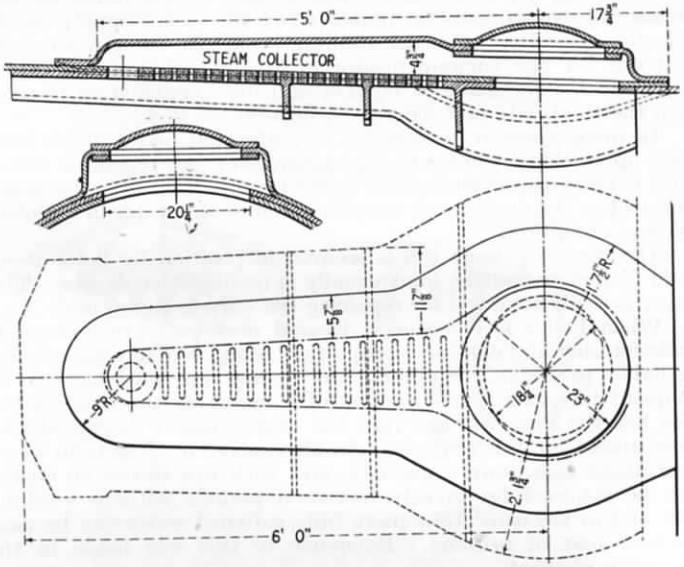


Fig. 42.—Sectional Elevation, Plan and Cross-Section of Steam-Collecting Device, L.N.E.R.

A centre spring holds the valves on their seats by means of an overhead lever with pivots extending downwards into coned recesses in the top of the valves.

The long end of the lever projects through the cab front, so that the driver is able to set the valves in motion should any sticking occur.

The valves are adjusted to the blowing-off pressure by a brass washer on the eyebolt, which holds the springs in position. These springs, being constantly under tension, gradually weaken or stretch, and the valves in consequence blow off before the working pressure is reached. When this takes place the brass washer is taken out and thinned a little, and the tension increased thereby.

The "Pop" type of safety valve is now largely adopted

in locomotive practice, and most new engines are equipped with this pattern of valve. It has been designed to overcome the serious disadvantage experienced with the ordinary spring-loaded valve, in which, as the valve lifts, the load upon it is increased by the greater tension of the spring, an undesirable arrangement. The Ross "Pop" safety valve as manufactured

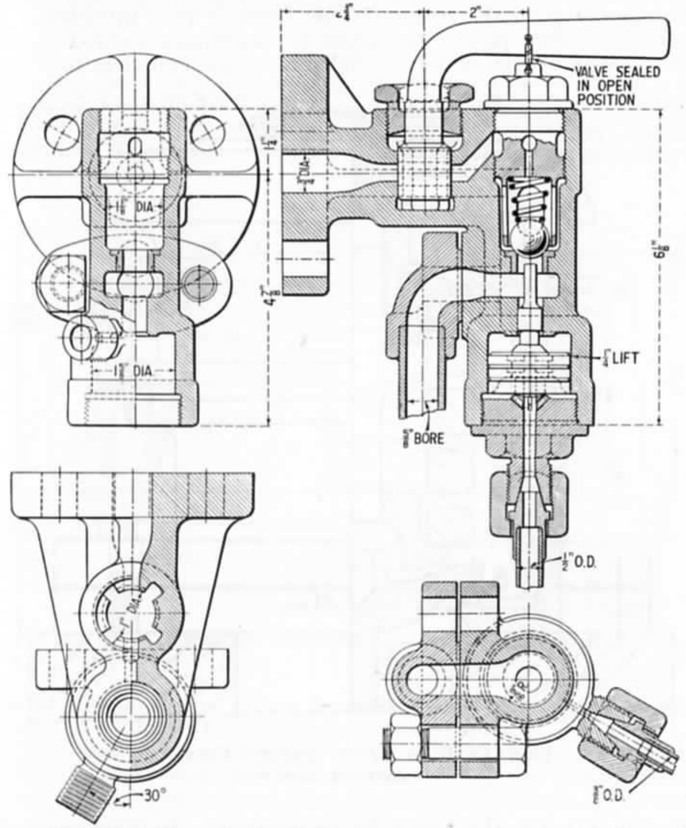


Fig. 43.—Automatic Continuous Blowdown Valve.

by the patentee, R. L. Ross & Co. Ltd., of Stockport, has been very popular for many years, due to the following features of design and action: large steam discharge capacity, prompt opening and shutting down, and low overall height. Fig. 44 shows a section of a 3½ in. diameter (250 lb. per sq. in. pressure) Ross "Pop" safety valve. The adjustment of the blowing-off pressure is made by screwing down the casing top 1 on the casing body 2, and this adjustment is limited by the intervening ring 3 of a thickness to suit the required pressure. The casing top is locked in position by pins at 4 and sealed.

The lip of the valve at 5 and the small holes at 6 cause the "pop" action. The valve seat proper 7 is a ground flat face. The holes 8 are adjustable over the holes 9 and are for the purpose of setting the amount of steam loss after the valve has commenced to blow.

The smokebox is usually fixed in position after the cylinders and boiler have been fitted to the framing. It is fixed on the sides and top to the flange on the front or iron tubeplate. In inside cylinder engines the front is sometimes secured to the front flange of the cylinders, and for outside cylinders to a stay

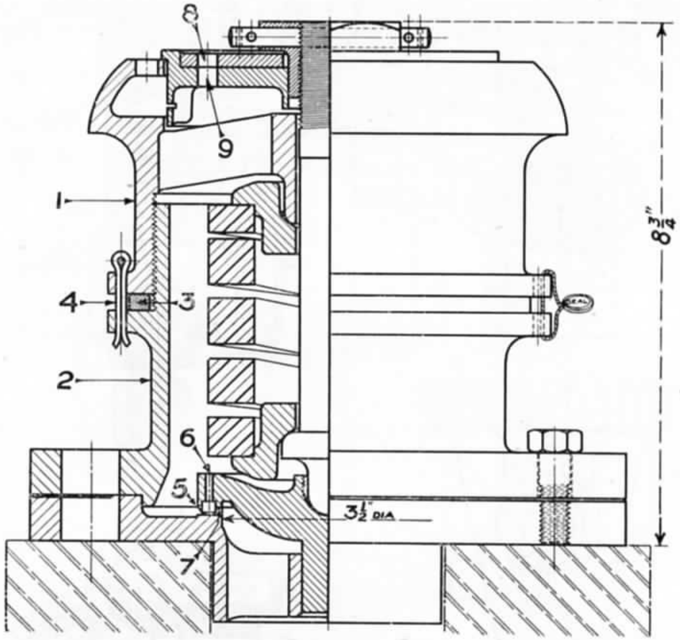


Fig. 44.—Ross "Pop" Safety Valve for Locomotive Boilers.

specially fitted to the frames for its reception. In other examples a saddle casting is fitted above the inside cylinder casting, or between the frames, when the cylinders are outside, and the smokebox, which is then made circular, rests upon the saddle.

In some cases the front plate is pressed into shape by hydraulic pressure, although the most common practice is to use a plate about $\frac{1}{2}$ in. thick, a hole being cut out for the smokebox door to required dimensions. This door hole is strengthened on the inside by a $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in. angle.

On account of its greater strength the "dished" form of door, about $\frac{3}{8}$ in. thick, is mostly adopted, so that it can be tightened up securely and airtight. It is prevented from excessive heating by means of a circular baffle plate held about

2 in. from the inside of the door by ferrules and secured by rivets. A dart or drawbolt is fitted through the centre and engages with a crossbar which is held in position by lugs riveted to the circular angle, the door being tightened home by means of a small wheel or handle on the dart screw. The door is provided for cleaning out the ashes carried through the tubes by the draught, for sweeping the tubes, and for examining, washing out, and repairing the front part of the boiler.

The bottom of the smokebox in inside cylinder engines is formed by the cylinders or steamchest top; these are protected from the gases generated by the fuel by steel plates about $\frac{1}{4}$ in. thick, or with firebrick only. The plates are held in position by small angle irons attached to the iron tubeplate and smokebox sides. The intervening space from the top of the cylinders to

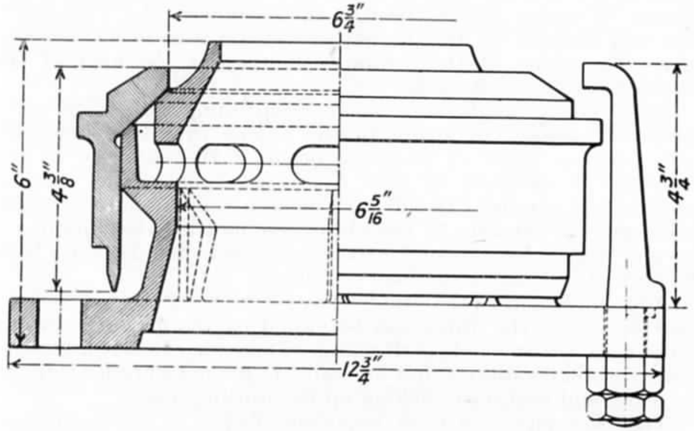


Fig. 45.—Automatic "Jumper" Blast-Pipe Top, G.W.R.

the underside of the plates is usually filled with firebrick and cement as a further preventive against corrosion.

The blast-pipe is generally made of cast iron, and may be of the breeches or the straight pattern to suit the various forms of cylinders. The bottom joint of the pipe is about level with the aforementioned protection plates.

Little theoretical assistance has been obtained in determining the proper size of the top of the blast-pipe, the sizes having been arrived at generally from observation of actual practice. For this purpose it is usual to fit a separate piece or cap, which is bolted to the top of the pipe, so that it is an easy matter to alter the size of the outlet to suit the running of any particular engine. Great care is taken in setting the pipe to see that it is exactly in alignment and central with the chimney, so that the steam, after leaving the blast-pipe, does not strike the top of the smokebox or the sides of the chimney.

Since the exhaust pipe in the early locomotive engines was first turned into the chimney for convenience, almost innumerable attempts have been made to eliminate the intermittent action of the exhaust discharges, and thus to regulate the action of the blast with a view to controlling the conditions of combustion on the firegrate and to relieve the back pressure on the pistons in the engine cylinders.

The automatic "jumper" blast-pipe top and ring (Fig. 45) were introduced on the Great Western system by the late G. J. Churchward when Chief Mechanical Engineer. In ordinary working, engines which use part of the exhaust steam in the injectors or for other purposes require a smaller blast-pipe orifice than they would otherwise do, but, on the other hand, when the engine is being pressed the blast may easily become too fierce and the back pressure on the pistons be increased correspondingly. When the engine fitted with this particular type of blast-pipe comes to a gradient, or from any other cause the predetermined amount of steam passes through the cylinders, the "jumper" rises and remains up till the exhaust steam is reduced, when it falls. The rising of the "jumper" increases the area of the blast-pipe orifice by 9 sq. in.

With heavy loads and the corresponding admission of a maximum amount of steam to the engine cylinders, excessive back pressure must of necessity occur if the capacity of the blast-pipe is designed to give a free discharge under normal conditions of service. It will thus be seen that by automatically increasing the capacity of the blast-pipe, as with the "jumper" top and ring, a free outlet for the exhaust is available under both the normal and maximum load conditions.

Adjustable blast-pipe outlets have sometimes been fitted, so that the size of the orifice can be varied by the driver according to the work the engine is performing. These may be advantageous under certain conditions, but are liable to get out of order through the ashes and coal dust choking up the working parts.

The blast-pipe is a most important factor in the economical working of a locomotive, and the engine runs at its best only after the correct height and diameter of orifice have been obtained.

The exhaust steam rushes up the pipe at a high velocity, and care is taken in designing that the exhaust does not become throttled, otherwise a serious back pressure would be set up in the engine cylinders.

With the object of improving the draught in locomotive boilers and, by facilitating the passage of the exhaust steam, bringing about a reduction of back pressure in the cylinders, there has been fitted to a number of engines in this country and abroad an arrangement incorporating a double blast-pipe and chimney. This is known as the K.C. (Kylchap) double-exhaust system. The device was invented by MM. Kylala and Chapelon, and is used extensively on French locomotives.

The steam on leaving the blast-pipe displaces a portion of the gases in the smokebox, and this displacement, together with the high velocity of the steam, induces a partial vacuum. It is an old saying that "Nature abhors a vacuum," and as a consequence of atmospheric pressure the air rushes through the firebox, giving up its oxygen in its passage through the fire, thereby assisting in the combustion of the fuel, and sweeping

forward the hot products of combustion to be sent out of the chimney at the next exhaust discharge from the engine.

A leaky or badly fitting smokebox door will seriously impair the quality of the blast. A certain amount of resistance is offered by the tubes to the air in its passage to the smokebox, and the air entering by the path of least resistance would therefore pass through the leaky door, thus robbing the fire of its due supply of oxygen. Modern locomotive practice favours a short blast-pipe, with a cowl or petticoat fitting directly under and central with the chimney.

As there is no exhaust when the engine is standing, a jet or blower is provided for stirring up the fire when the exhaust is not available. There are many forms of blowers. One method is to bore a cavity in the short end or cap of the blast-pipe, with small holes through the top, and to connect the steam supply from the blower valve and through the tubeplate directly to the blast-pipe.

Another form of jet is a copper pipe made circular to suit the outside diameter of the blast-pipe outlet, and resting on a ledge cast on the pipe for this purpose. This copper tube, which is about 1 in. diameter, is drilled on the top side with a number of small holes, and is connected through the smokebox tubeplate to the blower valve on the front or doorplate.

The main steam pipe passes through the smokebox, and is connected to the internal steam pipe already mentioned. In engines using saturated steam it passes from the smokebox tubeplate to the cylinders, is usually made of copper, is about 5¼ in. diameter, and is shaped to the curve of the smokebox sides. It will be seen that the smokebox forms a good protection for the steam pipe, preventing losses due to radiation by using the heat arising from the escaping gases.

The vacuum exhaust pipe is connected from the tubeplate to the blast-pipe and arranged so that it will discharge through the chimney. It is made of steel about 2½ in. diameter, with brazed metal flanges, and controlled from the vacuum-ejector in the cab.

The spark arrester is made of steel in many different forms, perhaps the most common of which consists of flat plates with perforations, or the one with crossbars on an angle, after the pattern of a venetian blind. It is usually fixed immediately above the top row of tubes, with the object of arresting the small particles of hot fuel from going up the chimney and into the atmosphere.

The chimney is supported by the smokebox and is usually slightly tapered, larger at the top than at the base. It is made in various shapes and sizes to suit the height of the engine and bridge levels, etc., and is built up from steel or iron plates, or of cast iron. Modern practice is to use cast iron with an internal lining of the same material, which can be renewed without dispensing with the outer shell.

The tubes which conduct the hot gases from the firebox to the smokebox vary in size and number, according to the size and design of the boiler, and are made of such materials as steel, charcoal iron, copper, or special alloys supplied by particular makers. The most commonly used nowadays is steel—sometimes with brass or copper ends brazed on at the firebox end. In modern locomotives the tubes vary from $1\frac{3}{4}$ in. to 2 in. in diameter, giving a heating surface of 900 to over 2,000 sq. ft., according to the number and size of tubes employed.

The ends of the tubes are expanded in the tubeplates, and thus made steamtight. It is the practice to drive ferrules into the ends of the tubes, usually at the firebox end but also in some cases at the smokebox end as well. It is good practice to bead the ends of the tubes over inside the firebox, thereby preventing them from wearing or burning short through the fire playing upon the otherwise sharp edges.

For convenience in connecting-up, most boilers are fitted with a brass casting known as the combination or steam stand, which is fixed on the top of the firebox outer shell immediately in the centre, and inside the cab. A corresponding seating is riveted to the firebox carrying the combination stand with branches and connections for steam supply to the vacuum ejector, the whistle or whistles, carriage warming cock, steam gauge, and the sight-feed lubricators. Steam is supplied to the stand by a copper pipe about $2\frac{1}{4}$ in. bore, directly from the dome.

The most important connection to the combination stand is the vacuum ejector. It is usually secured by studs to a brass seating, which is riveted on the front or door plate for this purpose. The exhaust pipe from the ejector passes through or outside the boiler and discharges up the chimney. The action of the ejector will be discussed more fully in the section dealing with brakes.

The two whistles where used are made in brass and are of a different size and tone. They are supplied separately with steam and have independent valves for actuating them.

The small whistle is for ordinary use, such as warning any person on the line of the approach of the train, or attracting the attention of the signalman or any other person within hearing.

The large whistle has a much deeper sound, and is intended for use in foggy weather, and for signalling to the guards in the train, or to the drivers of assisting engines, when it is required that the brakes should be applied to stop the train. The practice of using two whistles has gone out of vogue for modern locomotives, and only one whistle is employed for all purposes. On some railways there is an increasing tendency to adopt a deep rather than a shrill note, and what are known as "chime" whistles, incorporating more than one note at one opening, are employed in some cases, particularly in America and certain other countries.

The carriage warming cock, usually made in brass, is fixed on the fireman's side of the back plate. It has an independent steam-pressure gauge, and is secured in position by studs, which on assembly are screwed into a seating riveted to the firebox. Attached to the cock a reducing valve, set by means of a steel spiral spring, is sometimes provided to give the required pressure (usually about 40 to 50 lb. per sq. in.) into the pipe, which runs

the full length of the train. The warming cock is under the control of the driver and is used for heating the vehicles, according to the weather. To minimise the danger of bursting the hose pipes, care should be taken that steam is not turned into them too suddenly. The steam supply to the warming pipes should be shut off some few minutes before arriving at a station where the engine or vehicles are to be attached or detached, otherwise there will be danger of scalding the person uncoupling the pipes.

The jet cock is usually placed on the fireman's side of the front plate, although in some cases it is fixed on the side of the smokebox, and controlled from the handle on the front plate by means of a long rod. In most cases, however, the cock is placed on the front plate and supplied with steam direct from the dome, and the pipe on leaving the cock passes through the boiler to the jet in the smokebox.

Near the jet cock will be found the steam sanding cock, when steam sanding arrangements are fitted.

From the well-known fact that one of the most common causes of boiler explosions is shortness of water, it will be understood readily that the water-gauge fittings on the front plate are essential adjuncts to a boiler. Two sets of gauge-glass fittings are usually employed, so that one acts as a check against the other, and as a safeguard should one require repairing or not be working properly. The glass tube water-gauge consists of a straight glass tube connected by fittings at the top end to the steam space in the boiler, and at the bottom end with the water; the bottom end of the glass is fixed above the highest part of the heating surfaces. The gauge glass is a simple and yet effective method of showing the water level, the steam being transparent in the glass, and the water rising to its own level in the boiler. One of the principal objections to the use of gauge glasses is the chance of injury to the driver and fireman by the bursting of a glass.

In recent years, however, it has been the practice to incorporate in the upper and lower arms of gauge glass fittings, a ball and a spring valve which automatically shuts off the steam and water in the event of the gauge glass tube breaking under pressure. Further protection is also afforded by the adoption of protectors which prevent a shattered gauge glass from flying in all directions.

Dewrance & Co. Ltd., of London, is a well-known maker of water-gauge fittings with automatic valve and ball arrangements, an example of which is shown in Fig. 46. In the event of the gauge glass breaking under pressure, the ball in the lower arm rises to its seat and cuts off the rush of scalding water. The sudden rush of steam will also cause the patent automatic spring valve in the upper arm to close. The spring is made of phosphor-bronze or of a heat-resisting steel.

When a water-gauge glass is shattered the fragments may fly in all directions, and many men in the past have lost their sight through injuries received in this way. The Dewrance patent water-gauge glass protector shown in the left-hand illustration (Fig. 46) prevents such accidents. The glass plates forming the front and sides of the protector are toughened by their special process, and every plate is carefully tested before assembly to

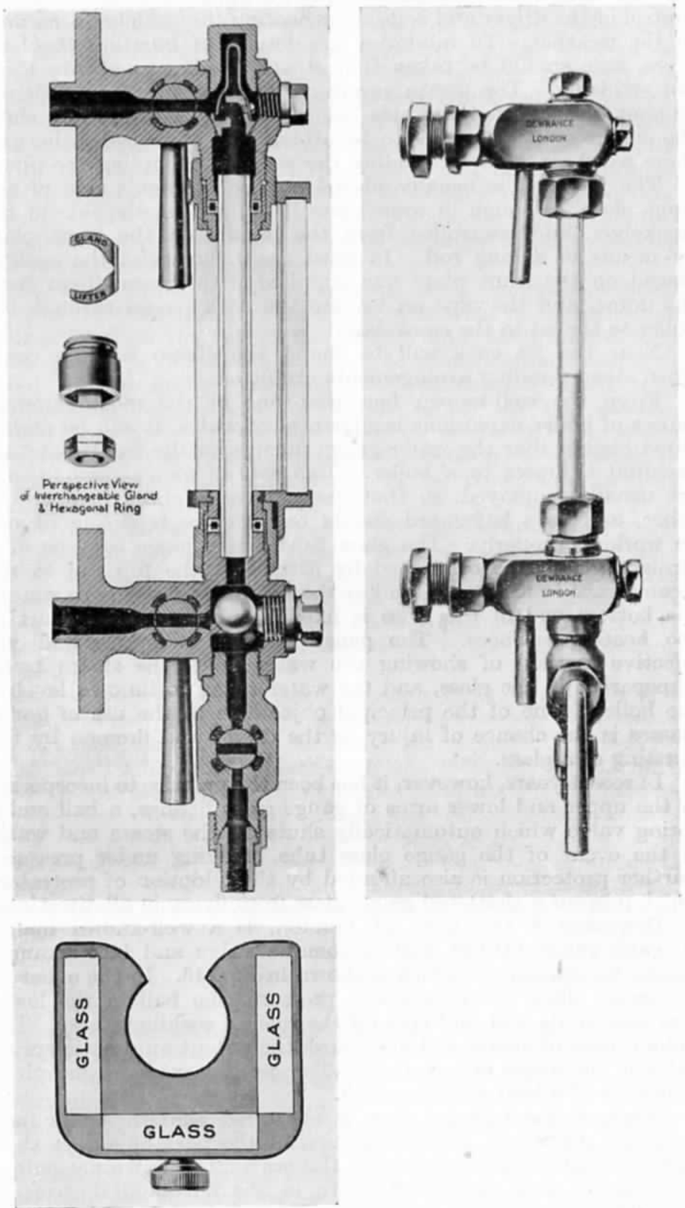


Fig. 46.—Details of Dewrance Water-Gauge Fittings for Locomotives.

ensure that it is strong enough to withstand the shock of a water-gauge glass breaking under high pressure. Considerable advance has also been made in the method of producing water-gauge glasses and in the design of fittings; consequently, breakages now are reduced to a minimum. At present, when the tendency is to employ high-pressure steam, the glass tube is often replaced by a plate-glass water-level indicator.

False readings of the water level will be given should any scale or obstruction be lodged in the orifices leading to the boiler, and on this account the gauge glasses must be blown through at regular intervals. For ordinary water-gauge fittings this operation should be carried out in the following manner :—

1. Close lower arm cock.
2. Open and close blow-through cock.
3. Open lower arm cock.
4. Close upper arm cock.
5. Open and close blow-through cock.
6. Open upper arm cock.

Some boilers are fitted with test cocks in addition to the gauge glasses, but it is the glasses that give the driver and fireman the greatest sense of security and satisfaction, on account of the water level being seen so readily.

By watching the glasses the fireman can fire according to the rate at which the boiler is feeding, and this, coupled with a knowledge of the gradients and stops, goes a long way towards economical working.

The corrosive matter, or soda, etc., in the feed water gradually deteriorates the glasses, and these should be changed before their limit of endurance is reached. A glass that is giving out will show signs of flaws and streaks at the upper end, and with practice these can be detected in many cases when they appear.

Many glasses are broken through the strains set up as a result of the use of unsuitable gland packing. To a large extent this trouble has been overcome by the makers of the water-gauge fittings, Fig. 46, who were the originators of the now well-known patent hexagonal stuffing-box and hexagonal packing ring. This type of stuffing-box is shown in the illustration.

With this design, the guide for the gland is hexagonal and prevents any torsional strain being exerted on the glass when screwing up. The part that forms the guide is below the packing and not exposed to corrosion; the gland is therefore not liable to become slack and be forced over when screwing up and so break the glass tube. By inserting the gland lifter under the collar at the top of the gland, and unscrewing the gland nut, the joint can be broken easily.

Water-gauge fittings having a round stuffing-box (right-hand view, Fig. 46) are more efficiently packed with a packing ring. Both the hexagonal and round packing rings manufactured by Dewrance & Co. Ltd. have a rubber core encased in a flexible covering of cohesive asbestos, and experience has shown that they do not corrode the stuffing-box as do ordinary rubber rings.

The type K.B.D. reflex water gauge for locomotives (Figs. 47 and 48) is the latest standard pattern manufactured by Richard

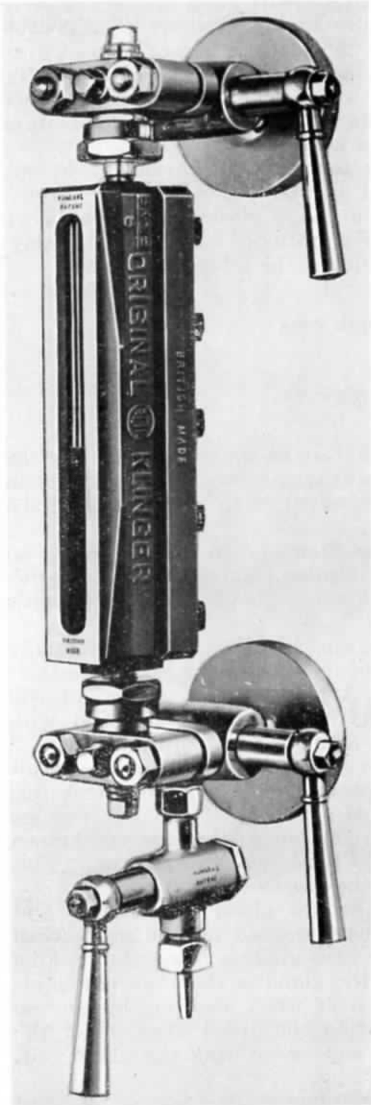


Fig. 47.—Klinger Reflex Water Gauge for Locomotives.

Klinger Ltd., of Sidcup, Kent, and has been used on locomotives in this and other countries for many years. The advantages claimed for the reflex type glass as against ordinary glass tubes are that there is absolute immunity from the danger of broken or burst glasses, whilst the water level is clearly visible so that no mistake can be made as to whether the gauge glass is full or empty, even if the actual water level is out of sight.

The gauge consists of a thick glass plate mounted in a metal body and having prismatic grooves on its water side. The thickness of the glass is such that there is no danger whatsoever of its bursting or blowing out even if it should be broken accidentally by a blow from a firing tool. The action of the prismatic grooves at the back of the glass is such that light striking the glass in way of the steam space is reflected back to the eye of the observer, so that that part appears bright and silvery, while light striking the glass in way of the part occupied by water passes right through to the back of the gauge and is absorbed by the dark metal body, so that the water space appears black. The gauge fits into special stuffing-boxes on the top and bottom cock bodies which can be quickly and easily disconnected from the cocks by simply removing two nuts at either end. The removal of the gauge is therefore very quick and simple. The design of the stuffing-boxes is such that the gauge is free to expand without any restriction, and can also be turned about its axis while under steam to face any desired direction for maximum visibility.

All the cocks in the K.B.D. type water gauge are of the Klinger

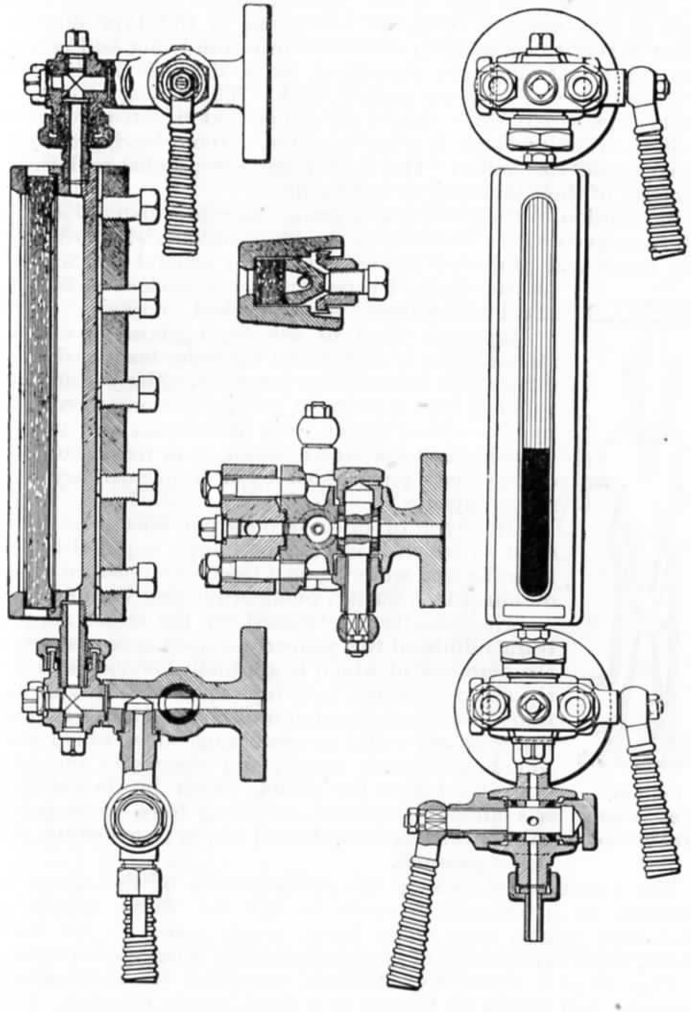


Fig. 48.—Details of Klinger Reflex Water-Gauge Fittings.

sleeve-packed type and are kept tight by resilient packing-sleeves of " Klingerit " which can be retightened easily during service. When after long use they require repacking, this is a simple and quick operation and a new packing sleeve makes the cock equal to new again. The great advantage of this type of cock is that it is not necessary to remove it from the boiler and return it to the repair shops for repacking, as in the case of the old-fashioned type of asbestos-packed cock. The fitting of a new packing sleeve is such a simple operation that it can be carried out in the running sheds in a few minutes, without having to take the cocks off the boiler. The cock plugs are parallel and there is no risk of their jamming or seizing up.

In addition to the reflex water gauge described above, Klinger water-gauge cocks for locomotives are also available with ordinary glass tubes and protector glasses, similar in general appearance to the standard type of asbestos-packed cocks but fitted with patent "sleeve-packed" cocks.

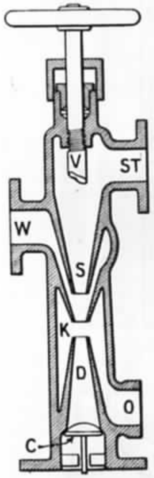


FIG. 49. FIXED NOZZLE INJECTOR.

Injectors fixed to the front plate have now almost entirely superseded the older-fashioned feed pumps for locomotive purposes. Many different types of injectors are in use, some worked entirely by live steam direct from the dome, and others by using exhaust steam taken from near the base of the blast pipe, aided by a supplementary live steam injector.

The type of injector does not affect the principle on which it works, the energy required to deliver the feed water against the boiler pressure being obtained by velocity, momentum, and vacuum.

The velocity is obtained by the steam supply being admitted to a properly-shaped cone or nozzle, the diameter of which is gradually reduced so that the steam attains a very high velocity. Having attained this great speed, it is discharged into a conical water space, called a combining tube, which surrounds the steam nozzle, and the water immediately condenses the steam, which by its velocity has already imparted sufficient force or impetus to the water and condensed steam to overcome the boiler pressure.

The vacuum induced by the condensation of the steam is sufficient in live-steam injectors to lift the water supply a reasonable height, cold water being much easier to lift than heated water on account of the condensation being more perfect.

Fig. 49 is a descriptive diagram simplified for explanatory purposes, and would be known as a fixed nozzle injector. S is the steam inlet, the supply being regulated by the valve spindle V, the valve when in position closing the orifice S. This orifice is narrowed until the steam attains a velocity of about 1,700 ft. per sec., or approximately 1,160 m.p.h., according to the boiler pressure and neglecting frictional resistance. At this speed it is admitted to the water space or combining tube W, where the steam is condensed, and carries forward by the force of its momentum about twelve times its own weight of water at a speed

of about 131 ft. per sec., or nearly 90 m.p.h. The speed attained is sufficient to carry the combined jet across the space K to the delivery tube D, and through the back check valve C into the boiler. If too much water is supplied to the space W, a certain amount will strike the inlet to the tube D and fall away through the space marked K into the overflow chamber O, to be discharged by the overflow pipe.

The oldest form of injector is that known as the Giffard, which was patented in July, 1858. Much difficulty was experienced in applying the earlier injectors to locomotives, not only on account of the trouble in starting them but by the continual interruption of the combined steam and water jet caused by the jolting of the engine when passing over points and crossings, etc., the steam and water having to be shut off every time a failure occurred, and the troublesome restarting repeated.

The feeding of a locomotive boiler is too serious a matter to be dependent upon an uncertain instrument, and engineers

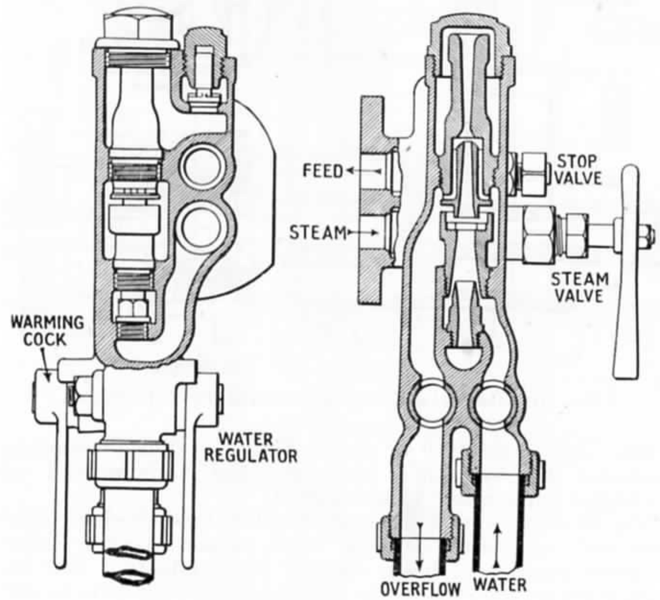


FIG. 50.—GRESHAM & CRAVEN AUTOMATIC RESTARTING INJECTOR.

by research and experiment gradually improved the action of the injector, till today we have various makes that will start working with absolute certainty, and automatically restart should any interruption occur to the combined steam and water jet.

These automatic restarting devices have been the subject of many patents, one of the best known of which is that of Gresham & Craven Ltd.

Fig. 50 is of the vertical combination type, combining in one complete fitting, steam valve, back-pressure valve, stop valve, water-regulating cock, warming cock, and all the necessary handles. It will be seen from the illustration that one part of the combining tube is movable, so that when the flow of the jet is interrupted the movable portion alters its position, and allows the pressure in the combining tube to be relieved through the overflow. When the pressure has been relieved the steam jet returns the movable part to its normal position, and the injector recommences its work without any external aid.

The more modern practice is to fit the injector under the footplate, where it will always work flooded and without having

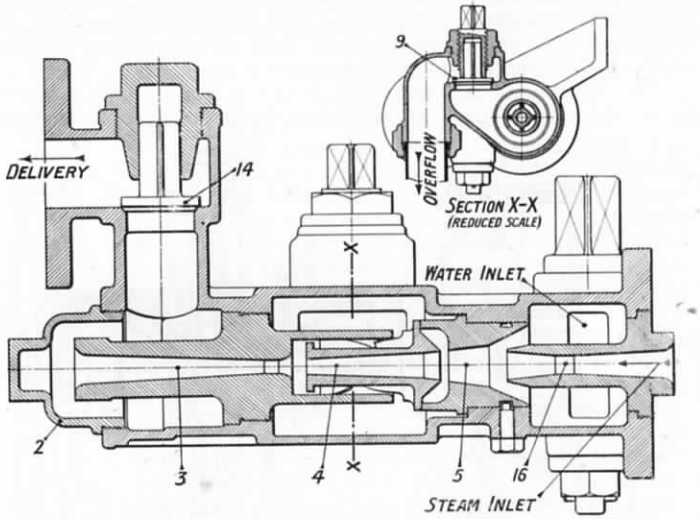


Fig. 51.—Gresham Under-Footplate Type Injector.

to lift. Any possibility of overheating and difficult starting is eliminated thereby, and at the same time it allows feed water at a higher temperature to be handled.

Fig. 51 shows a modern under-footplate type Gresham injector fitted with non-return or clack valve 14 and overflow valve 9, the latter capable of being shut off independently. The usual cones, namely, the steam cone 16, lifting or water cone 5, sliding combining cone 4, and delivery cone 3, are fitted. The last two are readily removable for examination or replacement or descaling by removal of cap 2, without the necessity of breaking a pipe joint.

The rate at which live-steam injectors will feed under normal conditions may be taken to be generally as shown in the following table; these figures are based on cold feed water, but the delivery will be reduced as the feed water temperature rises.

Size of Pipe Connection.	60	90	120	140	160	180	200	Pressure, lb. per sq. in.
1¼ in.	550	670	780	840	890	940	1,000	Delivery, gal.
1½ in.	1,240	1,520	1,760	1,900	2,030	2,120	2,273	per hr.

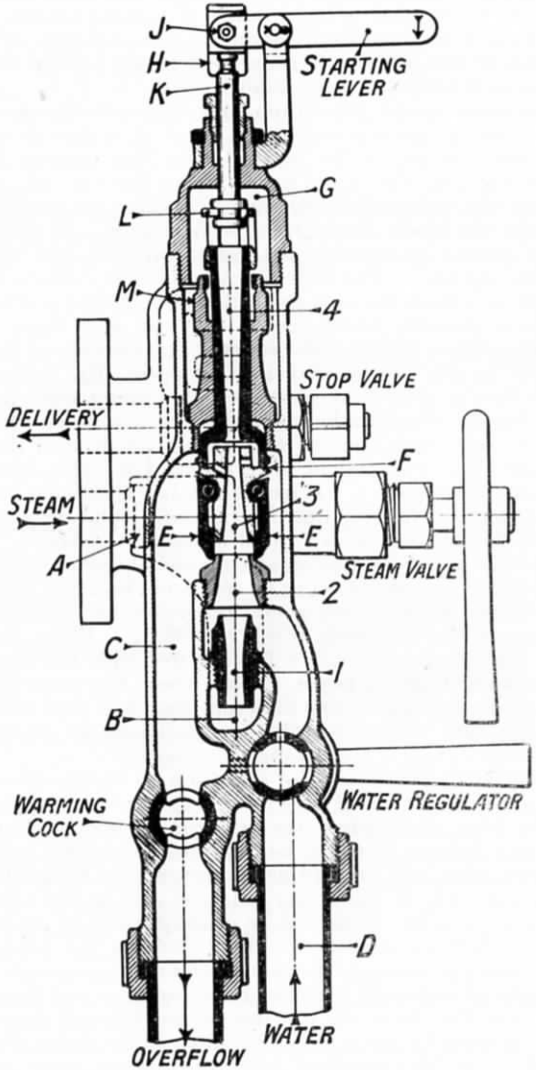


Fig. 52.—Gresham Patent Hot-Water Combination Injector.

The Gresham patent hot-water combination injector (Fig. 52) is designed to work with water at very high temperatures, and is automatic and self-starting. This injector will work with either hot or cold water over a large range of boiler pressure without regulation, and is exceedingly simple in construction. The lever on the top of the injector is connected to the sliding cone, and the action of the injector is as follows :—

An internal steam pipe from the dome of the locomotive conveys steam to the injector steam valve A, which, being open, admits steam to the steam nozzle 1 by the passage B. The steam issuing from the steam nozzle opens the two side flaps E ; it also lifts the sliding delivery cone 4, making an aperture at F, and passes out freely down the overflow pipe. In doing so it creates a partial vacuum in the water pipe D, and the water rises to the injector. The water then coming in contact with the steam travels with it through the lifting cone 2, and in condensing it creates a vacuum which closes the two side flaps E, thus preventing any air entering the cones. The velocity of the steam being now largely transferred to the water, the latter passes from the lifting cone 2 through the combining cone 3. After passing through this combining cone, the jet flows out of the aperture F and down the overflow pipe C until such time as it attains sufficient velocity to carry itself past this space, and enter the delivery cone 4. When it reaches this point the jet is at its maximum velocity, and is therefore sufficiently powerful to lift the back-pressure valve and so enter the boiler. At the same time the pressure thus created in the chamber G forces the sliding delivery cone down on to its seat and closes the aperture F, shutting in the water which would otherwise be boiled off when the injector is working with water at 130° F. When the water is below 100° F. the injector will work dry with the aperture F open, like an ordinary injector. When these hot-water cones are fitted to under-footplate type injectors they will deal with water at 140° F., and under favourable conditions at even higher temperatures.

The following points require attention to ensure the efficient working of these hot-water injectors : (1) The water cock should always be kept shut when the injector is not working, thus draining any leakage from the back-pressure or steam valves into the overflow pipe, and preventing the water pipe being filled with boiling water. (2) If the water gets too hot in the water pipe for the injector to lift, it should be drained away by opening the cock at the bottom of this pipe, first shutting the tender cock. After the water is drained the tender cock can be opened, when a fresh supply of water at a reduced temperature will flow to the injector. (3) The lever on the top of the injector occasionally should be worked by hand. (4) The joints of the water pipe must be airtight. (5) The overflow pipe must be as large inside as the branch in the injector, and if the pipe is long it should be increased to a larger size a few feet from the injector. Care must be taken to see that this pipe does not have its area reduced by being flattened. (6) About one-sixteenth to one-eighth of a turn of the steam valve is the best position for lifting ; afterwards a further half-turn of the steam valve will be sufficient to start

the injector feeding the boiler. (7) Should an injector begin to work irregularly after having worked satisfactorily for some time, often it will be found that this is caused either by sediment in the cones or by wear.

For removing the cones, detach the clip H on the top of the spindle K by taking out the bolt J. Unscrew the cap and draw it off the spindle K. Lift the spindle K out of the slot L on top of the delivery cone. Remove the delivery cone and guide complete (4) with the special box key and hexagon M. Remove lifting cone and steam nozzle with small end of box key in the usual way.

To replace the cones, fit the steam nozzle and lifting cone in the usual way, lowering them to their positions with a piece of stick. Screw in the delivery cone with the box key. Place

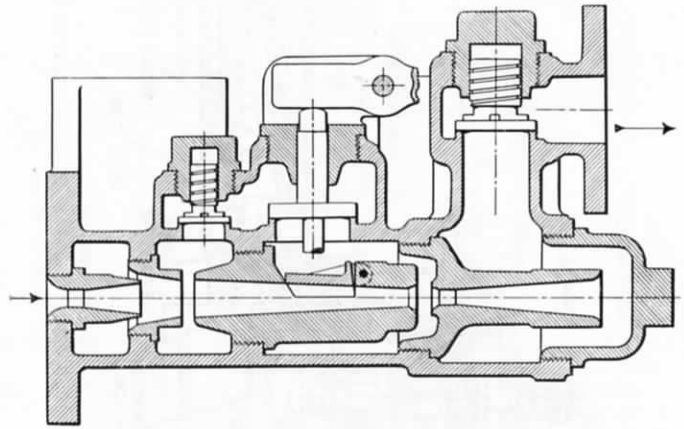


Fig. 53.—Metcalfe Hot-Water Injector, Section through Nozzles and Valves.

the spindle K in the slot L, force the cap over the spindle K, and screw up the cap. Replace the clip and lever.

This type of Gresham hot-water injector is also made as an under-footplate injector similar to the standard under-footplate type, but embodying the special hot-water flap cones and capable of dealing with feed water up to 135° F., or even more under favourable conditions.

It is to be noted that the sliding delivery cone should work freely, and it is important that the stuffing-box of the starting lever should not be packed tightly.

The Metcalfe hot-water injector has been designed specially for hot climates where conditions are generally too severe for the ordinary live-steam injector. It will operate successfully with feed water at any temperature up to 140° F., with boiler pressures up to 250 lb. per sq. in., and under these conditions it is entirely automatic and restarting in action.

The working parts consist of a steam cone, draft tube, combining cone, and delivery cone. The steam cone is of the solid jet type screwed into the injector body, and the combining cone is constructed on the flap nozzle system in which the cone is split longitudinally at its middle section for a portion of its length, and hinged so as to swing open freely and so afford free exit for

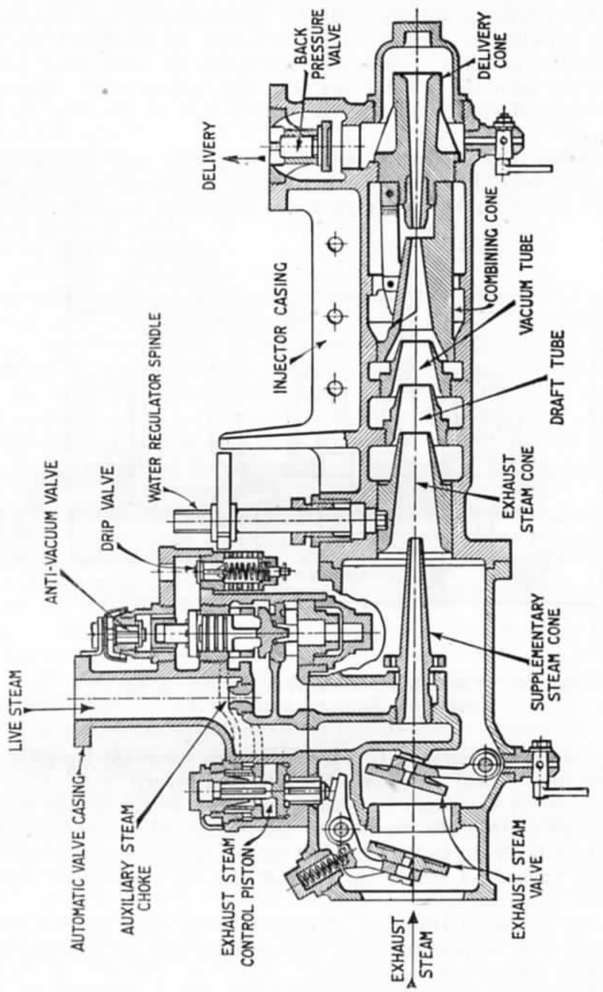


Fig. 54.—Section through Exhaust-Steam Inlet Automatic Valves and Injector Nozzles.

the water and steam. The opening of this flap ensures the prompt starting and automatic working of the injector. It will be seen from the drawing (Fig. 53) that two separate overflow chambers are incorporated; the first containing the draught tube and the second the combining cone. An ordinary drop non-return valve allows steam or water to escape from the first chamber into the overflow pipe, while the exit from the second chamber is controlled

by an automatic pressure-controlled overflow valve. As any system of hand-locking the overflow is too dangerous and would require constant attention, this type of valve is a necessity in view of the high delivery temperatures obtained with this injector. Since the delivery temperature with feed water at 140° F. may be as high as 260° F., a corresponding pressure will be found in the

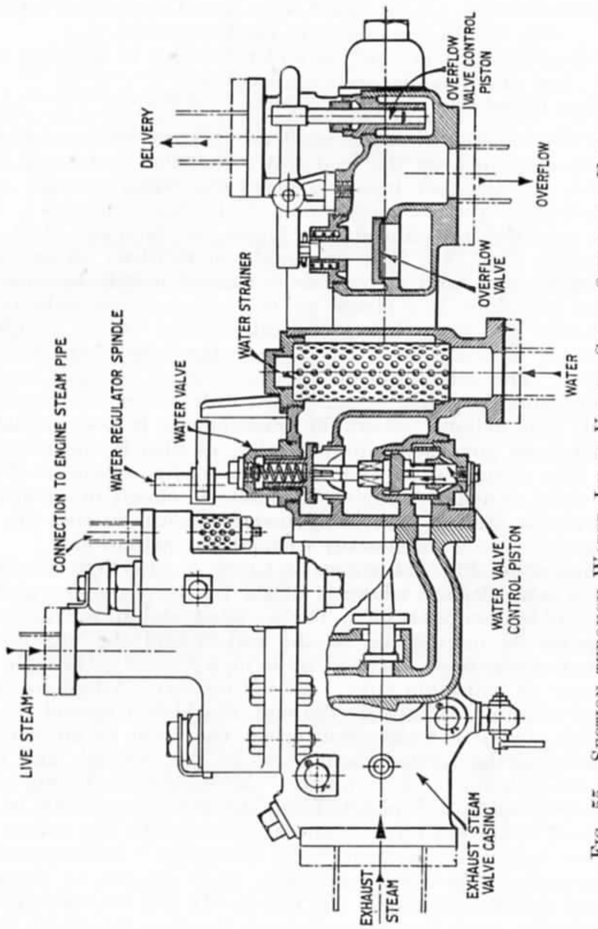


Fig. 55.—Section through Water Inlet Valve, Sieve Overflow Valve and Operating Piston.

main overflow chamber, and a pressure-controlled overflow is, therefore, imperative, as otherwise the jet of water would expand and waste into the overflow. The automatic overflow valve acts as follows :—

When the injector is working, the delivery pressure forces up a piston which, acting through a control lever pivoted to a fulcrum on the injector casing, forces the overflow valve on to its seat and thus seals the overflow chamber. If, therefore, the injector jet breaks off from any cause, the delivery pressure under the piston is reduced and the overflow valve is allowed to open.

The exhaust-steam injector is one of the most approved types of feed-water heaters,* and is much favoured because it possesses the following features :—

(*a*) Satisfactory fuel economy.
(*b*) Compactness, *i.e.*, it takes up a small space and adds as little weight as possible to the locomotive.
(*c*) Simplicity of construction and reliability in working with low maintenance and repair costs.
(*d*) Low initial and installation costs.

Since the exhaust steam is condensed in the feed water, and serves not only to heat the feed water but also to force it into the boiler, the exhaust injector serves the same purpose as a combination of pumps, reservoirs, and spray devices. The exhaust injector introduced by Davis & Metcalfe Ltd., is illustrated in Fig. 54. It is as simple to work as an ordinary live-steam injector, and in practice is started merely by opening the valve to admit live steam to the injector, the only other manipulation necessary being the adjustment (when required) of the water regulator in order to vary the rate of the feed to the boiler. The admission to the injector of exhaust steam, water, and auxiliary live steam (used only when the regulator is closed, and exhaust steam in consequence is not available) is in each case governed automatically, as also is the overflow valve. The change over from exhaust to live-steam working, or vice versa, when the engine regulator is closed or opened is also automatic, and is practically instantaneous, so that the injector continues to work steadily without any attention.

Reference to Fig. 54 shows exhaust steam first admitted through a central cone where it meets the condensing water in the form of an annular jet. The exhaust steam is condensed and imparts its momentum to the water, and the mixture of steam and water flows forward at a high velocity through the second cone or " draught tube," as it is termed. A high vacuum is created within this tube at the end of which a second supply of exhaust steam is then admitted in the form of an annular jet, thereby giving further momentum to the mixture, and this, passing through the " vacuum tube," enters the combining cone, where condensation is completed and the energy available in the steam used in its entirety to impart velocity to the water jet. The latter finally passes through the divergent " delivery cone," thus converting the energy available from kinetic to pressure form, and delivers thence to the boiler. It will be noticed that the combining cone is constructed on the flap principle, being split longitudinally up to a point near the vacuum tube, where the diameter is such as to facilitate the exit of water and steam. Prompt starting and automatic working of the injector are thus ensured. Fig. 55 shows the admission of live steam to the underside of the water-control piston, also the section through the water inlet valve, sieve and overflow valve and operating piston.

The temperature of the water delivered to the boiler ranges

* Feed-water heating systems with pumps are dealt with at a later stage.

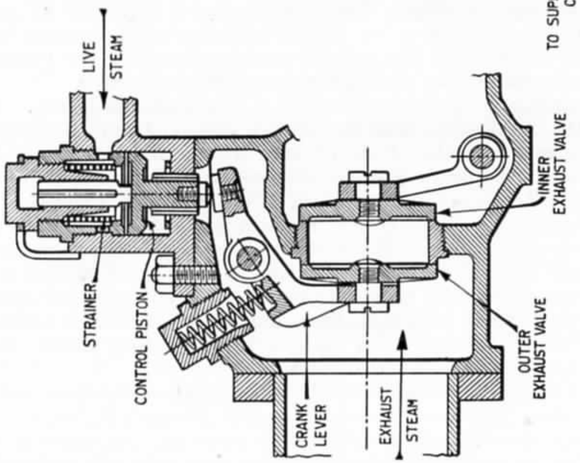


Fig. 56.—Section through Exhaust Inlet Valves and Piston Valve.

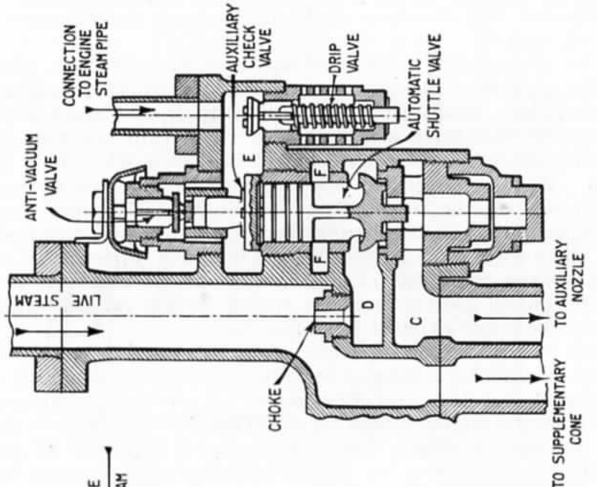


Fig. 57.—Section through Automatic Valve and Drip Valve.

normally from 190° to 200° F. with a maximum value of 230° F. The economy in fuel realised is from 8 to 12 per cent., that of the water ranging from 10 to 12 per cent. The injector is capable of adjustment between 50 per cent. and the maximum feed capacity. It will, therefore, be realised that this instrument is a feed-water heater, which, in addition to low cost of installation, is both compact and of light weight. The automatic features of this injector will be more easily understood on reference to Figs. 56, 57, and 58.

Fig. 56 shows the outer and inner exhaust valves, which control the admission of exhaust steam to the injector, and also prevent any live steam from escaping into the exhaust steam pipe when the injector is working as a live-steam injector, and prevent any exhaust steam entering the injector when it is not operating. When the injector is started with the regulator open, live steam acts on the top face of the control piston and forces this down on to its seat, thereby moving the crank lever and opening the outer exhaust valve. When the injector is not operating or the regulator is closed, pressure is removed from above the control piston and the spring acting on the crank-lever closes the outer exhaust valve.

Fig. 57 shows the automatic portion of the injector which effects the automatic change over from live-steam working to exhaust-steam working, and vice versa. A small pipe connects chamber E to the engine steam pipe. When the regulator is shut and the injector working, live steam enters chamber D and, forcing the shuttle valve on to its upper seating, passes into chamber C, and so into the injector casing to replace the exhaust steam, at the same time closing the inner exhaust valve.

The injector is then working as a live-steam injector. On opening the regulator, however, steam passes from the engine steam pipe into chamber E and forces the auxiliary check valve on to its seat. This causes the shuttle valve to fall on to its lower seating and thus cuts off communication between chambers D and C, thereby eliminating the introduction of any live steam into the injector casing. The shuttle valve, however, now being on its lower seating allows live steam to pass from chamber D into passage F, and so to the upper side of the exhaust steam control piston which is forced down and opens the outer exhaust valve. Exhaust steam then enters the injector, which then functions as an exhaust-steam injector.

Fig. 58 shows the automatically self-closing water inlet valve. This is a drop valve controlled by a live-steam-operated piston and remains closed until the injector is started. On opening the steam valve to work the injector steam passes to the underside of the control piston and forces it up, thus opening the water valve and admitting water into the injector. When the steam valve is closed the pressure from the underside of the control piston is removed and this drops and allows the water valve to fall on to its seat, thus shutting off the water supply.

The grease separator (see Fig. 59) is automatic in action and needs no attention beyond cleaning at periodical intervals. A helical vane in the inlet passage imparts a whirling motion to the incoming steam, with the result that the heavier particles of

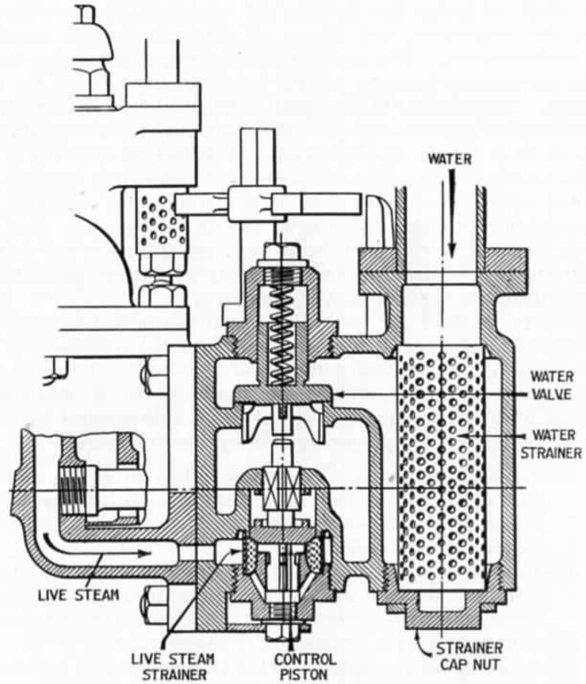


FIG 58.—SECTION THROUGH WATER INLET VALVE AND OPERATING PISTON AND WATER SIEVE.

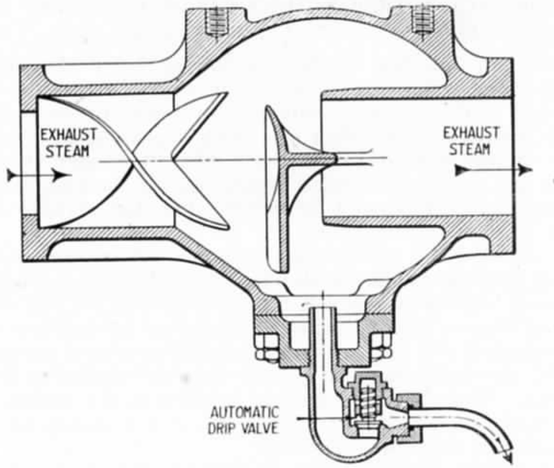


FIG. 59.—SECTION THROUGH GREASE SEPARATOR AND DRIP VALVE.

grease, dirt, or water are thrown off by centrifugal action to the wall of the separator, and blown off through the automatic drip valve at the bottom. The purified steam then passes to the injector.

The remaining features of the injector do not call for special comment. Regulation of the feed is effected by an eccentrically-controlled sliding cone, and provision is made for a supplementary supply of live steam to the extent of about $2\frac{1}{2}$ per cent. of the feed (to reinforce the exhaust steam when feeding against boiler pressures which are higher than it can overcome unaided). This supplementary steam is returned in its entirety to the boiler, without thermal loss, apart from very small losses by radiation. Fig. 60 shows the general arrangement of the component parts of the system, as applied to a locomotive.

Injectors should be subjected to periodical examination, and the scale, etc., carefully removed from the nozzles and tubes. In the case of one working badly or gradually deteriorating in its efficiency, a report should be made without waiting until it fails entirely. The causes of failure as a rule are not far to seek, and may be looked for generally among the following :—

1. Leaky suction pipes. To test for this, plug the end of the pipe and block the overflow branch of the injector. When steam is turned on, the leak will be indicated by an escape of steam.
2. Feed water too hot in tank. When this happens a discharge will be observed in the overflow branch. Cooling the water will prove whether or not this be the reason.
3. Shortness of steam or choked delivery pipe.
4. Presence of boiler scale or other obstruction in nozzles.
5. Back check valve in injector delivery not working aright.
6. Injector too hot owing to faulty steam valve or other causes.
7. Wet steam caused by foaming or priming.
8. Suction pipe throttled by accumulation of scale or dirt in the pipes.

When an injector starts overflowing after the engine has been working some time, it is a sign that the cones or delivery pipes are being choked gradually by sediment or scale. This can be removed by soaking the parts overnight in a solution of 1 part muriatic acid to 10 parts of water, and the portions washed and wiped over before replacing. If the scale be removed by scraping, care should be taken that the scraper does not enlarge or damage the cones.

In view of the well-known economy of exhaust-steam feed-heating, and the facility with which the water in the tender may be heated with steam which otherwise would be lost or thrown away by reason of fluctuating loads, some locomotive engineers have adopted the use of independently-operated steam pumps whereby the boiler may be fed whether the engine be running or standing. This form of pump is positive in its action, and can deal readily with feed water at temperatures largely in excess of those suitable for most injectors.

The outstanding features of the A.C.F.I. feed-water heater for locomotives, illustrated in Fig. 61, are that all the heat units contained in the allotment of exhaust steam delivered to the

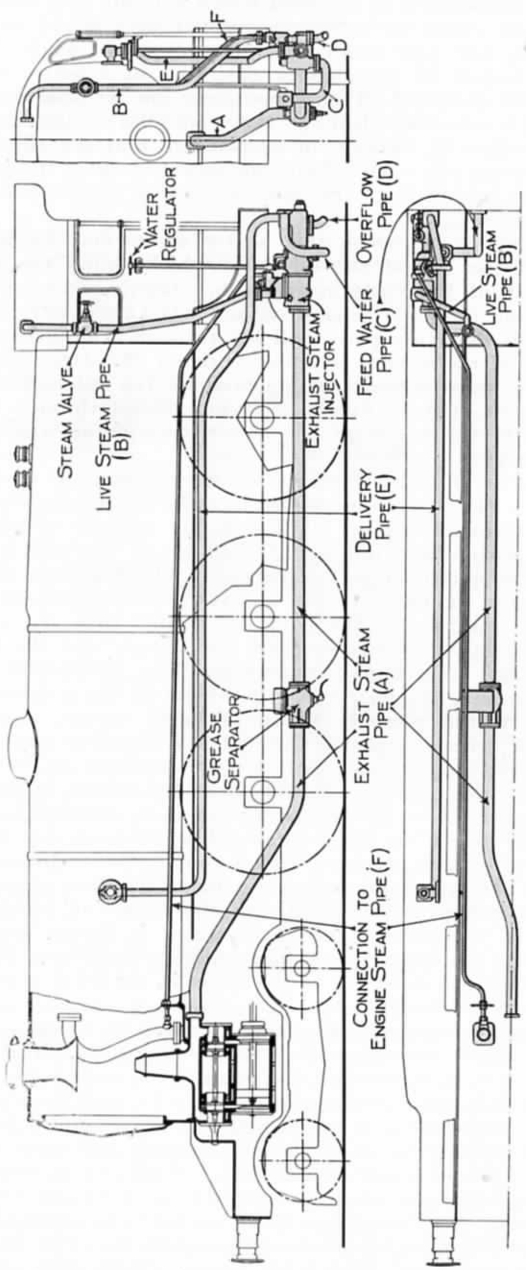


Fig. 60.—Arrangement of Metcalfe Exhaust Injector with Independent Check and Steam Valves on a Locomotive.

heater are transferred to the feed water without loss, that there are no small tubes to become encrusted with scale, and that there is only one pipe under high pressure in the whole system. The first feature is particularly desirable in cases of engines working with short cut-off and consequent low terminal pressure; the second is essential when the water supplies contain lime and other impurities in solution or suspension, and the elimination of high-pressure pipes with their tendency to leak at the joints is of enormous benefit from the point of view of shed maintenance and running costs.

The principle on which this heater works may be followed easily with the aid of the diagram, which shows the general arrangement of the component parts. Briefly, exhaust steam is taken from the blast pipe 13 which, when necessary, is fitted with a fixed diverting plate and led through a branch pipe 15 to one end of the mixing chamber or drum 12. Here this main supply of exhaust steam is augmented by the exhaust 29 from the feed pump (where fitted). Having passed through the oil separator 16, the whole of the steam then enters the mixing chamber proper.

Feed water from the tender is drawn through the cold-water cylinder 7 of the feed pump, forced into the mixing chamber, and delivered through a pipe 10, the upper surface of which is perforated with a large number of small holes. The feed is forced upwards through these perforations and rebounds from the roof of the drum in the form of a fine spray. This arrangement effects a thorough mixture of the cold feed water with the exhaust steam; the latter is consequently condensed, and the feed is thereby raised to a high temperature. The feed water in the mixing chamber, together with the steam it has condensed, is subjected to the pressure of the exhaust steam, under the influence of which it passes through a connecting pipe 17, so arranged as to form a water seal, into the settling tank 18 and 19. Incidentally, this chamber, for the sake of clearness, is shown on the diagram in line with the mixing chamber, although in actual practice the drums are almost invariably arranged side by side. The settling tank is provided with a vent or outlet to permit of the escape of oxygen and carbon dioxide, since these gases, when allowed to remain in the feed, are the causes of pitting and corrosion in the boiler. The feed water is drawn from this chamber and delivered by the hot-water cylinder 6 of the feed pump through the clack box to the boiler in the usual manner.

As the cold-water cylinder of the pump has a greater capacity than the hot-water cylinder, there is always an excess of water in the hot-water compartment of the settling tank. This excess flows over a baffle plate into the overflow compartment, thence by gravity into the overflow return valve 23, and then into the suction vessel 26, where it mixes with the water coming from the tender preparatory to passing again through the cycle already described. The overflow return valve, which is connected with the settling tank, consists of a balanced piston having two faces of equal area. The lower face of the piston is in communication with the settling tank by means of the equilibrium pipe 24, which remains permanently filled with water. This head of water

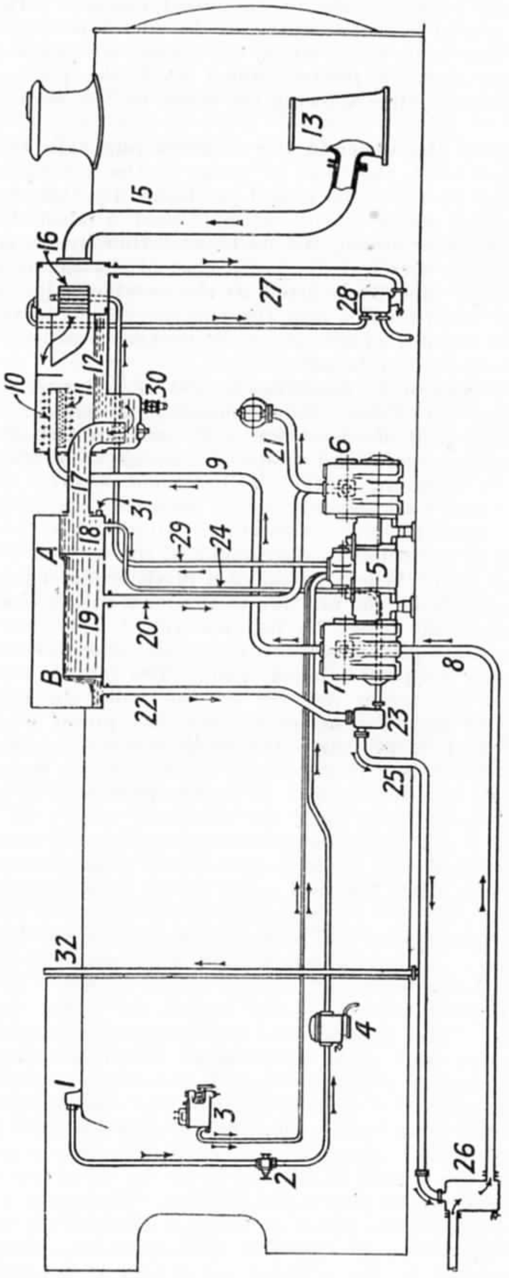


Fig. 61.—Arrangement of A.C.F.I. Feed-Water Heating Apparatus and Pump on a Locomotive.

maintains the piston in the up or closed position. The upper face of the piston is so connected to the overflow compartment of the settling tank that, when the excess of water fills the overflow pipe above a predetermined level, the piston, by its own weight, drops, thus allowing the water to flow to the suction vessel.

Immediately the water in the overflow pipe falls below this predetermined level, the head of water in the equilibrium pipe again lifts the piston to its closed position. By this means the escape of excess water to the suction vessel is ensured without any loss of exhaust steam, the feed water thereby being heated to a temperature corresponding with that of the engine exhaust. An atmospheric pipe 32 is fitted to the overflow pipe, between the overflow return valve and the suction vessel, to permit of the escape of vapour, so that in no circumstances will the suction of the cold-water pump be affected.

The oil separator 16 comprises a nest of Y-shaped plates, so arranged that no direct through passage is afforded to the steam. All oil held in suspension is thrown down as the steam impinges on these plates and drains off through the drain pipe 27, shown in the diagram, to the oil drain and security valve 28. It will be noted that exhaust steam pressure acts on both the top and the bottom faces of this valve. In addition, the bottom of the valve is subjected to the weight of the column of oil and water in the pipe. When it reaches a predetermined height, the valve lifts and allows the mixture to drain off to the track. The valve automatically closes by its own weight when the oil and water in the drain pipe falls below the predetermined height, thus preventing any escape of exhaust steam. The valve is so designed that, should the pump delivery to the boiler be completely obstructed for any reason, even with the pump working at maximum speed, it will allow the whole delivery to be drained away to the track and thus prevent the feed water from finding its way down the blast pipe. A small drain hole is provided in the equilibrium pipe near the oil-drain valve; it is most important that this drain should be kept free from all obstruction. It will be noticed that a small quantity of steam escapes from the drain when either the feed pump or the Westinghouse pump is working.

The feed pump is of the horizontal tandem type, the pistons for the steam 5, hot water 6, and cold water 7 cylinders respectively being mounted on one common rod. The water cylinders are provided with bronze bushes, the piston rings being of vulcanite. The suction and delivery valves, which are of large diameter and small lift, follow usual pump practice. Intercommunicating pipes, fitted with automatic control valves, for the evacuation of vapour, connect the corresponding ends of the hot and cold water cylinders respectively, their function being to condense, prior to delivery, any vapour or gases which might still remain in the hot feed. In the steam cylinder, two valves effect the steam distribution. The main valve (of the piston type, having heads of unequal diameter) is housed in the steamchest above the cylinder. The secondary, or reversing valve, is located in the cylinder cover and is operated by a reversing spindle working in the main piston rod, its action being practically identical with that of a Westinghouse air pump. These valves, together with the ports, are so designed that the piston speed of the pump is sensibly diminished at the commencement and end of each stroke, thereby eliminating shock to the parts and minimising the risk of trouble arising in service with the pump. The pump drain cocks are operated from the cab by a pull rod.

A mechanical lubricator 3 for the pump is located in the cab. Water pressure generated by the pump is transferred by a pipe to the working plunger of the lubricator and effects the upstroke, during which the oil is delivered, a spring actuating the return. A lever, provided to enable the lubricator to be worked by hand when necessary, also serves as an indicator for the working of the pump, as it reproduces every stroke made by the latter. The working plunger operates, through a shaft, the three oil pistons (two delivery and one suction) located in the reservoir. The two feeds from these pistons are adjusted by knurled caps above the sight glass; by unscrewing the caps, the feeds are increased, and vice versa. The right-hand cap adjusts the fore feed, and the left-hand, the back; one oil pipe delivers to the pump steam pipe and the other to the steam cylinder end. The lubricator is automatic in action and ceases to work immediately the feed pump is shut off. There is, therefore, no necessity to disturb the adjustment of the feeds once they are set.

A "Zenith" steam trap 4 is provided to ensure a supply of dry steam to the feed pump, and contains vanes on which the steam impinges and throws off any water it may be carrying in suspension. This water is automatically drained off to the permanent way. An ordinary drain cock is provided in addition and should be used regularly (at least once daily) to discharge the residue. A thermometer for registering the temperature of the hot feed water is mounted in the cab, and is of the vapour tension dial type, with capillary tube connection to the bulb in the settling tank. The bulb end is inserted and screwed into a special boss 31 provided in the settling tank, and the capillary tube is led from it to the thermometer which is situated in a convenient position in the cab. The dial of the thermometer is graduated in degrees Fahrenheit, and is coloured in two colours to enable the fireman to distinguish when the injector can be used in preference to the pump.

Before leaving the boiler and passing on to the engine, a few words relative to the clothing or lagging will not be out of place, although this is not fixed in position till after the boiler is permanently secured to the framing.

The loss of heat due to radiation would be very great if a locomotive boiler were unclothed, much greater in fact than in the case of stationary ones. The surfaces of stationary boilers are protected somewhat by the settings on which they are placed, but in the case of the locomotive such settings are not available, and the scouring action of the cold air on the boiler plates when in motion would produce great loss of heat, resulting in the consumption of a large amount of coal, the heat of which would be wasted.

A steam pipe, 30 in. diameter, conveying steam 100 lb. pressure has been found to radiate approximately 5,000 B.Th.U. per ft. run when uncovered. The same pipe when covered with a fairly efficient covering 2 in. thick radiates only 500 B.Th.U. per ft. run. These comparative figures will show the importance of having efficient clothing for the large amount of exposed surface on a locomotive boiler.

Many different kinds of coverings are in use. Perhaps the most common is asbestos applied in blocks about $1\frac{1}{2}$ to 2 in. thick, and sometimes, above the level of the boiler centre line, in the form of a thick paste which subsequently dries out but is kept in position by the lagging plates. One of the best-known insulating materials for locomotives is that known as the "Limpet" asbestos mattress; there is also sprayed "Limpet" asbestos. These are products of J. W. Roberts Ltd., of Armley, Leeds. "Alfol" insulating material, used to quite a considerable extent, takes the form of very thin asbestos foil, for which the merit of extreme lightness is claimed. The foil is kept in position by wire netting. The illustration on p. 72 shows a locomotive boiler lagged with this material.

The clothing plates are placed immediately over the top of the boiler covering or lagging. They are made from mild steel sheets usually a little under $\frac{1}{8}$ in. in thickness, rolled to a half-circle, and are held in position over the clothing by belts placed where the plates join to each other and having brackets riveted on the ends, through which a bolt about $\frac{1}{2}$ in. diameter by 5 in. long passes, so screwing the plates up tight, and holding them securely in position. These belts are usually made from $1\frac{1}{2}$ in. by $\frac{5}{16}$ in. flat wrought iron, shaped to two half-circles and joined together on a bracket resting on the boiler plates, to which they are secured by countersunk headed screws. The depth of this bracket gives the required distance from the boiler plates to the underside of the clothing plates, which may be from $1\frac{1}{2}$ to 3 in. according to the thickness of clothing or lagging.

The same principle is followed in clothing the firebox. Studs made from square iron about $1\frac{1}{2}$ in. section are screwed into the box sides with screw holes drilled and tapped in their outer end. The flat irons previously mentioned are fixed to these studs by set screws, the length of the studs defining the thickness of the clothing.

The firebox clothing plates, also made from sheet steel, are rolled to suit the various forms of fireboxes, and are held in place by clothing belts passing through brackets secured to the firebox sides.

The dome covering plates are made from charcoal iron or thin sheet steel, and worked into shape at the bottom to suit the curvature of the boiler barrel.

A strengthening plate of wrought iron, about 5 in. by $\frac{3}{8}$ in., is riveted inside the top or cap, through which a stud or a regulator lubricator cap passes and secures the cover firmly in position.

Notwithstanding the limitations of the normal type locomotive boiler and engine, both in regard to steaming capacity and safe working pressures, developments are continually in progress which have for their ultimate object the production of more powerful engines than have been available hitherto. The requirements of modern railway traffic conditions, therefore, have been conducive to considerable research and experiment, in endeavours to evolve a locomotive which not only will be more powerful, but also more economical in fuel consumption. By reason of various limitations both in design and operation, the overall thermal efficiency of the normal type locomotive engine is still comparatively low, thus providing ample scope for potential improvements. Probably these improvements will be mainly along the lines of higher steam pressures and temperatures, the more economical conversion of the fuel into heat energy, and the more efficient use for tractive effort of the energy thus obtained.

Developments associated with locomotives take several different forms. A common feature of locomotive firebox construction in the United States, and to a less extent elsewhere, is the device known as the "thermic siphon." This takes the form of a flattened funnel-like structure connecting at its lower end with the front water space and at the top with the crown-plate of the firebox. It is of Y shape with a long narrow opening at the top and a curved smaller opening at the base. Water passes from the bottom to the top by siphonic action as part of the water-circulation system of the boiler, adding to the heating surface area at the most effective point, namely, within the firebox above the firebed. Two or more siphons are built into the firebox in this way according to the size and other characteristics of the design.

Where very large fireboxes are employed, and as a consequence the difficulty of hand-firing becomes very much increased, mechanical stoking apparatus is often used. By means of this, the coal, reduced in size, is fed by a rotating worm to the firebox, thus dispensing with the need for shovelling. This mechanism varies considerably in design, although in general principle it is the same.

An interesting example of a locomotive in which steam is employed as the motive power, but not in the usual way with cylinders, pistons, and rods, in other words the reciprocating type, is afforded by the turbine-driven locomotive. An example of this is the engine built at the Crewe works of the L.M.S.R. in 1935. The boiler for this engine is of the ordinary locomotive type with Belpaire firebox, and a working pressure of 250 lb. per sq. in. There is a main turbine for ahead running, and also a reverse turbine, and geared transmission is used to the coupled wheels. The forward turbine is of 2,000 h.p., and of the non-condensing multistage type; the reverse turbine is of the impulse type. The steam supply to the two turbines is taken first through the main regulator on the boiler, and then to other regulators on the nozzles of the two turbines, six of which are provided for the forward and half that number for the reverse. These are operated from a control box in the cab. The locomotive is fitted with roller-bearing axleboxes throughout, and since its introduction has done a large amount of useful work with satisfaction and economy. It is, however, regarded more or less as an experimental type, and has not so far been duplicated. The locomotive referred to is illustrated on p. 254.

The maintenance in sound condition of the inner and outer firebox shells of locomotive boilers is a matter of great importance. With the normal type of locomotive boiler, any very considerable increase of steam pressure is liable to be accompanied by excessive maintenance costs, and the figure usually worked to nowadays for large and powerful locomotives ranges from 225 to 250 lb. per sq. in. There have been many locomotive boilers built more or less experimentally with pressures considerably higher than this, but except for a few constructed to withstand the pressure of 300 or 350 lb. per sq. in. with the normal design of boiler, they have all been of a special type, usually employing the water-tube form of construction.

A very clever design was worked out by the late Sir Nigel Gresley, Chief Mechanical Engineer, L.N.E.R., in conjunction with Yarrow & Co. Ltd., in the locomotive No. 10000, which was built in the year 1929 at the company's works at Darlington as a four-cylinder compound. The Yarrow-Gresley water-tube boiler carried a pressure of 450 lb. per sq. in. Notwithstanding the use of high steam pressure coupled with compounding, the engine did not prove economical in coal consumption, and, as it was burning considerably more fuel than the L.N.E.R. standard Pacifics, it was rebuilt in 1937 as a three-cylinder single-expansion engine with a steam pressure of 250 lb. per sq. in. The comparative particulars of the engine as originally built and as converted are as follows :—

	Original Engine	*Rebuilt Engine*
Cylinders (four) .	h.p. 10 in. by 26 in.; l.p. 20 in. by 26 in.	(Three) 20 in. by 26 in.
Coupled wheels diam.	6 ft. 8 in.	6 ft. 8 in.
Coupled wheelbase .	14 ft. 6 in.	14 ft. 6 in.
Total engine wheelbase	40 ft.	40 ft.
Boiler pressure . .	450 lb. per sq. in.	250 lb. per sq. in.
Total heating surface .	2,126 sq. ft.	3,346·5 sq. ft.
Grate area . .	34·95 sq. ft.	50 sq. ft.
Weight of engine in working order .	103 tons 12 cwt.	117 tons 17 cwt.
Weight of engine and tender in working order . . .	166 tons	172 tons
Tractive effort (85 per cent. b.p.) . .	41·437 lb.	35·455 lb.

Illustrations showing it as originally built and after conversion appear on p. 493.

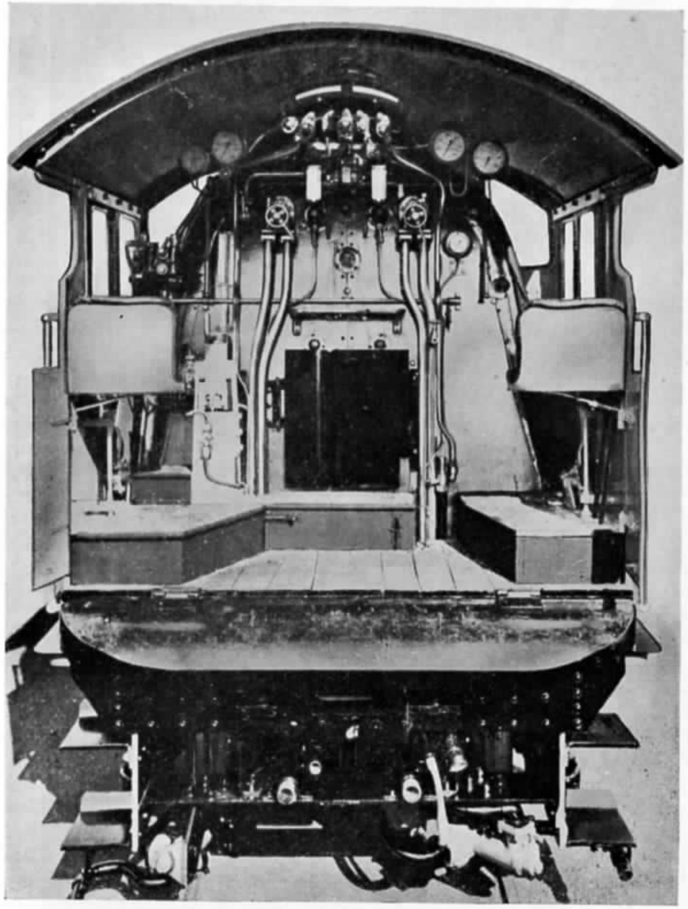


Fig. 62.—A Modern Locomotive Cab and Fittings (L.N.E.R. 4-6-2 Locomotive).

Fig. 63.—View in the Erecting Shop at Crewe, L.M.S.R., showing 4-6-2 Locomotive No. 6208 under repair.

Chapter 7

FRAMING, AXLEBOXES, BOGIE, AND SIDE RODS

The frame plates (Fig. 64) are usually made of mild steel, about $\frac{1}{16}$ in. thick, and are of a substantial depth, shaped to suit the number of wheels, etc., according to the design of the engine. They are placed vertically inside the wheels the full length of the engine, and stayed transversely the proper distance apart, the whole forming a strong, deep framework, which carries the engine and boiler, and is suspended through the springs from the axles.

The large plates forming the side frames are straightened by means of presses or hammering. Several of them are then bolted together and machined to the proper shape for the reception of the horn blocks and axleboxes, etc., the necessary holes for the bolts and rivets being mostly drilled a little under the finished sizes.

After leaving the machine the frame plates are finally straightened, and horn blocks, usually steel castings, are fitted and secured to the plates by turned bolts or rivets (1 in. diameter), which are made a good tight fit in the holes.

The axleboxes are then fitted into the horn blocks, which retain the boxes in their proper position, allowing at the same time a vertical movement, by which, in conjunction with the springs, the vibration due to the jolting of the engine is reduced.

There are many types of axleboxes. The materials usually employed in modern locomotive practice are cast iron and steel, bronze, and gunmetal. When not of the non-ferrous type, bearing brasses are fitted into the boxes, and these brasses usually are cast with pockets for the reception of white or Babbitt metal, which does not damage the bearings should they run warm, and is also employed for its smooth-running qualities.

Fig. 65 illustrates an example of the latter type of driving axlebox, which has been designed to meet the heavy traffic and high-speed long-distance non-stop requirements on the Great Western Railway. The box is fitted with a gunmetal bearing, which is prepared for the reception of a whitemetal liner, and arrangements are also provided whereby the journal may be efficiently lubricated. A felt pad in the keep is used for lubricating the journal, in addition to which another pad is used for lubricating the wheel box surface and two for the horn surfaces.

The axlebox (Fig. 66) is representative of the pattern now fitted to modern engines on the L.M.S.R. It is of generous dimensions and consists of a steel casting into which a semi-circular gunmetal bearing is pressed and located in position by

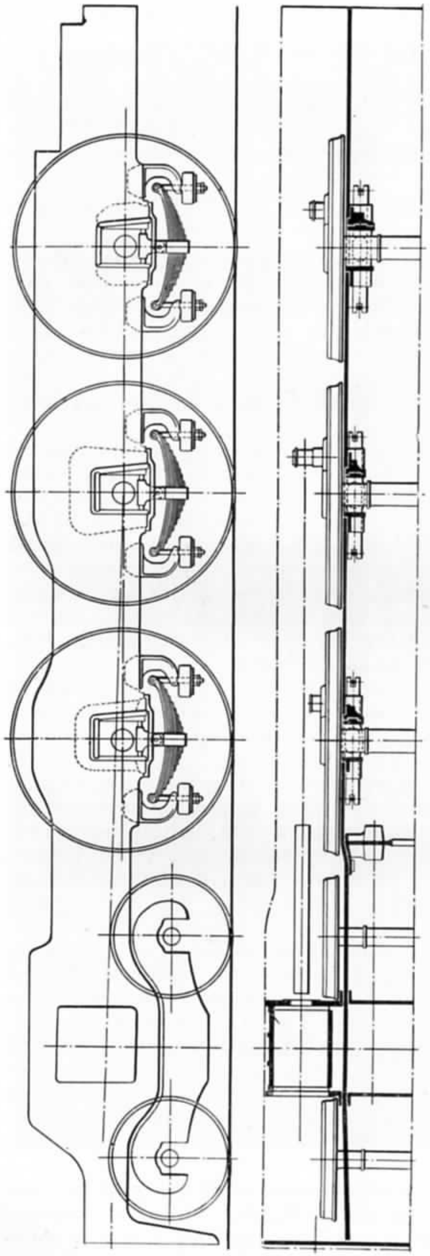


Fig. 64.—Main Frame of a 4-6-0 Type Locomotive.

set screws. Serrations are cut longitudinally in this brass to form a shallow cavity $\frac{3}{16}$ in. deep, extending round to within $1\frac{3}{4}$ in. of the horizontal centre-line of the box. This cavity is filled with whitemetal containing 60 per cent. of tin, forming the bearing surface which rides on the axle journal.

Lubrication is effected by a mechanical lubricator situated on the footplate of the locomotive delivering oil through flexible piping to the top of the axlebox. From this point, the oil, instead of being delivered to oil grooves on the crown of the box as in former practice, is now led through suitable channels to a series of holes practically on the centre-line of the journal. The brass is bored to a slightly larger diameter than the axle journal so that when it is resting in position there is a wedge-shaped clearance into which the oil is introduced and is drawn upwards by the rotation of the journal and lubricates the bearing surface of the axlebox. This arrangement has the advantage that there are no oil grooves on the crown of the brass to break the continuity of the oil film and reduce the effective bearing surface.

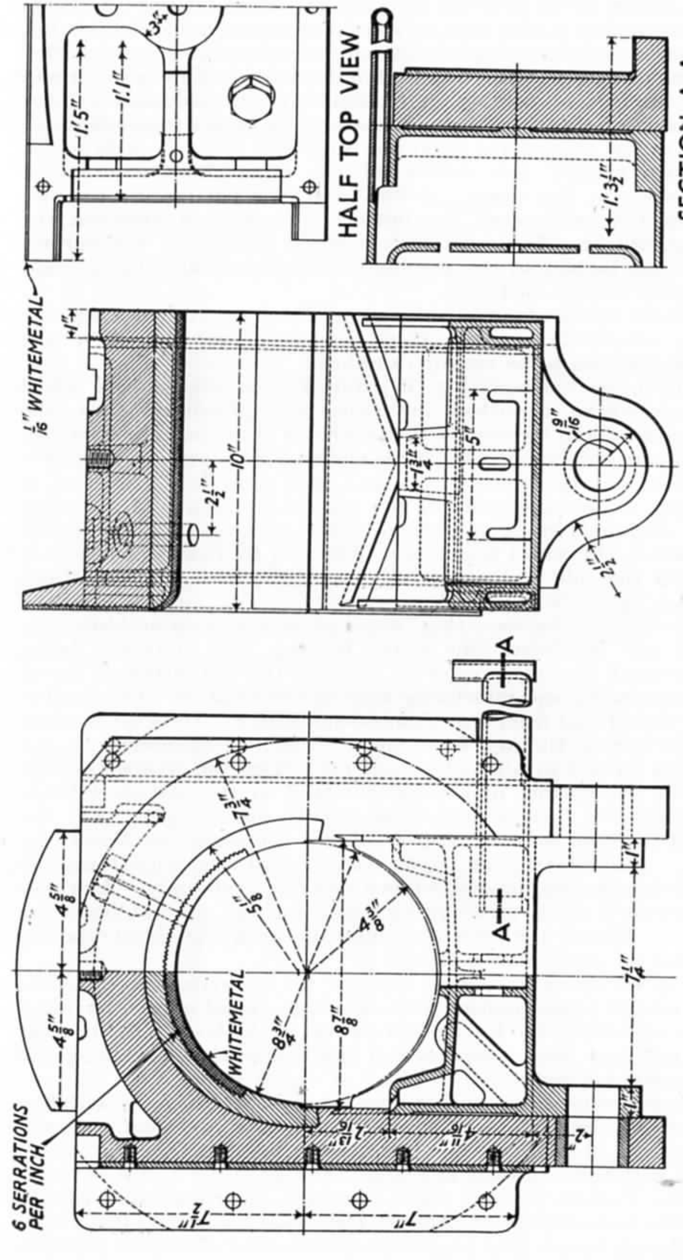


Fig. 65.—Sections through Locomotive Driving Axlebox, G.W.R.

The portions of the axlebox which slide in the horn guides have bronze strips studded in position. The underkeep is made of brass and is in the form of a deep rectangular box with a flat bottom in which rests a lubrication pad of generous proportions. The keep is filled with oil as an auxiliary form of lubrication and apart from the oil passing up the strands of the pad and on to the underside of the journal, it is also able to escape through small holes in the side of the keep and lubricate two felt pads which butt up against the surface of the wheel boss and ensure lubrication at this point. A 2-in. diameter pin bridges the two legs of the axlebox at the bottom, to which is attached the spring hanger. To avoid any possible scoring of the surface of the guides should the pin become displaced laterally, a brass button is let into each end.

Where axleboxes of this design are fitted to straight axles, the keeps are made so that they can slide out and allow the lubrication pad to be readily examined.

The bogie axlebox (Fig. 67) differs from the coupled wheel axlebox above described in taking its lubrication from the underside of the bearing only, and this is true also of pony truck and tender axleboxes of the same engine. No oil inlet is therefore provided on the crown of the box, and a well-designed pad is held up to the underside of the journal by means of a spring. Oil is contained in the underkeep, and as in the case of the coupled axleboxes, the wheel bosses are lubricated by means of felt pads let into the side of the axlebox keeps and taking oil therefrom through small diameter holes.

The driving axlebox (Fig. 68) is of bronze with anti-attrition metal cast into serrations in the bearing, bars of bronze being left around the oil grooves to prevent the anti-attrition metal from spreading and interfering with the lubrication. Lubrication is by forced feed from a mechanical lubricator. The load is taken by the spring through a tee piece, which is connected to the axlebox by a 2-in. diameter steel pin. This pin passes through lugs in the bottom of the axlebox and in the cast-steel keep. This latter is further supported by two smaller pins. On the top of the keep rests a cast-iron oil tray containing an Armstrong oiler. The oil tray and oiler can be entirely withdrawn for inspection on the removal of two securing bolts only. A triple-coil worsted swab prevents dirt reaching the journal from the inside. Where the axlebox slides between the horn cheeks, circular oil grooves are provided.

Fig. 69 shows a coupled axlebox for an express locomotive. It is a solid bronze casting with two white metal inserts, having a single oil feed at the top and an oil pad in the keep. The bearing surfaces have been proportioned generously to ensure long life and minimum wear.

Considerable progress has been made in recent years with the use of anti-friction bearings for locomotives and rolling stock, and the L.M.S.R. turbine locomotive illustrated on p. 254 is fitted with roller-bearing axleboxes throughout.

The Timken tapered roller bearings, illustrated in Figs. 70 and 71, have rollers of tapered form running on conical races. The design is such that projections of the lines of contact between

rollers and races meet at a common point on the bearing centre-line. Full line contact and true rolling of the rollers is thus obtained. The construction is clearly shown in the diagrams.

The bearing is mounted on the journal with a substantial press fit; an assembly pressure of 3 to 5 tons per in. of journal diameter is required. This method of assembly is simple and safe, and reflects standard railway practice as in the fitting of

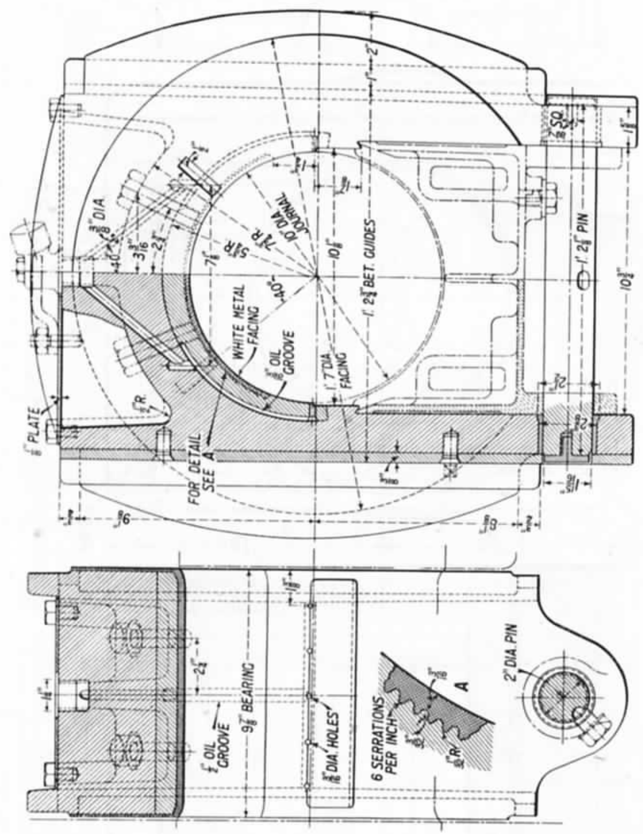


FIG. 66.—DRIVING AXLEBOX FOR MODERN ENGINES, L.M.S.R.

wheels, cranks, gears, etc. The axlebox containing the bearing is of cast steel and is simple in construction. Oil lubrication is employed, and oil is retained by a simple labyrinth type enclosure having no wearing parts. The starting resistance of a Timken-equipped coach or tender is about 3·5 lb. per ton weight, compared with a figure of 16 to 25 lb. per ton for a similar coach or tender fitted with plain bearings.

This of course is a very important factor in the conduct of the traffic, as much depends on the ability of the engine to master

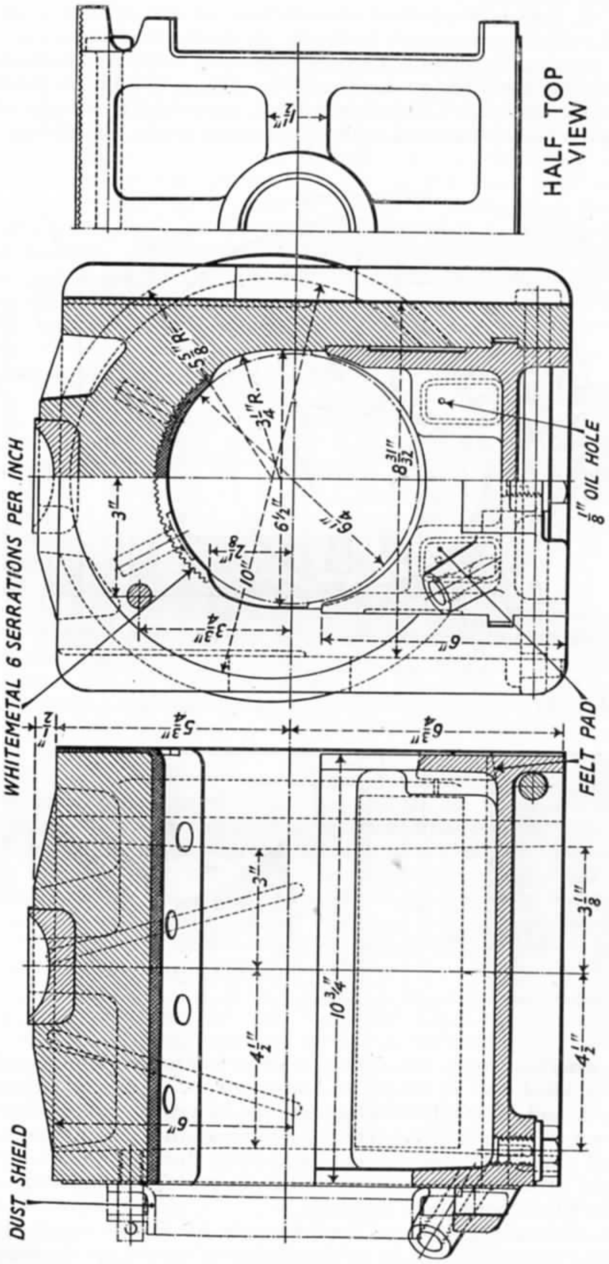


Fig. 67.—Type of Axlebox used for Bogie Wheels, L.M.S.R.

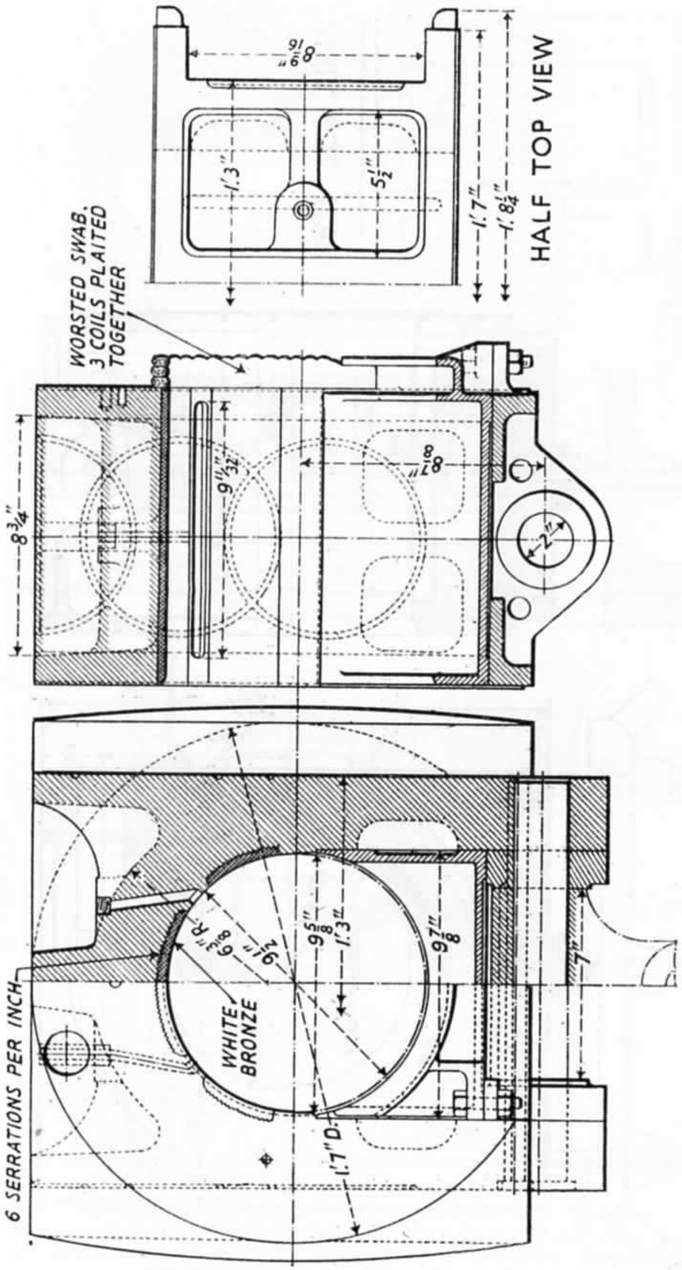


Fig. 68.—Driving Axlebox, L.N.E.R.

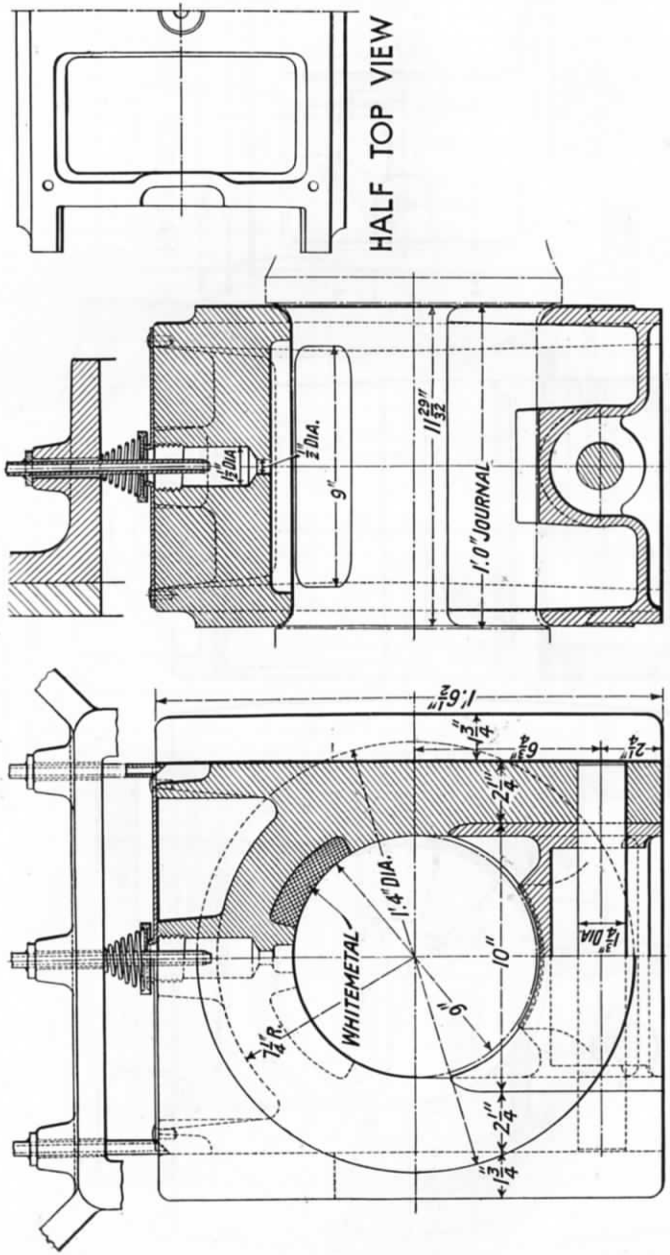


FIG. 69.—SECTIONAL VIEWS OF LOCOMOTIVE AXLEBOX, SOUTHERN RAILWAY.

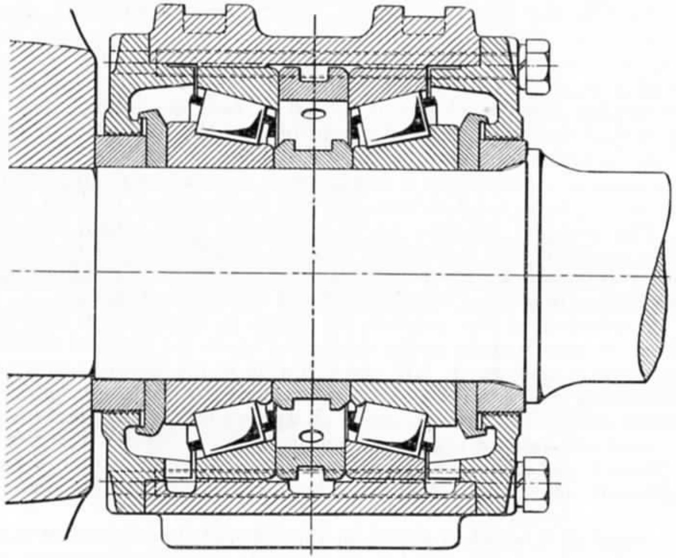


FIG. 70.—TIMKEN AXLEBOX FOR INSIDE JOURNALS, AS USED ON LOCOMOTIVE LEADING BOGIES, CONTAINING TWO SINGLE-ROW TIMKEN TAPERED ROLLER BEARINGS

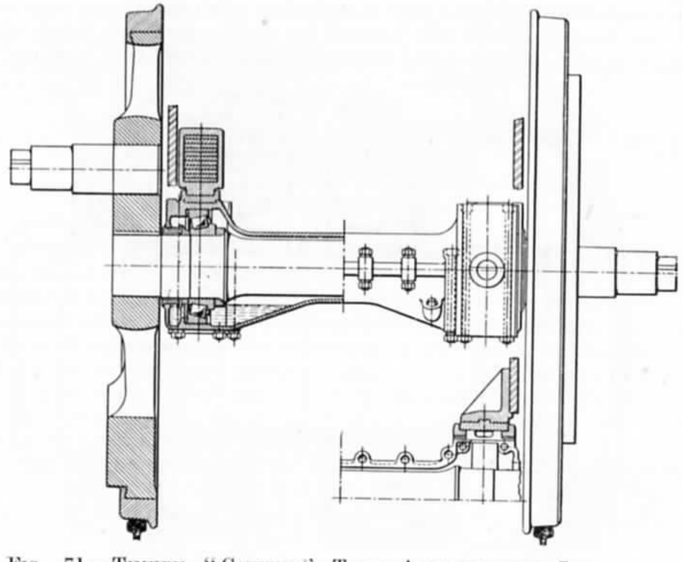


FIG. 71.—TIMKEN "CANNON" TYPE AXLEBOX FOR LOCOMOTIVE DRIVING AXLES. SINGLE TAPERED ROLLER BEARING MOUNTED ON EACH JOURNAL, HOUSED IN TUBULAR-TYPE AXLEBOX, EMBRACING THE ENTIRE AXLE BETWEEN WHEEL HUBS.

its load in the course of a run. No journal wear takes place, as the inner race is an immovable fit on it. This and the fact that the journal is completely supported through 360° by the bearing is of particular importance in locomotive driving axles, preventing the development of wear and pounding, and so increasing the smoothness of operation and the life of the motion. There is no rubbing motion in an axlebox so equipped, so that the running temperature is rarely more than a few degrees above the atmospheric temperature, and the bearing does not run hot.

The axlebox referred to is a reliable unit which requires little attention and is virtually trouble-free, therefore locomotives and rolling stock fitted with it are less prone to failure and breakdown in service than those fitted with plain bearings.

Inspection of the axlebox oil levels is required at intervals of six to nine months only, depending upon the type of axlebox and service concerned. Oil consumption is practically negligible, amounting in a standard average axlebox to about ·04 gal. per 10,000 miles run. A high-grade oil approximating to good steam cylinder oil, and of approved quality only, is used. The life of a Timken railway bearing varies in general from 500,000 to over 1,000,000 miles, depending upon the type of application and the service operated.

The S.K.F. axlebox shown in Fig. 72 with two spherical roller bearings is generally fitted to the outside journals of tenders and locomotive-carrying axles. This box is in halves and the bearings are secured to parallel journals by tapered sleeves. The split box permits of accessibility to the bearings for inspection, cleaning, and regreasing, and the sleeve mounting permits of easy removal of the bearings from the journal for replacement, or when this course is necessary to carry out the periodic wheel tyre turning.

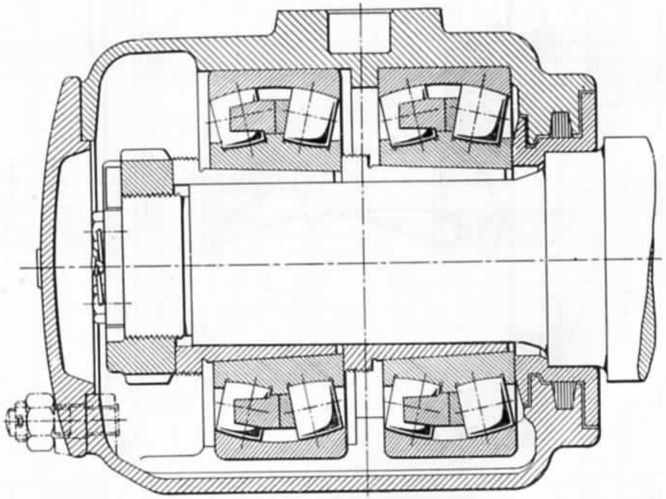


Fig. 72.—S.K.F. Roller-Bearing Axlebox for Outside Journals.

A soda-soap grease, as recommended by the bearing manufacturers, is used for lubrication, and one filling of grease made by hand with the box halves removed suffices during each periodic inspection when the bogies are lifted for the purpose of turning the wheel tyres. The used grease is removed before replenishing.

The axlebox (Fig. 73) applied to inside journals is also of the split type, and the bearing and sealing collars are shrunk direct on to their respective seatings. The box is lubricated with soda-soap grease as previously described. Coupled wheel axleboxes for high-speed locomotives are, however, sometimes oil lubricated, but for both designs the spherical labyrinth seals are filled with approved grease for sealing purposes, and the efficiency of the seal is maintained by periodic replenishment of grease to the labyrinth clearances, which can be done with the aid of the lubricating nipples fitted for this purpose.

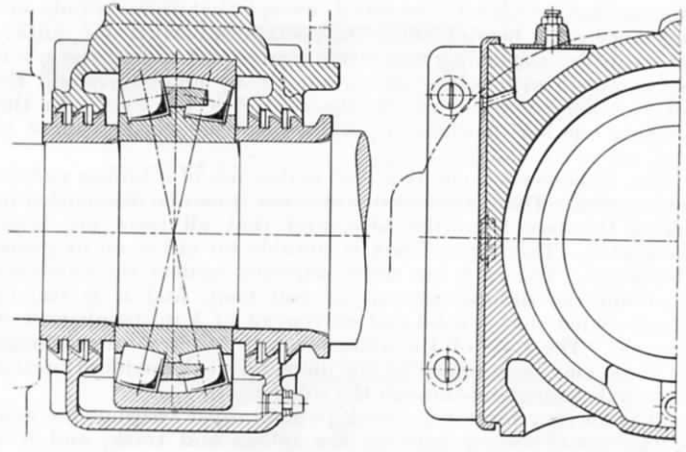


Fig. 73.—S.K.F. Roller-Bearing Axlebox for Inside Journals.

Removal of an inside journal bearing is seldom necessary, but, should the necessity arise, this can be done after pressing off the wheel. It is permissible to shrink on a new bearing to the existing seating and the existing wheel can be pressed on, providing the pressure of the fit is within the recommended limits. The roller bearing and sealing collars, which are shrunk on to the axle, are heated in oil up to 100° C. and 200° C. respectively, at which temperatures these parts can be passed easily over their respective seatings.

Fig. 74 shows the type of axlebox supplied by the Hoffmann Manufacturing Co., Ltd., which is doing good service on several main-line locomotives, and is suitable for outside bogie boxes and for tenders. The journal load is carried by two substantial parallel roller bearings, and the thrust load by a deep-groove ball location bearing. The latter has an outside diameter slightly smaller than the bore of the box, which ensures that it does not carry journal load. The full capacity of the bearing is thus reserved for the thrust. A feature common to all Hoffmann boxes is that no single bearing is called upon to carry a load in more than one direction. For this reason the size of the bearings, and therefore the dimensions of the boxes, can be kept to the minimum. Lubrication is by good quality grease.

To dismantle this box it is necessary only to remove the outer cover, and then the locking plate on the end of the axle ; and because the inner race of the ball bearing is made a push fit on the axle, the box, roller bearing outer races, with rollers and cages, and the ball bearing all come away as an integral unit, leaving only the roller bearing inner races and spacing collar on the axle. These can be protected with a wrapping of canvas or stout kraft paper when tyre turning is necessary.

The Hoffmann Manufacturing Co. also produces an inside bogie box that has given excellent results. In essentials it is the same as that previously described, except that there is only one long inner roller-bearing race. Inspection is carried out quickly and easily by slackening the inside clamp and sliding the whole box, complete with roller-bearing outer races and rollers and the ball location bearing, towards the centre of the axle. In this box only one horn surface is provided, so that thrust cannot be imparted to the clamping ring.

Fig. 75 shows a bogie box that makes use of a bronze pad for end location. The main features are that it can be dismantled by pulling the box from the axle, and that all races are interchangeable. This type of box is suitable for either oil or grease lubrication. The pads are easily adjusted against the axle ends to obtain the desired amount of end float, and it is usually recommended that a total end movement of $\frac{1}{8}$ in. be allowed on the axle. The ends of the axles must be left free of markings, but these may be stamped on the diameter of the reduced portion of the axle projecting through the roller bearing.

It is an easy matter to check parallel roller bearings for wear by the use of feelers between the rollers and track, and it is impossible to overload them by incorrect adjustment.

When assembling any anti-friction bearing, much trouble can be saved by working the lubricating grease well into the bearings before they are enclosed, observing at all times scrupulous cleanliness.

What are known as " needle " roller bearings are nowadays applied to certain moving parts of a locomotive. This type of bearing (Fig. 76) is suitable for application in locomotive valve gear components where the presence of any play in the bearings has an adverse effect on the valve events. The bearings consist essentially of inner and outer races with small-diameter steel " needles " occupying the space between. They are essentially suitable for pins where there is a rocking rather than a rotating motion, and the overall diameter is considerably less than would be occupied by a ball or roller bearing, which gives an advantage in working the bearing into the existing designs of rods. The bearings are lubricated by grease, applied by a grease pump with suitable nipples.

Ball bearings are applied in some cases to the return cranks

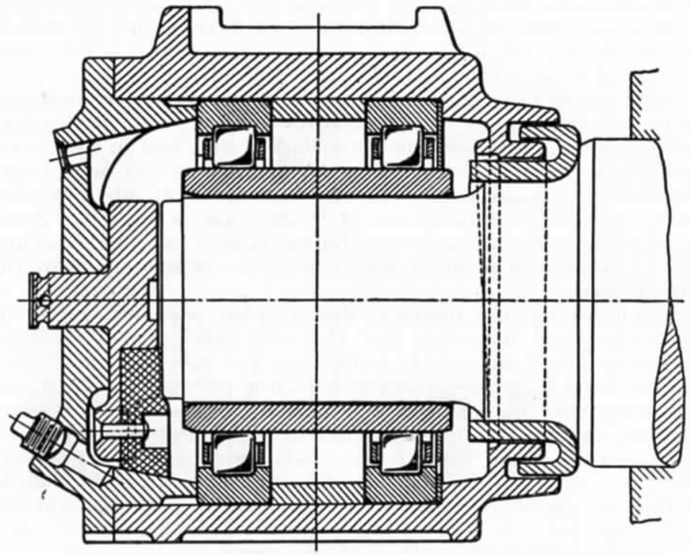


FIG. 74.—HOFFMANN ROLLER-BEARING AXLEBOX FOR OUTSIDE JOURNALS.

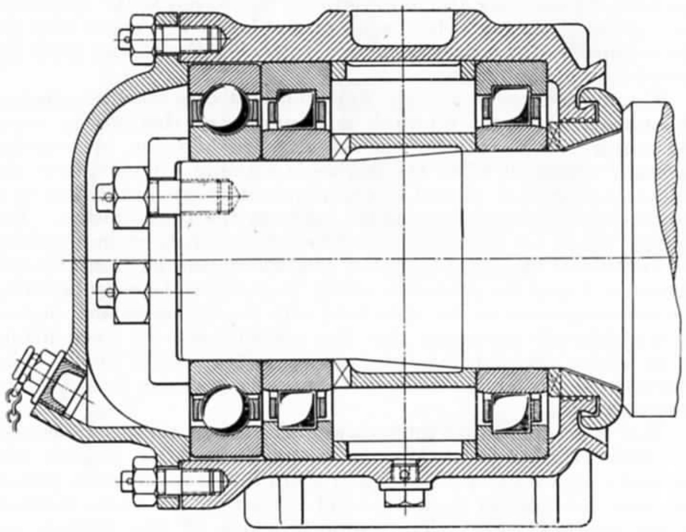


FIG. 75.—HOFFMANN ROLLER-BEARING AXLEBOX FOR OUTSIDE JOURNALS, WITH BRONZE PADS FOR END LOCATION.

of Walschaerts valve gearing (see Fig. 76). Present-day practice is in some cases to substitute the ball bearing for an S.K.F. spherical roller bearing, as the principle of mounting is the same. The latter form of bearing is shown in Fig. 77.

The cylinder castings of modern locomotives vary considerably as to size and shape. They are made from a good, hard, close-grained metal. Formerly, inside cylinders were cast in two pieces and joined through the middle of the steamchest, but now almost invariably they are made in one casting. Outside cylinders being right and left hand are, of course, cast separately. Some locomotives have three or four cylinders formed as a single casting, but in others the inside cylinders are cast separately from the outside ones.

After leaving the foundry, the cylinders are first bored out to the required diameter, and the port faces planed for slide valves or bored for piston valves, as the case may be. The various flanges on the cylinders are then planed or milled, and the steam and exhaust ports accurately machined after being carefully marked out from a template. The stud and bolt holes are also drilled and tapped, the studs inserted, and the covers fitted in position. So that no difficulty may arise afterwards in the erecting shop, where it is customary to place the various parts together, the pistons, valve spindles, glands, bushes, etc., are usually tried in their places at this stage.

The trailing buffer beam or bottom footplate when in position forms the foundation for that end of the engine. This plate or beam is machined, and the necessary holes for securing it to the framework are drilled before erection. To the underside of the beam are fastened the brackets for the brake shaft and the brackets for carrying the automatic or the steam brake cylinders, etc. Passing through the centre of the beam is a cored hole for the reception of the drawbar, which attaches the tender after the completion of the engine.

The motion plate is made from the best cast steel, toughened by annealing. Great strength is required, as this has to carry the major portion of the motion work in addition to resisting constant vibration when the engine is running. The ends of the plate are slotted or planed to the required gauge and drilled to a template for securing in position between the frame plates. The facings or lugs for attaching the slide bars and valve spindle guides are machined carefully, so that the faces can be used by the erector in fixing the plate accurately in position, thereby ensuring the true alignment of the slide bars with the cylinders and engine. It is absolutely necessary that the motion plate be fixed firmly in its place, and for this purpose cold steel rivets about $\frac{7}{8}$ in. diameter are used when it is eventually secured between the framing plates.

The frame-plate stretchers are made from mild steel about the same thickness as the main frames. After having the necessary angles fitted for securing them to the main frame plates, the ends are planed to gauge and drilled in the same manner as the motion plate. The cross bracings of the frames are sometimes formed as castings and alternately fabricated and welded.

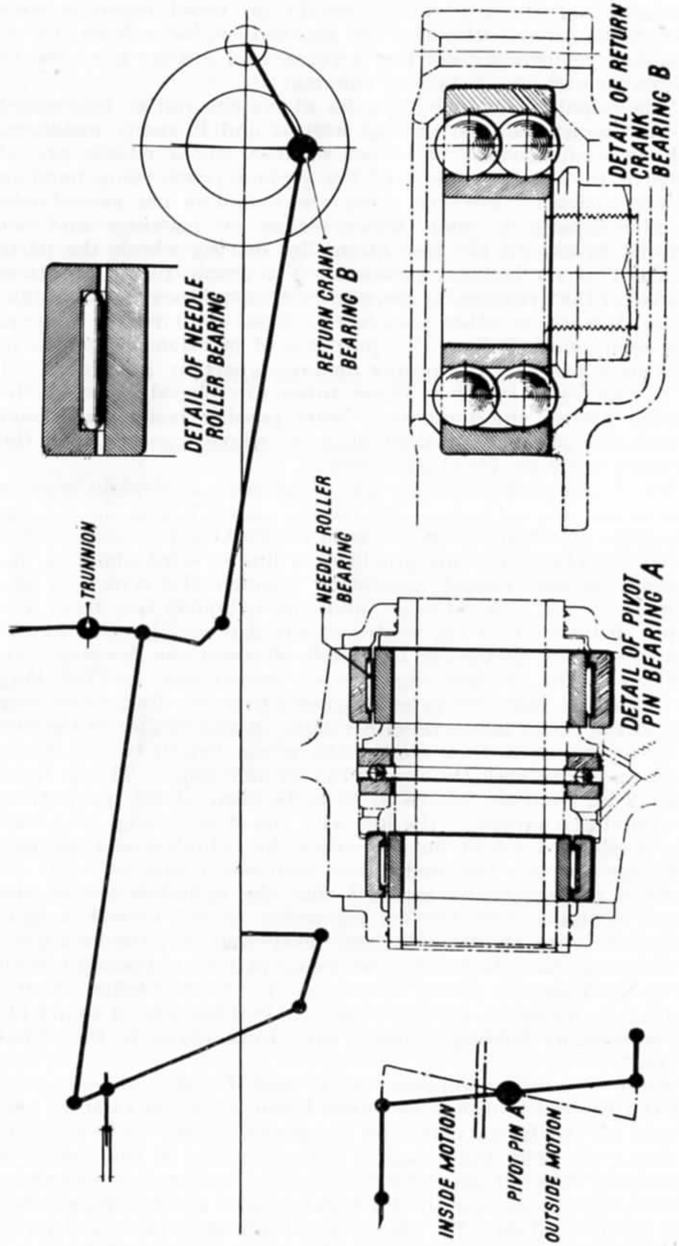


Fig. 76.—Details of Needle Roller Bearings and Ball Bearings of L.M.S.R. Locomotive Valve Gear.

It is essential that these principal parts required for the foundation of the locomotive should be fitted together with absolute accuracy, otherwise the finished engine will be out of alignment, constantly needing repairs, and always a source of trouble through unsatisfactory running.

The height of the driving axles above the rail is determined by the diameter of the driving wheels, and in many instances, such as with modern passenger engines, these wheels are of sufficient diameter to allow of the various parts being fixed in a level position. For this type the cylinders are accordingly placed temporarily upon wood blocks or packings and set perfectly level. In the case of smaller driving wheels the parts are fixed in an inclined position. The frame plates are then secured to the cylinders by temporary bolts and levelled throughout, with wood or other packings or jacks employed to support their ends and middle. For purposes of erection the plates in some cases are held the proper distance apart by iron tubes cut off to the right length. These tubes are placed between the framing plates, the temporary bolts passing inside them and through the plates, thus tightening the whole together until the necessary parts are fitted transversely.

To obtain true centering and alignment a straight-edge is fixed in the driving horn cheeks to the centre height the driving axles take up when the engine is in its working position. When special templates are not provided, a line or cord about $\frac{1}{16}$ in. diameter is also passed accurately through the centre of the cylinder to the straight-edge, and the cylinders are fixed the proper distance from the centre of the driving axles by means of a steel staff previously measured off from the drawing. In addition to the straight-edge already mentioned, another long one is fixed a little above and parallel with the first, projecting beyond the frame plates on either side. A line similar to the one in the cylinders is then strung the whole length of the frame plates and level with the top of the straight-edge. This is fixed about 2 in. from the plates so as to be clear of any projection. By applying a square to the line with the straight-edge as a base it is possible to see at once whether the cylinders and framing plates are perfectly true and square with each other.

After the erector is satisfied that the cylinders are at the proper distance from the driving axles, at the correct height, and square with the framing both inside and out, the bolt holes for securing the cylinders to the frame plates are opened out to the finished size by means of a rose-bit. Turned bolts, usually about 1 in. diameter, are then inserted, making a good sound fit, and so securely holding cylinders and frame plates in their final position.

After this the temporary bolts and ferrules are removed and the bottom footplate or buffer beam placed in position and secured to the frame plates by temporary bolts. It is possible to throw or twist the framing out of square if this beam is imperfectly fitted or inaccurately machined, so that it is necessary at this stage to go over the lines and squares again. After it has been ascertained that the frames and beam are square and level, the bolt holes are opened out to the finished size, and hexagon-

headed bolts, about 1 or $1\frac{1}{8}$ in. diameter and a good tight fit, finally secure the beam permanently in position.

The motion plate is placed between the framing and held in position by temporary bolts until adjusted to the proper height and distance from the driving axles. The height is determined by the line which passes through the cylinders and the distance from the driving axles, located by a steel staff measured off from the drawing. After the plate has been fitted to the proper height and fixed exactly square with the cylinders, the rivet holes are opened out, and the plate is secured in position as already described. The stretcher plates are also placed between the frame plates and riveted in position. This practically completes the main framing or foundation for the locomotive, which now may be considered ready for the reception of the boiler. This is received from the boiler shop in a complete state after having been tested to the required pressure. This test pressure

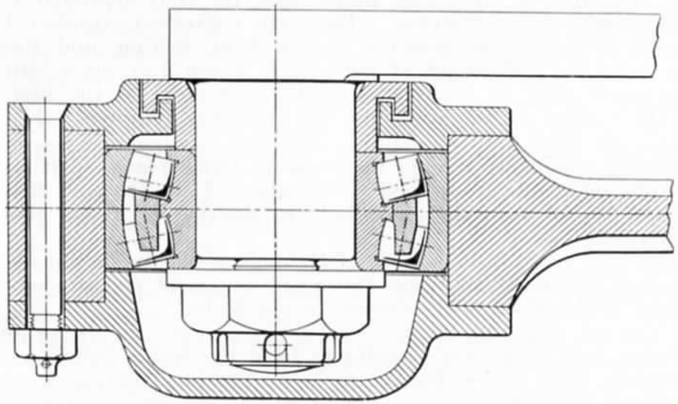


Fig. 77.—Roller-Bearing Return Crank.

is usually obtained by pumping water at a given temperature into the boiler, using two pressure gauges, one of which should have been calibrated carefully from a standard test pressure gauge. One and a half times the normal working pressure is in most cases applied, and a thorough inspection of the tubes, joints, etc., made with the pressure still on. Any sign of leak or fault is made good, and the result of the inspection is duly entered into books supplied for this purpose.

For erection, the front tubeplate is secured by temporary bolts to the back flange of the cylinder until the alignment of the boiler is complete. Expansion bars or brackets which have been riveted securely to the firebox sides rest upon the framing and form the supports for the trailing end. When under steam the boiler will be approximately $\frac{3}{8}$ in. longer than it was before the application of heat. This expansion, if restrained by rigid connections at both ends, would exert sufficient force to buckle or twist the framework and thereby throw the journals and engine parts out of their true alignment. The brackets are therefore fitted so that any longitudinal movement due to expansion is unrestrained. After being placed in position on the framing, the lines (which run the full length of the frame plates) are again tried to see that the boiler is sitting squarely in its place, and that the added weight has not disturbed the alignment of the framing. The holes in the cylinder flange and iron tubeplate are then opened out to the finished size, and turned bolts, about $\frac{7}{8}$ in. diameter, inserted as a tight fit, thereby securing the boiler permanently in position.

The buffer plates are made as a rule from mild steel; the plate to which the leading buffers are secured eventually is about $1\frac{1}{4}$ in. thick. This plate is attached to the main frame plates by strong angle irons and secured with hot rivets about $\frac{7}{8}$ in. diameter. The trailing or back buffer plate is usually about 1 in. thick and is secured to the cast-iron buffer beam by bolts and studs about 1 in. diameter. The buffer plates are fixed at the two ends of the frame plates, and therefore represent the full length of the framing. They are connected together by footplate angle irons about 6 in. by 3 in. section, and these are fitted the full length of the engine, about 1 ft. 10 in. from the outer sides of the frame plates, according to the design of the engine or the width of the footplate required. These angles are supported at suitable distances by footplate support brackets, which are riveted to the main frame plates. The top footplating, made from steel sheets about $\frac{3}{8}$ in. thick, is fitted on the top of the angles and held in position by rivets about $\frac{3}{4}$ in. diameter.

By this time various parts of the engine will be in course of erection simultaneously and the construction of the smokebox begun, as described in the chapter on the boiler.

The cab (Fig. 62), which forms the shelter for the driver and fireman, will have been brought in from the boiler shop almost complete, with the splashers for covering the trailing wheels attached, if large-diameter trailing wheels are employed in the design. The cab is usually made from mild steel plates about $\frac{3}{16}$ in. thick, with the front plates left loose so that they can be fitted to the firebox top and sides after the cab has been secured by bolts and rivets upon the footplate.

The sides and top, etc., of the cab are held together by angles about 2 in. by 2 in. section, and an angle about $1\frac{1}{4}$ in. by $1\frac{1}{4}$ in. is fitted round the firebox and close up to the cab front after the front plates have been riveted finally in position. The rounded beading which is fitted over the exposed edges of the plates forming the cab sides, etc., is intended as a protection to the hands and also to give the cab a finished appearance. The windows, which are afterwards fitted into the cab front, are made from best polished plate glass about $\frac{1}{4}$ or $\frac{5}{16}$ in. thick. They are held in position by brass frames, which may be hinged at the top or fitted upon pivots so that they can be opened for cleaning or other purposes.

In passenger engines the splashers for encasing the coupled wheels are usually made from plating similar to that employed in the construction of the cab, and are held together by suitable angle irons. They are as a rule secured in position by bolts to

the footplate and trailing splashers, bolts also passing through the splasher backs to the main framing. In most cases the splashers for covering driving and leading wheels on goods engines are made from cast iron, and a good finish is obtained thereby at a much less cost than is necessary for the larger wheels. The cast-iron or bottom footplate, which is immediately underneath the cab, is covered with timber, so that the driver may be at a convenient height for manipulating the regulator, and also be able to maintain a proper lookout through the cab windows. The timber is covered with an iron or steel plate about $\frac{3}{8}$ in. thick, and holes are drilled for the pipes and rods which require to pass through the footplate to the connections below.

The important duties performed by means of the fittings on the footplate, as previously mentioned, make it imperative that they should be mounted or fixed in the most accessible positions, for ease of manipulation by driver or fireman. The convenient manner in which they are arranged, together with the accessibility of the whole of the fittings in the cab, will be evident if reference be made to pp. 480-492 (Appendix).

The reversing lever bracket is usually on the top of the splasher on the driver's side of the cab, and the long rod attached thereto passes through the cab front to the reversing lever. A quadrant bracket is generally fixed on the side of the reversing lever bracket for retaining the lever which actuates the long rod passing through the footplate to suitable connections for the cylinder drain cocks. On many engines it is customary to rivet a strengthening plate about $\frac{3}{8}$ in. thick on one or both sides of the cab, to which are secured the sight-feed lubricators. The damper handles already mentioned will be found generally on the fireman's side of the cab.

Cast-iron sandboxes are fitted inside the splashers or secured by $\frac{5}{8}$ in. or $\frac{3}{4}$ in. diameter bolts to the main framing, footplate support brackets, and top footplate, through which a hole about 6 in. diameter is cut. If hand sanding arrangements are fitted, an ordinary butterfly type of valve is mostly in vogue, actuated by rods inside the cab, and the sand is conveyed by pipes to the rails immediately in front of the wheels. Many types of engines have sand pipes applied at the back of the trailing coupled wheels for use when running in the opposite direction, *i.e.*, in reverse.

Many modern locomotives are fitted with Gresham & Craven's patent steam sanding arrangement (see Fig. 78). This is controlled by the steam sanding cock mentioned among the front-plate fittings, from which steam pipes are led to a sand ejector fixed so as to be above the rails, and immediately in front of the wheels. A small hole will be found in the bottom of the ejector for draining any moisture that may accumulate. The principle upon which ejectors are worked is applied to the sand ejector. Steam is admitted to a contracted cone, so that a partial vacuum is created, which induces a current of air in the air inlet of the sand trap. This current lifts the sand from the trap and carries it down the sand pipe till it comes in contact with the steam, which then directs it under the tread of the wheel. The amount of sand used is varied to suit different conditions by the regulation of the steam sanding cock. The sand should be sieved thoroughly before being placed in the sandboxes, otherwise pebbles, etc., are liable to choke up the pipes and trap. A faulty steam sanding cock is also likely to give trouble, and for this reason special cocks are made to prevent, as far as possible, any leak when the apparatus is not in use. If the cock is not maintained in good order, trouble will be caused by steam leaking into the pipes and becoming condensed. The moisture thus produced retards the passage of the sand, which in time chokes the pipes, especially in frosty weather. The air inlet to the trap should be cleansed from time to time, and the plug, which is fitted in the bottom, taken out, so that any grease or damp lumps of sand that may have formed can be removed.

Facilities are provided in the apparatus to meet these different requirements. The patent steam sanding trap (Fig. 79), for example, is extremely simple in construction, and a description of its manipulation will be sufficiently indicative of its efficiency, accessibility, and ease of operation. By giving the handle A a quarter-turn, as indicated by the motion-line, the interior of the trap is exposed for inspection or cleaning. At the same time, sand is prevented from running out of the sandbox by the flat valve B, which is fixed on spindle C, and moves with the handle A. If it is desired to empty the sandbox, the handle A is turned in the reverse direction.

Gresham & Craven Ltd. now manufactures and supplies the Lambert type of wet sanding. In this type of application the sand does not require to be dried, as it is applied to the rails in a wet condition by a flush of water supplied from the boiler. In hot, dry countries, and particularly where high winds are encountered, this type of sanding has advantages, as the sand cannot be blown away and adheres to the hot, dry rails and tyres in an effective manner.

The apparatus (Figs. 80 and 81) consists of a master water valve with which the amount of water fed to the sanders can be regulated according to requirements, and a control valve which works the sanders according to the direction of movement, namely, front or back. The pipes are provided with suitable automatic drip unions to empty all pipes and connections when not in use. The arrangements of all three fittings and sandtraps are illustrated on the diagram of a typical locomotive.

The sanding traps and apparatus consist of a sandbox with suitably distributed water pipes and flushing jets fed from the control valve, and the trap with its adjustable sleeve regulating the sand opening. The sand normally lodges on the "step" of the trap, but is carried out with the water and led to the point of application when water is turned on.

Compressed air sanding arrangements are sometimes fitted somewhat on the lines of the steam arrangement. This type is usually attached to locomotives fitted with the Westinghouse brake.

There are various arguments in favour of steam or compressed air as against the older-fashioned hand-sanding gear. The most important advantage gained or claimed is the certainty of delivering the sand at the point of contact between the wheels

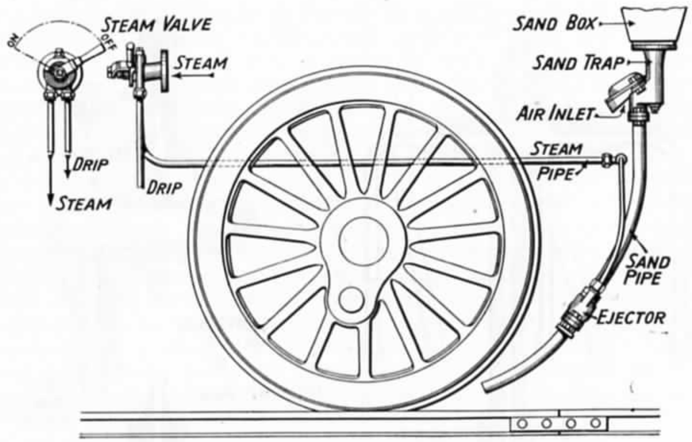


FIG. 78.—ARRANGEMENT OF STEAM SANDING GEAR FOR LOCOMOTIVES.

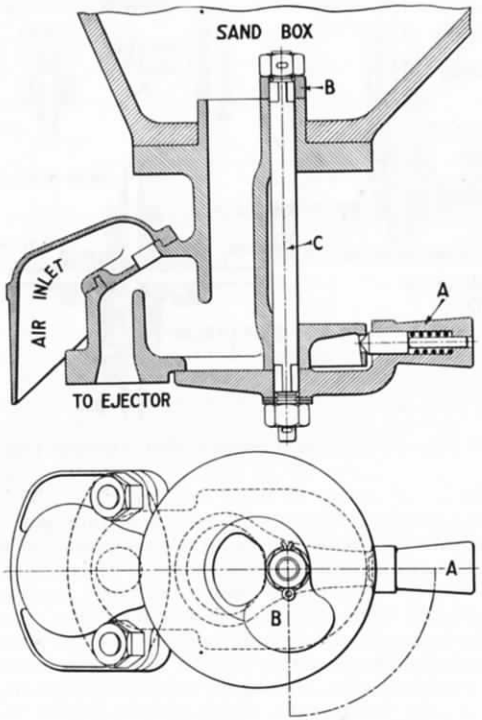


FIG. 79.—SECTION AND PLAN OF SANDBOX AND ATTACHMENTS.

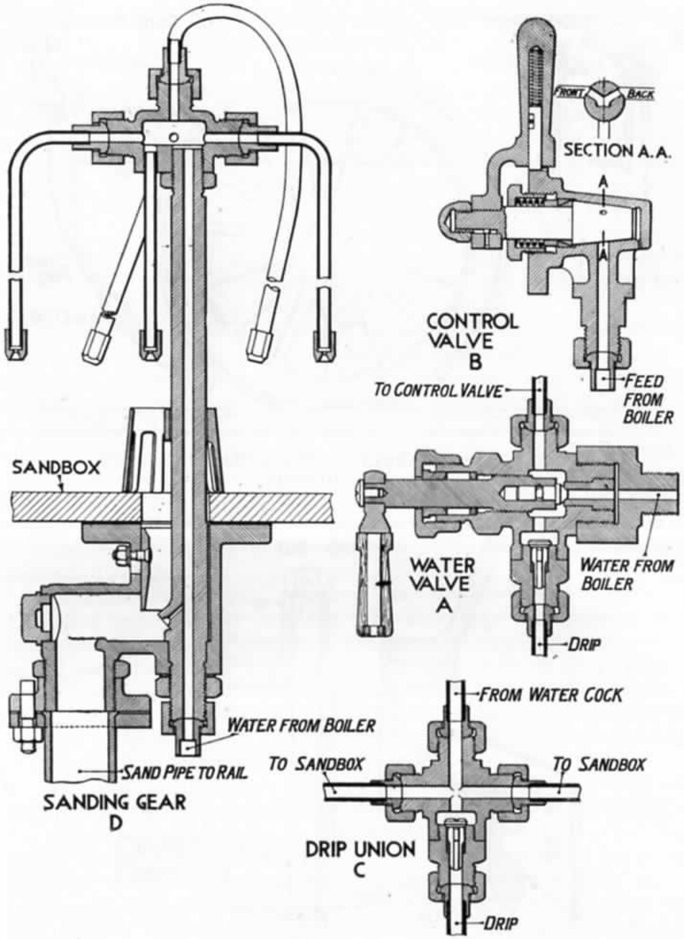


Fig. 80.—Details of Lambert Wet Sanding Gear.

and the rails in all states of wind and weather. This does not always obtain with the hand gear. A strong side wind, for instance, is liable to blow the sand away from the rails, more especially when going round a sharp curve. It is also pointed out that if the engine is slipping badly and not moving forward, the sand will fall upon the rails in front of the wheels unless delivered where required by some positive action, such as steam or compressed air. At the same time, it must be remembered that a certain amount of care should be used when sanding. If the engine is slipping badly, the regulator should be shut before the sand is applied, otherwise there will be a sudden jerk when the wheels begin to grip. A good driver knows that this neglect

to close the regulator is a vicious practice and should not be tolerated, because the violent shock passed through the driving axles, crank-pins and motion work is always liable to cause fractures. The damage may not show at the time, but it is quite possible that incipient cracks may be started, and eventually develop until a fracture occurs, causing perhaps one of those serious breakdowns for which no apparent cause can be found at the time of the accident. It is also bad practice to use more sand than is absolutely necessary, because sanded rails offer greater resistance to the vehicles on the train than clean ones, thereby increasing the load on the engine. Should it be required to make an emergency stop at a signal or other obstruction, when running down a bank, this increase of resistance due to sanding may be used to advantage, as the sand is of material assistance in pulling up. The hand-sanding gear under these conditions would be found the most efficient, inasmuch as the sand is absolutely dry, and there need be no anxiety on the

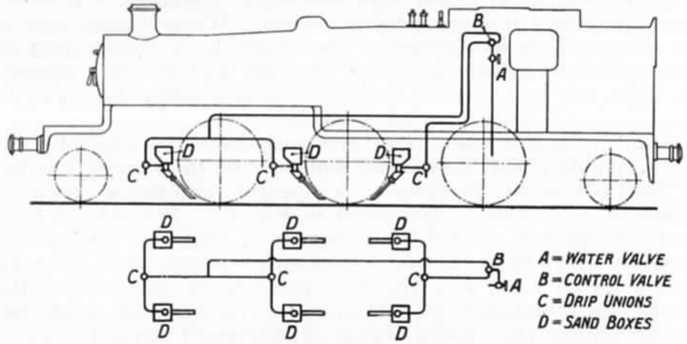


Fig. 81.—Arrangement of Lambert Wet Sanding Gear on Locomotive.

part of the driver and fireman in frosty weather as to whether the pipes are frozen. From the foregoing it will readily be understood that violent twisting strains are sent through the axles when the sanding arrangements fail on one side of the engine only. If this occurs, the danger of straining or fracturing the axles is very great, and the driver and fireman should therefore take every precaution to see that both sides of the engine are being sanded equally.

The framing and boiler being ready for the axles and wheels, it is proposed to take a brief glance at some of the methods adopted in building the wheels, axles, tyres, and eccentrics before their delivery in the erecting shop.

The driving axle required for an outside cylinder engine is much simpler than that for one with inside cylinders. As previously stated, outside cylinders drive direct to the wheels, and the driving axle is thereby modified and made from a straight steel forging. The journals for the reception of the axleboxes are turned smaller in diameter than the ends which form the wheel seats, and a collar is also turned on the inside of the journal to limit the end play of the axle. In the case of inside cylinders, the driving axles are made from steel and forged with two cranks, one for each cylinder, and set at quarter centres. The cranks are turned to the required shape and dimensions in a specially designed lathe, which allows of their being turned to the necessary throw, usually about 13 in., according to the stroke of the engine. The crank cheeks or webs are sometimes circular in shape, although those that are slotted to an oval or elliptical form are the most common. The Z crank axle is very common on the Continent, where outside valve gears are very generally adopted. The thickness of the crank webs is often restricted by the distance between the centres of the cylinders, the width of the journals, and the room required for the eccentrics, so that in some cases the webs are strengthened by shrinking a wrought-iron or rolled-steel hoop over them.

Crank axles may be of two types, either solid or built up. The solid forged crank is the more usual practice for engines of small or medium power with two inside cylinders, and under these conditions it gives reliable service. Where higher powers are concerned, or in the case of the single throw cranks used on three-cylinder engines, increased bending and twisting stresses are imparted to the axle, and there is a liability for flaws to develop after a limited period of service.

Built-up crank axles were first introduced by the late Mr. F. W. Webb, Chief Mechanical Engineer of the former London & North-Western Railway. A typical two-throw built-up balanced crank axle is illustrated in Fig. 82. It is of the type used on modern L.M.S.R. locomotives, and the cylindrical portions, which form the wheel seats and bearings, have the webs shrunk on to them and keyed in position, to ensure that the cranks are maintained at 90° apart. This type of crank has the advantage that under undue or continued stress the parts will tend to loosen rather than develop flaws, and as the different elements can be renewed as required, the crank may be said to have an almost indefinite life. In order to reduce weight, a hole is sometimes drilled through the centre, the result being what is known as a hollow axle.

The full force of the steam in the cylinders and the vibrations due to the road are passed through the crank axle and journal. Failures in crank axles are therefore fairly frequent, and to obtain further security in the event of a fracture, a hole is sometimes bored through the centre of the crank journal, and a bolt or screw about 2 in. diameter fitted through and riveted over.

The main-bearing journals are accurately turned, and may be from 7 to 10 in. diameter and 9 to 11 in. in width, according to the size of the engine. The body of the axle on which the eccentrics are fixed is usually made about the same diameter as the journals. The axle ends or wheel seats for either driving or coupled wheels are turned slightly taper, and the wheels are afterwards pressed into position by hydraulic pressure and securely fastened by steel keys. The wheel centres of a modern passenger engine are generally made in the form of a steel casting, which is toughened by annealing. In this manner it is possible to make the bosses for receiving the crank-pin, and the increased

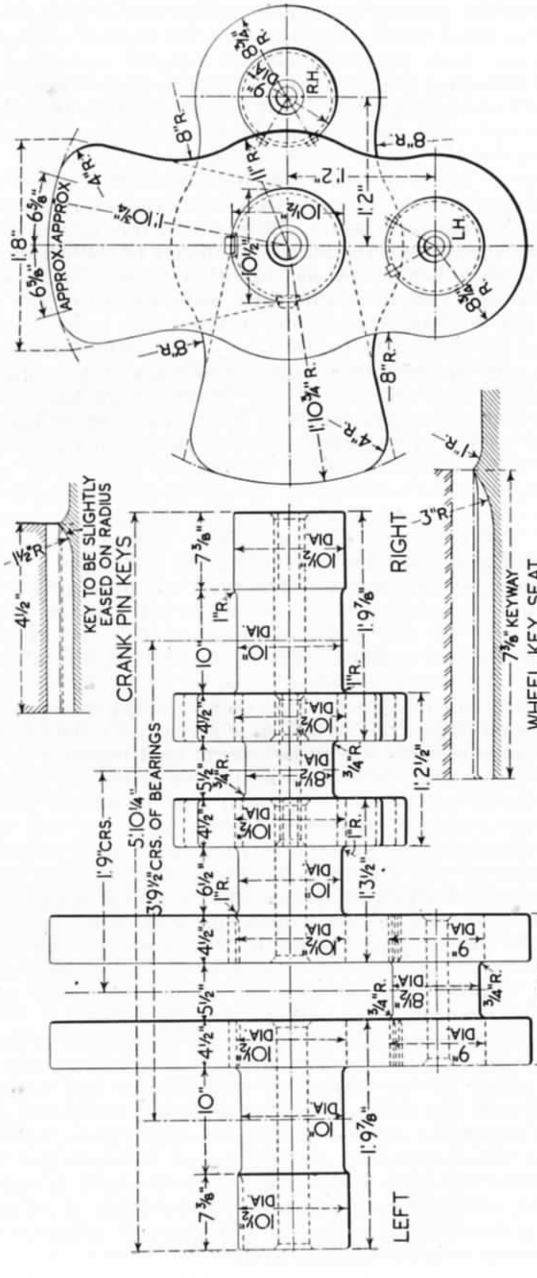


Fig. 82.—Built-Up Balanced Crank Axle, L.M.S.R.

rims for counterbalancing the weight of the cranks and motion-work, part of the casting, so that the initial cost of manufacturing the wheels is much lower than when the old type of wrought-iron wheel centres with separate balance weights was used. For goods and shunting engines cast-iron wheel centres made on the lines of steel centres have been used. The bosses for the reception of the axle and crank-pin are bored out in the lathe, and the rim is turned to suit the particular design of tyre to be used.

The tyre is made from one piece of best steel, rolled to the required size and shape in specially constructed rolls, so that there is no joining or welding. It is bored out to suit the rim and a little smaller than the outside diameter of the wheel centre. The tyre is then heated by gas or other means, and sufficient expansion is obtained to admit of its being placed in the proper position. In cooling, contraction takes place and causes the tyre to grip the rim of the centre firmly. For additional security the tyre is also fastened by means of studs about 1 in. diameter, which pass through the rim of the wheel centre between each spoke, or, secured by rivets about $\frac{5}{8}$ in. diameter, through the front flange of the tyre opposite each spoke when the retaining-ring principle is adopted. After the wheels have been pressed upon the axles and keyed fast, the tyres are turned to the required shape, and are coned on the rim to suit the angle at which the rails are fixed. The coning of the tyre assists in keeping the engine central with the track, thereby reducing the rocking or "nosing" tendency as much as possible. The tyres are also turned to the proper width of gauge, special care being taken to see that the wheels are all of the same diameter. This is important, especially in coupled engines. The crank-pins are also fitted into their respective bosses and driven home by hydraulic pressure.

When the crank-pins are finished, and the crank-axle pin turned in the crank-pin lathe, the driving axle is ready for the eccentrics. These are made of cast iron in two parts held together by studs about $1\frac{1}{2}$ in. diameter, and the nuts on the studs are secured in position by cotters. For the forward and backward gear two eccentrics are required to each cylinder, and they are usually of the twin pattern cast together. Their duty is to convert the rotary motion of the driving axle into a reciprocating motion, the amount of eccentricity giving the required travel to the valve. The eccentrics are fixed upon the axles in advance of the cranks at the proper angle, which is determined by the lap and lead of the valve, and by the design of the valve motion. It is intended to describe more fully, at a later stage, the relative positions of the eccentrics and cranks.

The wheels and axles with the eccentric sheaves in position are, when finished, taken to the erecting shop, where the axle-boxes are fitted to the journals. The frames and boiler are lifted bodily and lowered on to the wheels, the horn plates sliding on to their respective axleboxes, and the spring links, which are attached to the frames, are coupled up to the springs. These are made from the best special spring steel, which is carefully tested. The complete spring is tested to see that it returns to its normal shape without taking up a permanent set after being weighted to well over its working load.

The laminated type is most generally used, although the coiled or spiral form of spring is sometimes adopted for the driving and trailing wheels; nests of volute springs are also used on several types of engines. Laminated springs are composed of a series of flat steel plates about 5 in. wide by $\frac{1}{2}$ in. thick, and vary from 10 to over 16 in number, according to the weight they have to carry. The back plate, which may be from 3 ft. 6 in. to 4 ft. in length by $\frac{5}{8}$ in. thick, is the longest of the plates forming the spring, and has suitably forged ends to receive the pins about $1\frac{1}{2}$ in. diameter, or the hooks of the spring links or hangers, which permit the span of the spring to widen as the camber varies with the shocks or inequalities that are transmitted through the wheels and axleboxes from the road. The spring plates, which are lipped or slotted to prevent side play, are held securely together by a wrought-iron buckle accurately fitted so as to clasp the middle of the spring. A hole about $\frac{5}{8}$ in. diameter is usually drilled through the buckle and plates combined, into which a pin is fitted and riveted over, to prevent end play in the plates, or the buckle from working out of centre. The springs are fixed above or below the axleboxes according to the design of the engine. When they are below, a suitable fork is forged and machined upon the buckle for the reception of a pin about $1\frac{3}{4}$ in. diameter, which connects the spring to the centre spring link. Perhaps the most common method is to secure the other end of this link into the bottom of the axlebox, and in this type it is usual to suspend the springs from the bottom of the boxes by the centre link before the wheels are fitted, so that it only remains to couple up the ends of the springs to the links attached to the framing as the engine is lowered on to its boxes.

The strength of a laminated spring is determined by the number, width, and thickness of the plates; the flexibility by the length and radius of the camber. It is usual to give engine-bearing springs from 3 to 4 in. of camber unloaded, and when the weight of the engine is upon them the camber will be $1\frac{1}{2}$ or 2 in.

Spiral bearing springs are about 10 in. long by 6 in. diameter and are made from the best special spring steel of a suitable section, square, rectangular, elliptical, or Timmis, about $1\frac{1}{8}$ in. across the thickest part. When this type is used, exceptionally strong hornstays are employed and recessed $\frac{1}{2}$ in. deep to suit the outside diameter of the springs, so as to form a guide in place of the usual centre link already mentioned. Two of these, with centres about 7 in. apart, are fitted to each axlebox, and two bolts, 2 in. diameter, which pass through the hornstays, are attached to the bottom of each box. The springs are placed over these bolts and held up by a wrought-iron plate about 1 in. thick, which is screwed up to give the required compression.

Many other devices, such as compensating or "equalising" levers connecting the driving and trailing springs, and special methods of suspension, may be met with, for each of which advantages are claimed.

In past years, many railway accidents undoubtedly have been caused by the shifting of a wheel upon its axle, and care is taken today to ensure the application of a suitable amount of hydraulic pressure, when the wheels or axles are forced into position.

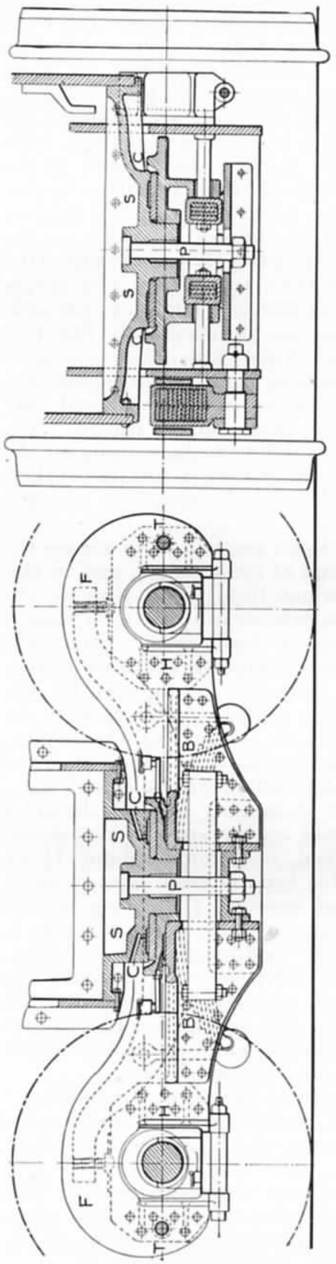


Fig. 83.—Details of Locomotive Bogie Truck.

The flexibility required to enable the engine to pass round sharp curves is obtained by supporting one end of the engine on a bogie (Fig. 83). Any deviation from the straight on the part of the road is liable to set up a certain amount of flange friction, which in sharp curves would become excessive and exceedingly dangerous with the long rigid frames and speed of the modern locomotive. Many devices, such as radial axleboxes and different types of bogie, have therefore been designed from time to time for enabling the engine to pass round the curves as easily as possible, and to give the necessary flexibility when passing points and crossings, etc.

Flexibility is also of importance at the trailing end of the engine, especially where high consecutive speeds are called for and the curvature of the line, length of wheelbase, and other contingencies have to be taken specially into account. Trailing four-wheeled bogies are sometimes used in this country, but only for tank engines, although in the United States, locomotives with tenders are frequently so equipped. Special types of axleboxes with provision for added freedom of movement for the wheels and axles, including that known as the Cortazzi axlebox with curved guides, are, however, used to permit of greater flexibility of movement at the rear end of the engine.

The bogie frame plates F are made from the same material as the main framing, machined to templates, and finally straightened, as already described. Two

steel bearing castings B, 2 ft. 9 in. long, are fixed between the frames about 10 in. apart and equidistant from the centre so as to guide the lower portion of the centre casting C, which bears directly upon them. This centre casting is not fixed rigidly, but is allowed to slide sideways, within certain limits, between the bearers; the bearing surfaces, about 2 ft. long by 6 in. wide on each side, are machined, and are lubricated through holes drilled in the upper casting. The top side of the centre is machined or dished out for the reception of a brass friction ring about $\frac{3}{4}$ in. thick and 1 ft. 9 in. diameter, which is sandwiched between the saddle plate S and the centre casting.

The saddle plate, usually a steel casting, is firmly secured through flanges at each end to the main frame plates by bolts $\frac{7}{8}$ in. diameter, made a good driving fit. The bottom side of the saddle plate is circular, accurately machined to form a smooth-bearing contact with the brass friction washer, and the spigot, which is also turned upon the bottom side of the plate, is designed to extend downwards about 10 in. through the friction washer into the hole bored for its reception in the centre casting, thus forming the centre about which the bogie swivels when in position. Any upward movement of the engine is checked by a strong bogie centre pin P, which is fixed through the saddle plate and continues downward through the bogie centre casting, sometimes holding in position a circular wrought-iron plate secured upon the pin a little below the bearers with a nut and steel cotter. The amount of side play allowed for the centre casting varies in different engines from as little as $\frac{1}{2}$ in. at each side in some to as much as $1\frac{1}{2}$ in. in others. This side play may be controlled by laminated or by spiral bogie check springs about $9\frac{1}{2}$ in. in length by 5 in. diameter. Horn plates H of cast steel are secured to the frame plates by $\frac{7}{8}$ in. diameter cold steel rivets. The rigidity of the bogie is ensured by two round stays T.

The axleboxes are made of brass with cast-iron keeps, into which a small oil-box is fixed, so that the packing underneath can be lubricated in addition to the top feeds.

COUPLING OR SIDE RODS

Assuming the engine to be a coupled one, as nowadays is always the case, the coupling rods will require to be placed upon the crank-pins, which are fitted into the wheels for this purpose.

The coupling rods are necessary so that the adhesion required in using the tractive effort of the engine may be distributed or divided between the four, six, eight, or ten wheels, as the case may be.

The effort exerted by a locomotive in moving a given load is known as the tractive force, or effort, and the conversion of this into motion is immediately dependent on the adhesion or friction of the wheels upon the rails, which in turn is governed by the weight of the engine and climatic conditions, as well as by the character of the rails and tyres. The effort exerted in moving most modern heavy trains is so great that the necessary adhesion could not be obtained through a single pair of drivers without a considerable amount of slip, which would soon destroy the tyres and rails ; hence the advantage of dividing the requisite adhesion between a number of wheels by coupling them up.

Before dealing with the subject of the rods themselves, it may be opportune at this stage to refer to the method of calculating the tractive effort of a locomotive. A simple formula serves for this purpose. Thus :

$$\frac{D^2 \times S \times P}{W}$$

where D=diameter of cylinder,
S=piston stroke,
P=boiler pressure,
and W=diameter of driving wheel in inches.

An example of a two-cylinder single-expansion locomotive having 20 in. by 26 in. cylinders, boiler pressure 200 lb. per sq. in., and 6 ft. 9 in. coupled wheels (expressed in inches), is :

$$\frac{20 \times 20 \times 26 \times 200}{81} = 25{,}679 \text{ lb.}$$

It is usual, however, to calculate the tractive effort at 85 per cent. of the boiler pressure, which in this case brings the figure to 21,827 lb.

Many sudden and varying stresses are set up in the coupling rods by the slipping of the wheels, inertia, sanding, and side bending due to the curvature of the road. They are usually made of ordinary mild steel and machined to the required shape, which may be either rectangular or a fluted H section. The older types of rod-ends are usually fitted with gibs and cotters, or cotter and block, so that the length of the rod can be adjusted with the brasses without altering the forged part of the rod, and the wear taken up by closing the joints of the brasses, which are made in halves. In taking up the wear, however, the centres of the rods are altered unless special care is taken, so that for this and various other reasons, it is now almost universal practice to make a plain bored end suitably bushed to obtain smooth running. Where exceptional power and speed are required in conjunction with minimum weight, special alloy steels are now employed for the purpose, and the rods in question are made of Vibrac steel, which is an alloy containing nickel, chromium, and molybdenum, and which has high tensile strength, enabling the cross-section and rod-ends to be reduced in area and the rod as a whole made light in weight.

The rods (Fig. 84), which are for a six-coupled engine, are in two sections hinged behind the intermediate crank-pin in order to allow for the rise and fall of the wheels in passing over the track. The crank-pins work in bronze bushes, which are lined with whitemetal, and these are pressed in from the inside, and brass oiling rings are fitted to the outside, so that the steel rod itself is prevented from rubbing against either the crank-pin cap or connecting rod big end as the case may be.

Lubrication is supplied from oil-boxes formed in the material of the rod itself. As the coupling rod revolves, the oil is thrown upwards inside the oil-box and passes down into the oil-hole

through a fluted plug at the entrance, which restricts the quantity of oil which can pass. A felt pad occupies the groove in the brass at the bottom of the oil-hole, and this rubs on the surface of the crank-pin, thus lubricating it. An advantage of the use of felt pads in this connection is that any small particles of grit which may enter the oil-box with the oil cannot pass through the felt on to the surface of the crank-pin with the possibility of consequent scoring. The coupling rods are held in position on the crank-pins in different ways according to their position. On the leading crank-pins the rods are secured by a dished washer

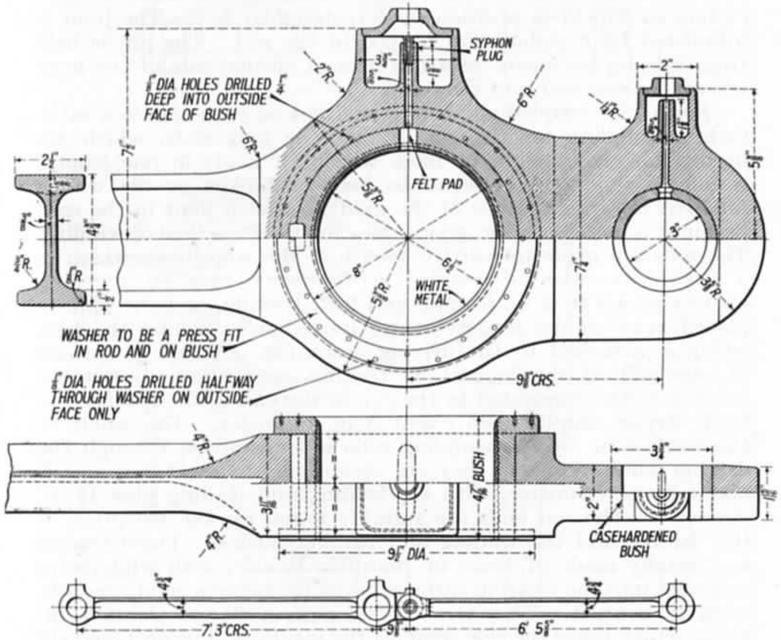


Fig. 84.—Details of Coupling Rods of 4-6-2 Type Express Engine, L.M.S.R.

let into the end of the crank-pin, so as to provide sufficient clearance for the connecting rod which is moving in an adjacent plane. The washer is held by a bolt of high tensile steel passing right through the length of the crank-pin. On the intermediate coupling wheels, the big end of the connecting rod works on a continuation of the crank-pin, and the eye of the coupling rod comes between this and the wheel boss. On the trailing wheels, the rods are secured by means of a washer, which is screwed on to a projection of the crank-pin and pinned in position. The rods shown in Fig. 84 are those employed on the L.M.S.R. for modern express engines.

The coupling rod shown in Fig. 85 is for a Southern Railway 4-6-0 type four-cylinder express locomotive. The rod is of

Vibrac steel. It will be noted that the rod is of rectangular cross-section. Gummetal bushes lined with whitemetal are pressed into place in the rod, the load required being 10 tons in the case of each of the end bushes, and 12 tons for the bush of larger diameter on the middle pair of wheels. No key or other fixing is provided, but a groove is cut on the outer circumference of the bush from which oil holes radiate, so that in the event of the bush moving in the rod, the supply of oil, which normally enters through the hole at the top of the bush, is not cut off. The knuckle-joint has a case-hardened steel pin, and the portion of the rod between the jaws is provided with a bush of hard carbon steel held in position by a rectangular key. The joint is lubricated by a siphon cup formed in the rod. The pin is held from turning by means of a flat formed on one side of the head where it is recessed into the rod.

For a four-coupled engine a single rod on each side is a satisfactory coupling for the wheels, but the long rods, which are needed for six or eight or more wheels, if made in one length, would be rigid and liable to be bent or broken as the wheels followed the irregularities of the road, so that a joint in the rods becomes a necessity for giving the required vertical flexibility. The rods are made to suit the length of the wheelbase, which in a modern six-wheeled coupled goods engine may be anything up to about 8 ft. 2 in. leading and 9 ft. trailing, and the joint is placed between the longest centre immediately behind the boss which is attached to the driving crank-pin. A fork is formed at one end of the longest or trailing rod, which is suitably machined, and connected to the eye in the end of the leading rod by a strong coupling pin about 3 in. diameter. The whole of the work done by the coupling rods is transmitted through the driving crank-pins, and they are accordingly made the strongest, about $6\frac{1}{2}$ in. diameter, with the leading and trailing pins $4\frac{1}{2}$ in. diameter. The rod ends are suitably bored for the reception of the driving and the leading and trailing bushes. These bushes are usually made of brass or phosphor-bronze, with whitemetal strips let into the wearing surfaces, so as to ensure a good, smooth, working contact. They are turned with a flange about $\frac{3}{8}$ in. thick, which takes the side wear on the inside, and project slightly through the rod on the outside, so as to form the side bearing surface against the crank-pin washers. Different methods are adopted to prevent the bushes turning. A keyway is usually slotted in the eye of the rod, and a key fitted, so as to engage with a keyway in the bush. Additional security is obtained by inserting a $\frac{3}{4}$ in. diameter screw through the bottom of the rod and into the bush. No part of the rod-end comes into contact with any wearing surface, and the whole of the wear is taken up by the bushes, which can be renewed as required.

The rod (Fig. 86) is of a solid rectangular section. In this type, the knuckle-joint is fitted with a phosphor-bronze bush, and the pin is held in position by a washer and bolt, which passes through the centre of the pin.

The surfaces of the driving and other bearings are entirely covered with whitemetal, which is held in place by ring bushes with a coarse V-thread of six threads per inch,

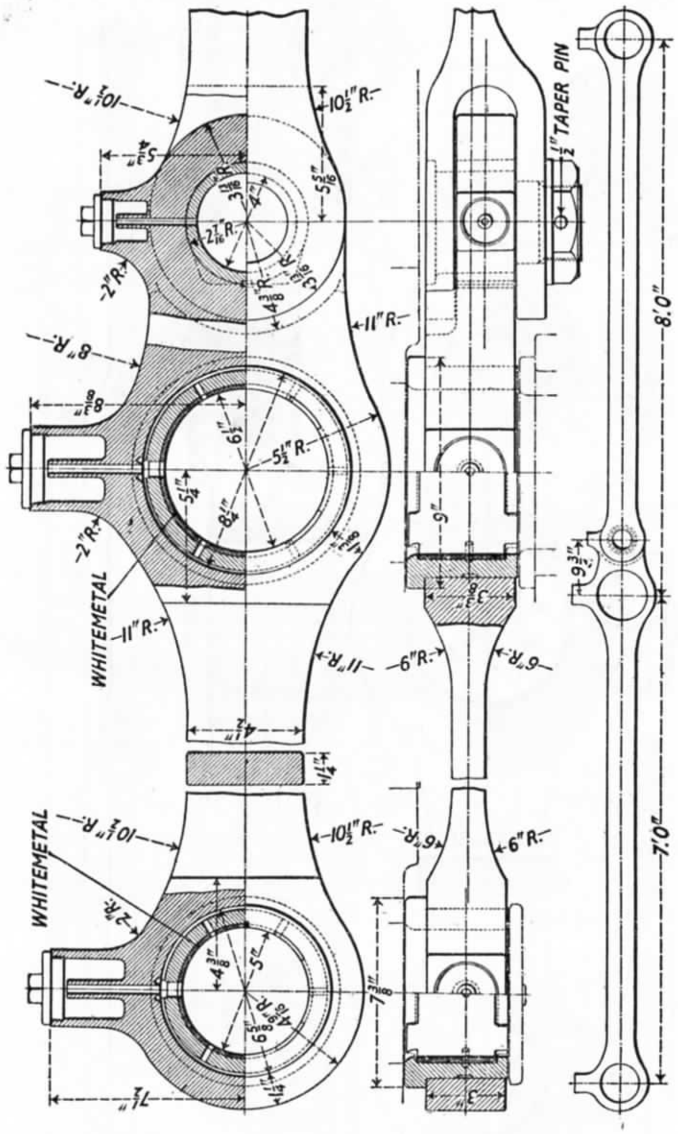


Fig. 85.—Coupling Rods of "Lord Nelson" Class Engines, Southern Railway.

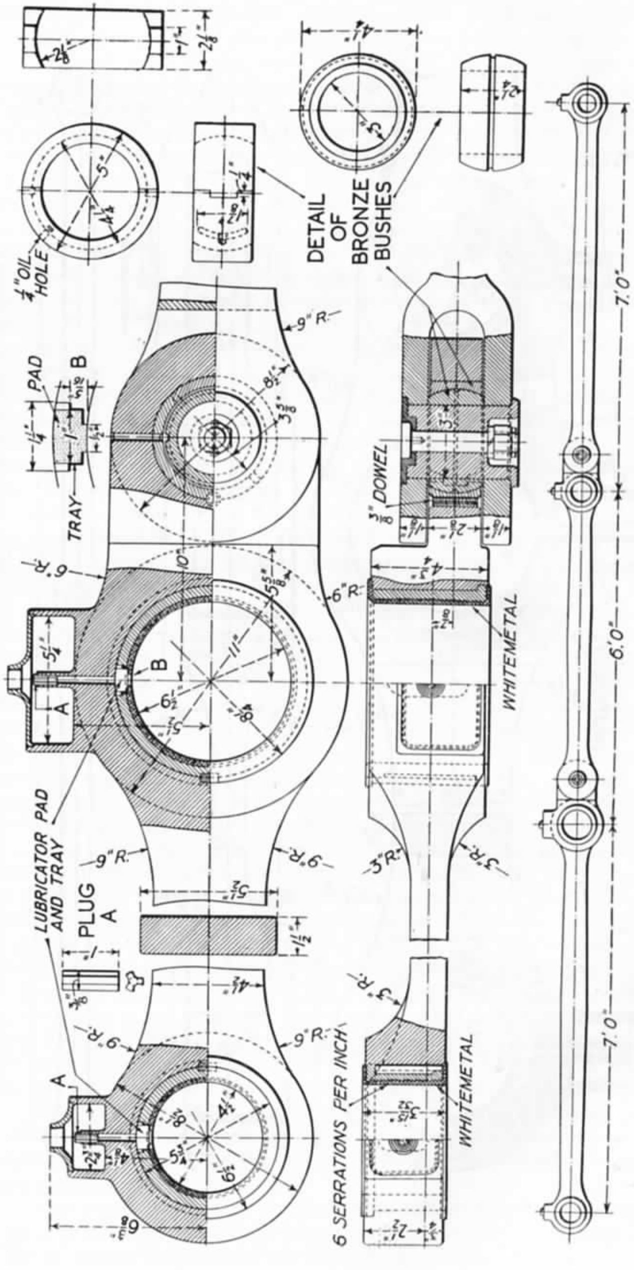


FIG. 86.—COUPLING RODS OF EIGHT-COUPLED LOCOMOTIVE, G.W.R.

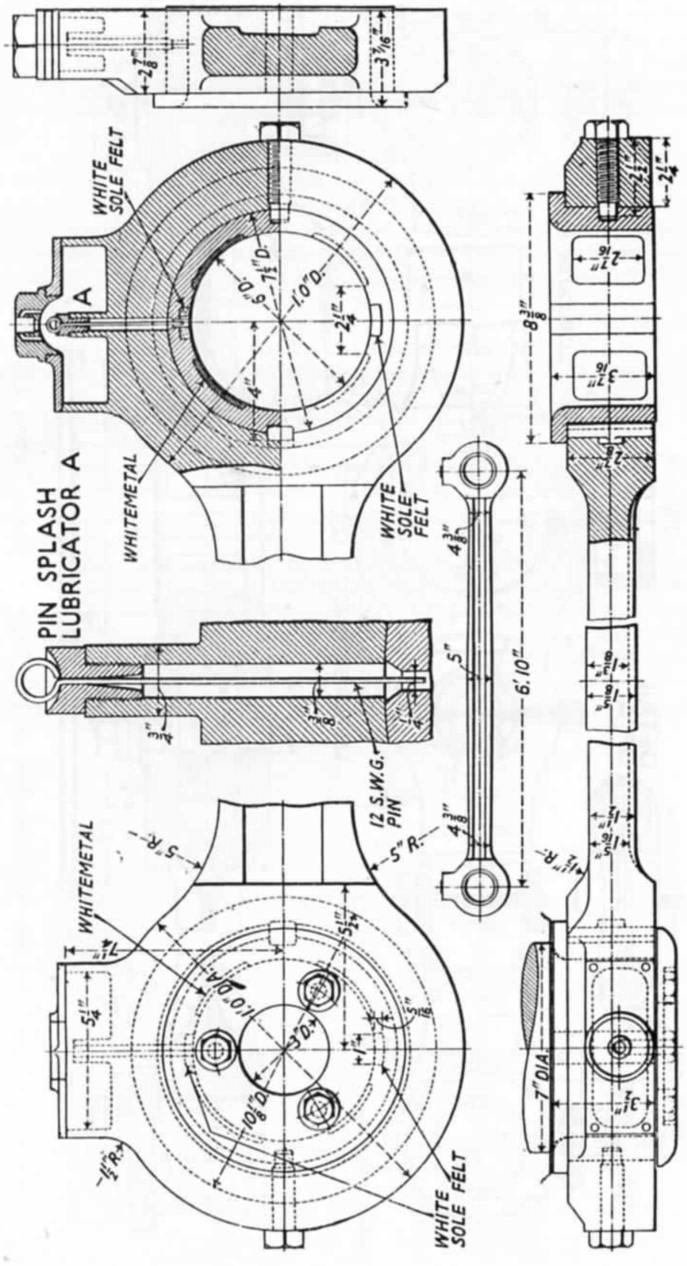


FIG. 87.—COUPLING ROD OF 4-4-2 TYPE ENGINE, L.N.E.R.

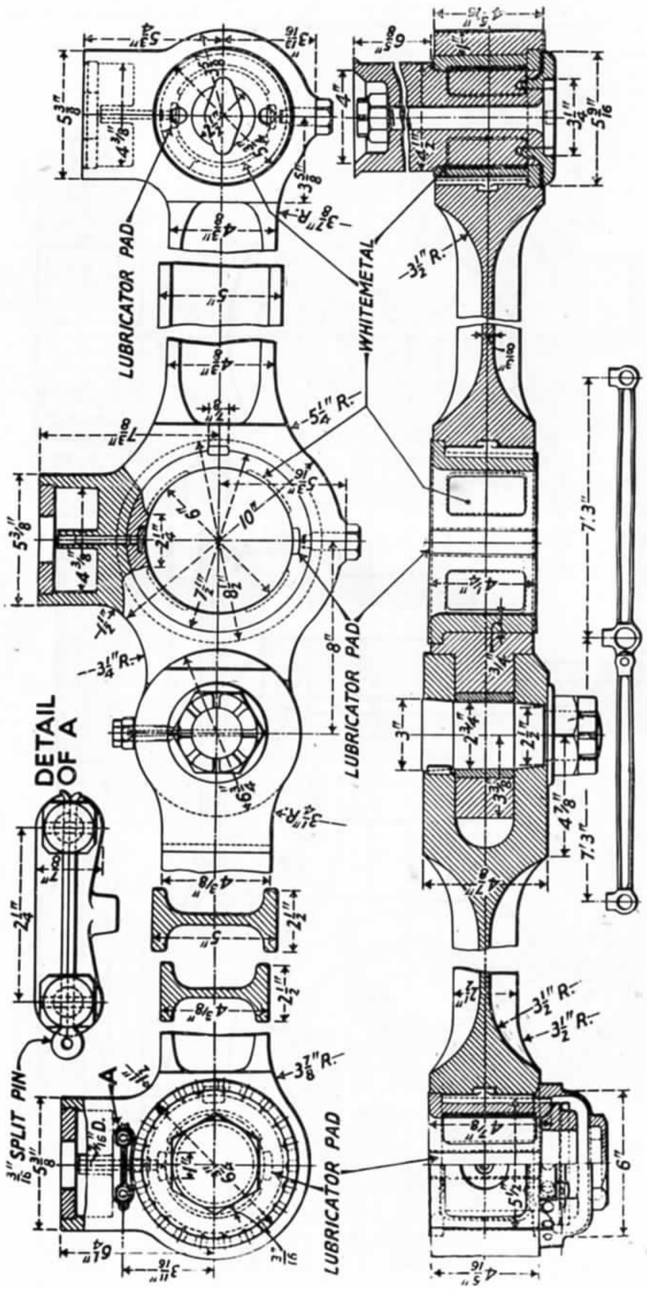


FIG. 88.—COUPLING ROD OF 4-6-2 TYPE (A4 CLASS) ENGINE, L.N.E.R.

The bush of the knuckle joint is divided by a spherical surface. It is made in three pieces. The inner ring which works on the pin is solid. Its outer surface is spherical. The outer ring is in halves, tongued together, as shown. The three pieces are fitted together and pressed in and secured by the screwed dowel. The clearance allowed in each knuckle joint is $\frac{1}{16}$ in. on each side.

A coupling rod, as used on an Atlantic or 4-4-2 type of engine, is shown in Fig. 87. The flanges on the inner side of the phosphor-bronze bushes are clearly shown, and the washer whereby the rod is retained on the driving pins is also shown in position. These flanged bushes are prevented from turning in the rod-end by keys, which are formed with dowel bosses $\frac{7}{8}$ in. diameter for fitting into bored recesses, as shown.

The coupling rods of L.N.E.R. express engines, of which the A4 Class is illustrated in Fig. 88, are of nickel chrome steel, of which the greater strength allows a lighter section to be used than would be possible with a carbon steel rod for a similar duty. The leading rod extends to the rear of the driving crank-pin, to form a knuckle joint to the trailing rod.

Lubrication of the knuckle joint is by oil through a securing set-screw direct to the bush. The leading bush is pressed in from the outside face of the rod, and the driving bush from the inside face. Both are keyed, to prevent them rotating in the rod, and are further secured by set-screws at the bottom. The trailing bush is pressed in from the inside face and keyed. The outer end of this bush is screwed externally to take a bronze dust cap, which is locked in position. All the bushes are of bronze with pockets into which whitemetal is cast. White sole felt pads retain the lubricant, and oil is supplied through a pin trimming from oil wells in the rods.

FIG. 88A.—4-6-0 LOCOMOTIVE NO. 5372, L.M.S.R., ON THE 70-FT. TURNTABLE AT CARNFORTH.

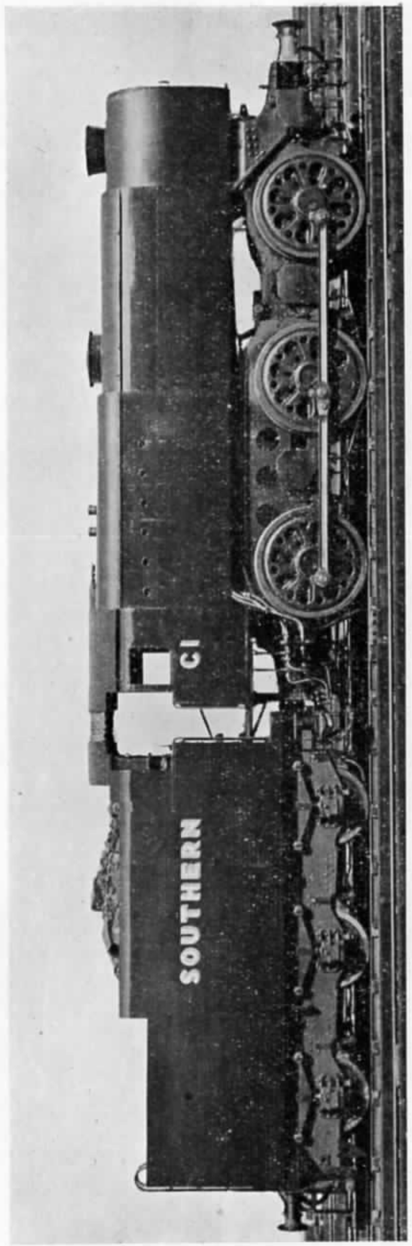


FIG. 89.—SOUTHERN RAILWAY "Q.1" CLASS 0-6-0 TYPE LOCOMOTIVE.

Mr O. V. Bulleid, Chief Mechanical Engineer.

(See p. 502 for Dimensions of Locomotive).

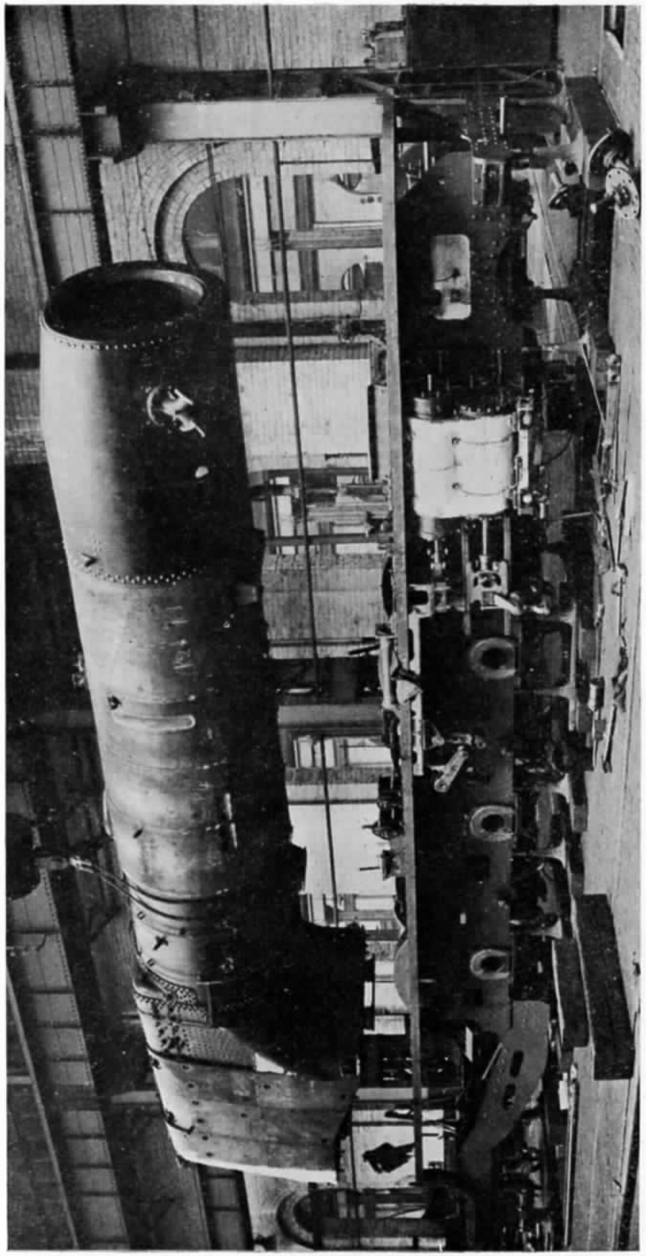


Fig. 90.—An Erecting Shop Operation. Boiler of 4-6-2 Express Locomotive being Lowered on to the Frames in Crewe Works, L.M.S.R.

Chapter 8

DESCRIPTION AND ERECTION OF ENGINE

An eccentric is a crank in which the diameter of the crank-pin is sufficiently large to enclose the shaft. It is therefore not necessary to gap the shaft, as eccentrics are not suitable for driving, but have to be driven. They will not transform reciprocating into rotary motion, but only rotary into reciprocating.

The motion of the eccentric is transmitted to the valve gear by means of a metal ring, which is known as the eccentric strap. The eccentric sheaves A (Fig. 91) are secured to the axle by screws and keys, and revolve inside the strap B, which is prevented from turning by the eccentric rod R, and a reciprocating movement is obtained.

Eccentric straps are usually made of wrought iron or mild steel. The oil cup is at L ; a suitable facing F is formed on one half of the strap for the attachment of the eccentric rod. The four straps, R H forward, R H backward, L H forward, L H backward, are placed upon the eccentric sheaves, with the two halves held together by bolts about $1\frac{1}{4}$ in. diameter.

Studs N, about the same diameter, are inserted in the strap facing, to which the eccentric rods are eventually attached ; nuts and lock nuts securely pinned by $\frac{3}{8}$ in. split pins, or small cotters, connect the rods firmly to the straps. The eccentric rods are forged with a tee or flat end to suit the facing on the strap, and forked at the other end for attachment to the slotted expansion link E, which is used for reversing the direction of the engine and for varying the amount of steam admitted to the cylinder.

A variety of link motions exist. The Stephenson or shifting link motion (Fig. 91) was the pioneer, which superseded the old-fashioned " gab " eccentric rod for reversing purposes. In this link motion, the reversing of the engine, and the variation of the point of cut-off, are accomplished by the raising or lowering of the slotted link.

Radial valve gears, which obtain their motion without the use of eccentrics, have also been designed. That known as Joy's valve gear (Fig. 92) was for many years employed on several different classes of engines in this country, and even now quite a considerable number of engines of the older types thus equipped are in service. By dispensing with the eccentrics, space is provided for a substantial increase of strength in the crank webs and width of driving axle journals for inside cylinder engines. Other advantages are reduction of the number of working parts, economy of construction, constant valve lead, and efficiency of steam distribution.

The necessary reciprocating movement is obtained from the connecting rod C, which is of special proportions for attaching and sustaining the weight of the motion-work.

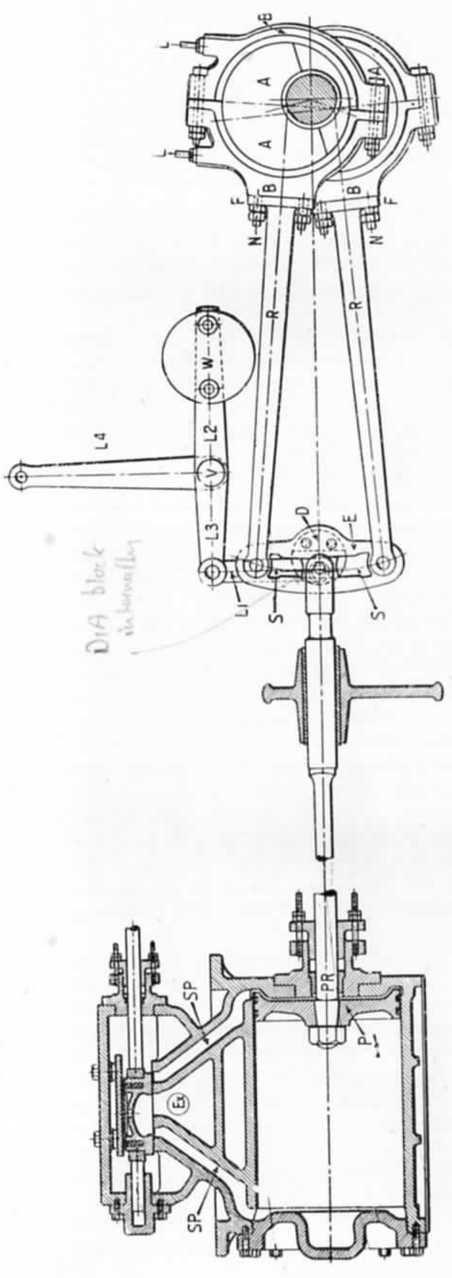


FIG. 91.—STEPHENSON LINK-MOTION VALVE GEAR.

At a point nearest to the small end of the rod, about one-third of the distance between the centres, a hole O, about 3 in. diameter, is bored, and bushed with phosphor-bronze, to which is attached the stirrup or connecting link S.

The stirrup link is connected at its other end to the anchor link A, which is anchored to a fixed point upon the motion plate M.

At K in the stirrup link, are connected the swing links L, the top ends of which are attached to the valve rod V.

The swing links are bored at an intermediate point P, and a pin is fitted so that its projecting ends carry the phosphor-bronze slipper blocks, which work in curved guides G inserted and secured into the rocking or reversing shaft R. This shaft is a steel casting toughened by annealing, with journals turned at each end about 5 in. diameter, which are fitted into suitable cast-iron bracket supports bolted to each frame by bolts about $\frac{7}{8}$ or 1 in. diameter. The recesses cast in the reversing shaft are slotted out and mild-steel slipper block shoes fitted.

The faces of the shoes are case-hardened, and special arrangements are made in the slipper blocks for lubricating the rubbing surfaces. The whole of the motion-work is forged from mild steel, and the bored holes fitted with phosphor-bronze bushes. The pins for connecting the links are usually about 2 in. diameter, case-hardened and burnished.

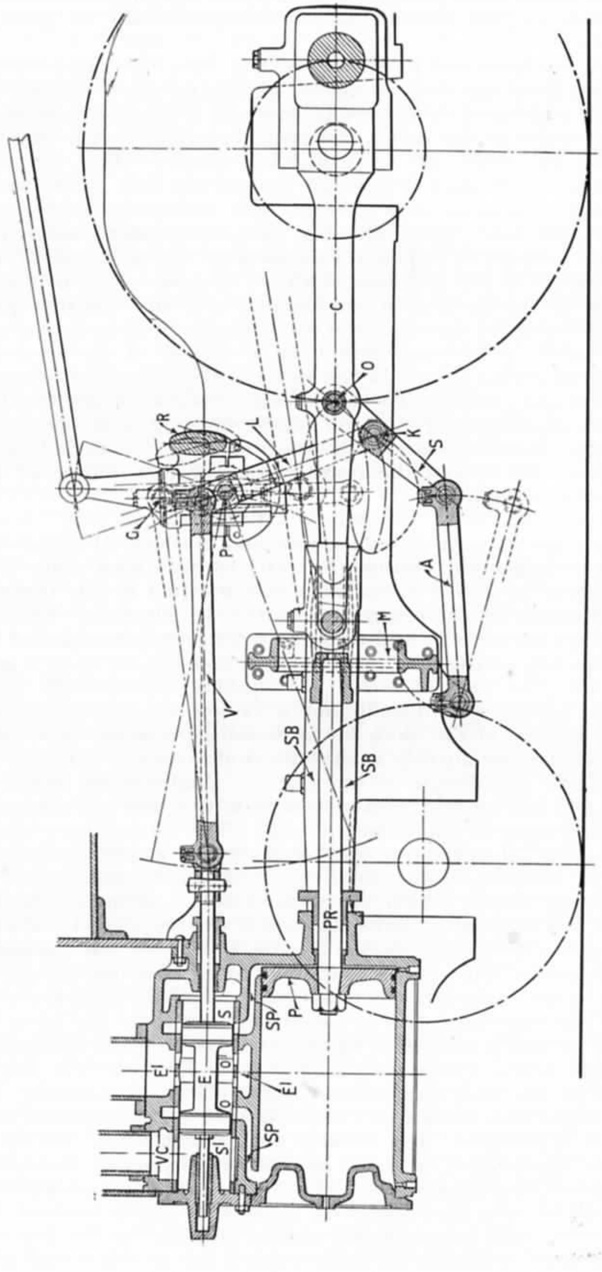


FIG. 92.—LAYOUT OF JOY'S RADIAL VALVE MOTION FOR LOCOMOTIVES.

When wear takes place, the bushes can be renewed and new pins fitted, so that the motion-work is practically as good as when new.

From the foregoing it will be evident that the valve derives its motion from the connecting rod at O, and since the rod has a circular movement at the crank end, and a straight movement from the slides at the other, the path described by the point O will take the form of an elongated ellipse. This elliptical movement is transmitted through the stirrup link to the swing links, and terminates in a vertical oval movement at the end of the valve rod. The deflection of this elliptical movement from the vertical is effected by changing the position of the curved guides in the reversing shaft, so that the point of cut-off is altered or the running of the engine reversed. The oval path taken by the end of the valve rod transmits an irregular movement to the valve, as the top and bottom curves of the oval are traversed at such a time that the speed of the valve is accelerated in opening and closing. The broad sides of the oval are therefore traversed with the valve at its fullest opening, and the correspondingly slower movement of the valve at this period of its travel gives an almost theoretically perfect distribution of the steam in the cylinder.

Referring again to the various link motions, it may be said that each has its own characteristics and methods of connecting up. The Stephenson motion (Fig. 91) has a strong plate E in which a curved slot S is cut at a radius equal to the distance from its centre to the centre line of the driving axle. The slot is machined accurately, and a forged block, sometimes called the expansion link or the quadrant block, is fitted so as to be a good sliding fit. To prevent wear, the rubbing faces of the block and link are case-hardened, and a hollow or other provision made in the top of the block for lubricating purposes. The block is connected either directly to the valve rod as shown, or indirectly, according to the design of the engine. Pinholes are bored at the top and bottom of the expansion link, to which are connected the forked ends of the eccentric rods. The forward-gear rod is usually attached to the top, and the back-gear rod to the bottom. A disc or bracket D is secured firmly to the expansion link by good fitting rivets, which are riveted cold. Attached to this disc are the suspension links L1, which are suspended from the lever on the reversing shaft V. The weight of the expansion and suspension links is counterpoised by the balance weight W secured on the lever L2, which is keyed or forged on the reversing shaft. The expansion link is raised or lowered by the lever L3, and this in turn is controlled by the lever L4, to which is attached a long rod, which passes either under the axle or over the driving splasher to the reversing lever or screw placed in the cab. The whole of the link motion is fitted together in the machine shop before it is erected. The various pins, which are about $1\frac{3}{4}$ in. diameter, are pegged or keyed in position to prevent them from working out, and all wearing surfaces case-hardened and polished.

It will be seen that when the expansion link is lowered, the valve travel will be controlled almost entirely by the top rod, and will work according to the setting of the eccentric connected

to it. When the link is lifted, the bottom eccentric rod controls the movement of the valve in the same manner, so that, as the two eccentrics are set for running the engine in opposite directions, the one will run the engine forwards and the other backwards. With the expansion link lifted to its middle position, the valve would have its minimum amount of travel, owing to each eccentric having equal control. It follows, therefore, that, as the link is lifted or lowered from this position, the point of cut-off is altered, and the period of admission gradually increased till the maximum travel of the valve is reached.

The Walschaerts valve gear (Fig. 93) was invented and patented by a young Belgian engineer named Walschaerts in the latter part of the year 1844. It is almost universal in Continental locomotive practice, and is very largely used in this country. In America, it has practically superseded the Stephenson link motion. Its first application on a British railway was to a 0-4-4 side-tank engine, built in 1878, and subsequently placed in service on the Swindon, Marlborough & Andover Railway.

Several important advantages are claimed for the Walschaerts valve gear, not only for its extreme adaptability for cylinders with steamchests above or below, without necessity for the intervention of a rocker, but also for its accessibility for inspection, lubrication, repairs, or cleaning, when used in conjunction with outside cylinders.

The reduction in the number of eccentrics required for inside cylinder engines, or their total abolition when outside cylinders are adopted, greatly reduces the engine losses due to friction, with a corresponding decrease in the risks of failure, and upkeep costs.

The Walschaerts valve gear consists essentially of two elements. The first is the motion derived from the crosshead by means of the crosshead arm anchor link and combination lever. This is so proportioned that the movement of the crosshead from one end of the piston stroke to the other will move the valve spindle by a distance equal to twice the lap plus the lead of the valve, and this remains constant for all positions of the cut-off. The second, or expansion, element of the gear is derived from a return crank or, in the case of inside cylinder engines, a single eccentric on the driving axle. The pin of this return crank is set to revolve about the centre line of the axle at a definite radius, and its motion is transmitted along the eccentric rod to the bottom end of the curved expansion link, which is held at its centre in trunnions fixed to the framing of the engine. The rod, known as the valve rod, joins the top pin of the combination lever to a die block, which slides up and down the expansion link, with its vertical position controlled by the reversing arm. It will be appreciated from reference to the drawing (Fig. 93) that, if the reversing rod arm lifts the valve rod so that the centre of the sliding die block coincides with the centre of the trunnions about which the expansion link oscillates, no movement due to the return crank will be passed forward to the valve spindle, and this represents the position when the engine is in mid-gear. As the die block is lowered or raised in the link, according to the direction in which the engine is travelling, an increasing amount of travel is

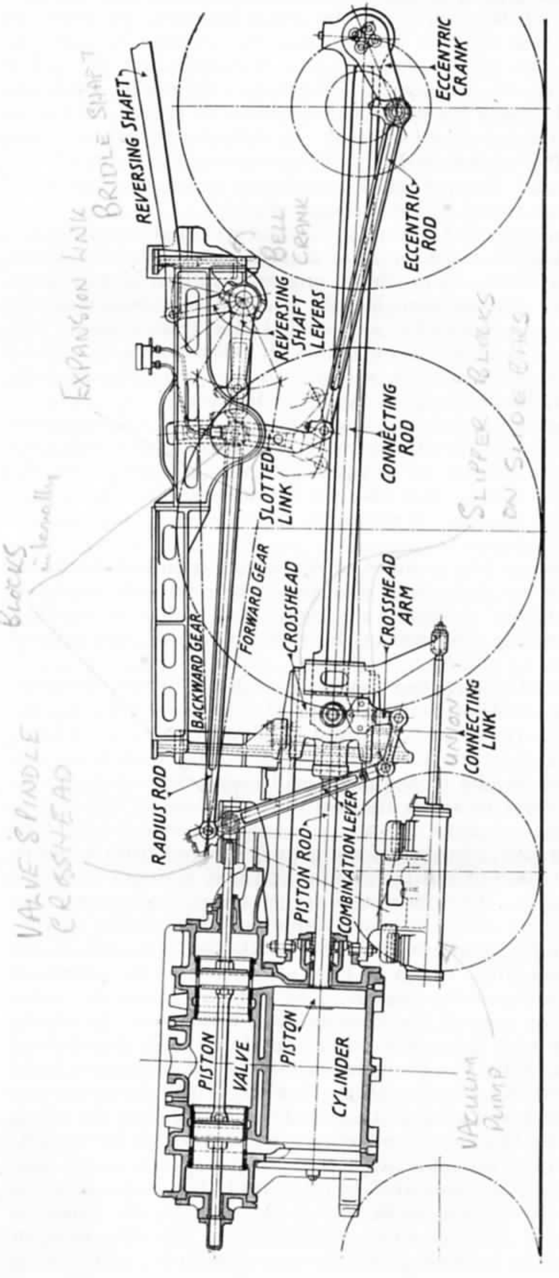


Fig. 93.—The Walschaerts Valve Motion applied to Outside Cylinders of a Modern Express Locomotive.

transmitted to the valve spindle over and above that derived from the crosshead, and it is the variation in travel obtained in this way which controls the point at which the steam is cut off. Early cut-off occurs when the die block is nearer the centre of the expansion link, and maximum cut-off occurs when the die block has been dropped to its lowest position in the link.

Locomotives with three or four cylinders can be fitted either with a separate valve motion to each cylinder, or two sets of motion only can be used and connecting mechanism employed for actuating the valves of the other cylinder or cylinders. This mechanism is located either in front of or behind the cylinders.

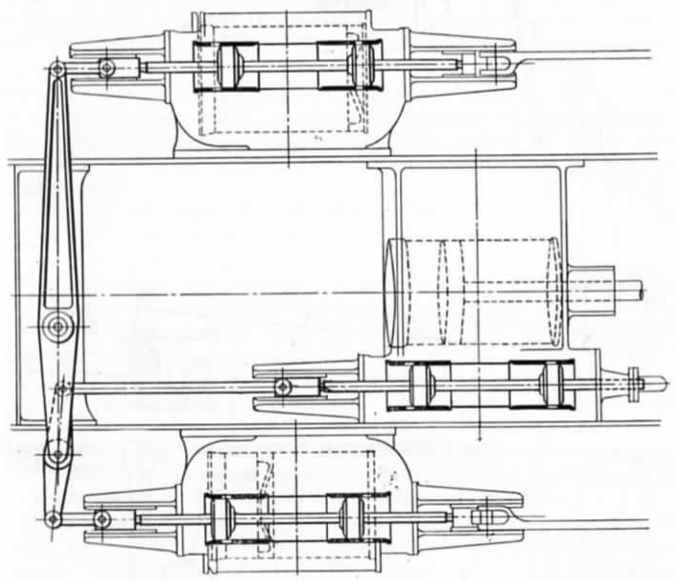


Fig. 94.—The Gresley Valve Gear in Plan.

In the Gresley valve gear, which has been applied to a large number of three-cylinder locomotives, the valve of the middle cylinder derives its motion from extensions on the outside cylinder valve spindles, and consists of two levers. The short or " equal " lever is attached to extensions on the middle and left-hand valve spindles, and is thus a floating lever. The long lever is pivoted to a fixed point, so that its arms are in the ratio of 2 to 1. The long end is joined to the right-hand spindle extension, and the short end to the centre of the floating " equal " lever. The combined action of the levers imparts to the centre valve a motion of 120 degrees out of phase with the outside valves, and of the same magnitude.

Fig. 94 shows the arrangement applied to a three-cylinder engine with the gear in front of the cylinders. Where circumstances permit, the levers may, as already indicated, be fitted behind the cylinders, in which case the expansion of the valve spindle of the outside cylinders has no effect on the middle valve.

In addition to the Gresley gear there are other arrangements used for four-cylinder engines on the Great Western and London Midland & Scottish railways. On the former, the transference of motion is effected from the inside to the outside, and the valve

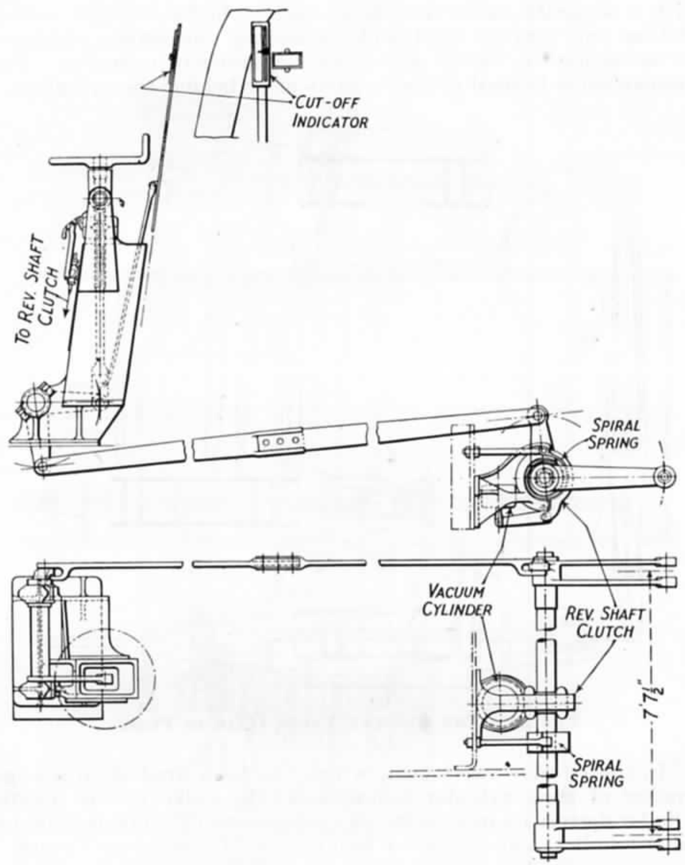


FIG. 95.—SCREW REVERSING GEAR OF L.N.E.R. 4-6-2 EXPRESS LOCOMOTIVE.

gear is driven from the axle of the centre pair of coupled wheels. In the other, the reverse is the case, and the Walschaerts motion is applied direct to the outside cylinders, the valve spindles of the inside cylinders taking their motion from those outside.

The screw reversing gear illustrated by Fig. 95 is that of an L.N.E.R. express locomotive of the 4-6-2 type. It is located

on the left-hand side of the cab, and consists of a vertical steel screw and a long bronze nut, which can be rotated by a handle. The thrust of the screw is taken in either direction by ball races, and the nut is free to swing in trunnions, to accommodate itself to the movement of a bell-crank, to which the lower end of the screw is connected. This crank is supported by two bearings in a heavy steel casting secured to the main frames, and its vertical arm is connected directly to the rear end of the long reversing rod. The forward end of this rod is attached to an arm on the reversing shaft. It is joined, slightly ahead of the boiler throat plate, by a forked joint with three bolts in double shear.

The reversing shaft is provided with a spiral spring, adjustable for tension, to balance the weight of the parts which must be lifted to reverse the engine. It is fitted with a vacuum-operated clutch. The clutch straps are Ferodo lined, and actuated by a vacuum cylinder through toggle levers. On the reversing quadrant, is a spring-loaded catch, which can be made to engage with a locking ring on the nut. At the same time, a link from this catch operates a cock, to connect the clutch cylinder to the vacuum chamber pipe.

A cut-off indicator is arranged on the cleading plate at the back of the boiler, and a pointer coupled to the reversing screw moves over a vertical graduated scale.

For reversing the engine, or altering the point of cut-off, the different valve motions and gears described are connected by a rod to the reversing lever on the footplate. In this manner, the driver is able to control the movements of the valves in accordance with the work the engine is performing. Many types of reversing gear are in use. Perhaps the most common is the simple hand lever, with trigger and notched sector, whereby the lever is retained in the different positions required for admitting a proper supply of steam to the cylinders, or for running the engine in a forward or backward direction.

The steam and cataract reversing gear, illustrated in Fig. 96, is fitted to the large 0-8-4 three-cylinder (simple) shunting engines on the L.N.E.R. (Great Central Section).

This gear is operated by means of the ordinary hand lever and notched sector, in such a manner that the engine may be reversed rapidly, or the point of cut-off altered, with a minimum of manual labour on the part of the driver.

The steam and cataract cylinders are bolted to the main frame, and the steam for actuating the gear is obtained from the boiler through the valve A, which is provided with a lubricator, as shown.

Both the steam and water cylinder valves have a rotary movement, and are directly connected by rods, as is also the reversing lever, to an arm centred on the crosshead. Any movement of the reversing lever will therefore rotate the valve in the steam cylinder, thereby opening one end to steam and the other to exhaust. Simultaneously the water valve of the cataract cylinder is opened and allows water to pass from one side of the piston to the other, thus releasing the gear, which is moved in accordance with the position of the reversing lever. The movement of the piston rod is transmitted to the bell-crank levers shown, and the links are raised or lowered accordingly. When the reversing lever has been moved and locked by the trigger in the notch on the sector, a new fixed centre is given to the crosshead arm, which, however, is returned to its normal vertical position by the movement of the piston rod. This again closes the valves and locks the gear in the required position. To charge the cataract cylinder with water, the steam valve A on the firebox is closed, and the cocks B B below the cylinder, and air cock D on the water valve opened. By moving the reversing lever in both directions, the water valve is opened to each end of the cylinder, until the apparatus is charged thoroughly as denoted by the appearance of water through the air cock D. The cocks B B D are then closed, and the steam cock A opened.

The water supply is obtained from the tank through the cock C, which is always open when the engine is at work, and the cock E is provided for draining the apparatus for inspection or repairs.

The power reversing gear (Fig. 97) has been fitted to several locomotives on the L.N.E.R. (Great Eastern Section). The necessary power is supplied by the Westinghouse brake pump without in any way interfering with its more important work, viz., that of creating the power for operating the continuous automatic brake.

A locomotive fitted with this gear can be reversed in the usual way by means of the hand wheel A, or it can be reversed by compressed air gear, operated by the handle B.

Either of these methods can be utilised at will, as the act of using one system of reversing automatically renders the other system inoperative.

The reversing shaft C is connected to the reversing rod D by the arm E, and to the piston rod F by the arm G. A guide H is provided for the end of the piston rod.

To operate the gear by hand in the usual way, the wheel A and the screw I are rotated; the half-nut J, and with it the reversing rod D and the arm E, are moved one way or the other, and the air (compressed or otherwise) in the cylinder K is displaced through the valve L in a manner to be described.

To operate the gear by power, the handle B is moved one way or the other, according to whether the engine is required to be put in forward or back gear.

Whichever way the handle is moved, the cam M attached to it lifts the half-nut J out of gear with the screw I. At the same time, the arm N, which is also attached to the handle B by the shaft O, causes the valve L to rotate, thereby opening one end of the reversing cylinder K to pressure and the other end to exhaust. It should be noted that the half-nut J is quite clear of the screw I before this opening of the cylinder K to pressure and exhaust takes place.

In the running position, both ends of the cylinder K are in communication with the main air reservoir P through the valve L, as the piston rod F is made of such a diameter that the reduced piston area reduces the pressure on the piston rod side of the piston, and balances the weight of the motion hanging on the lifting link Q.

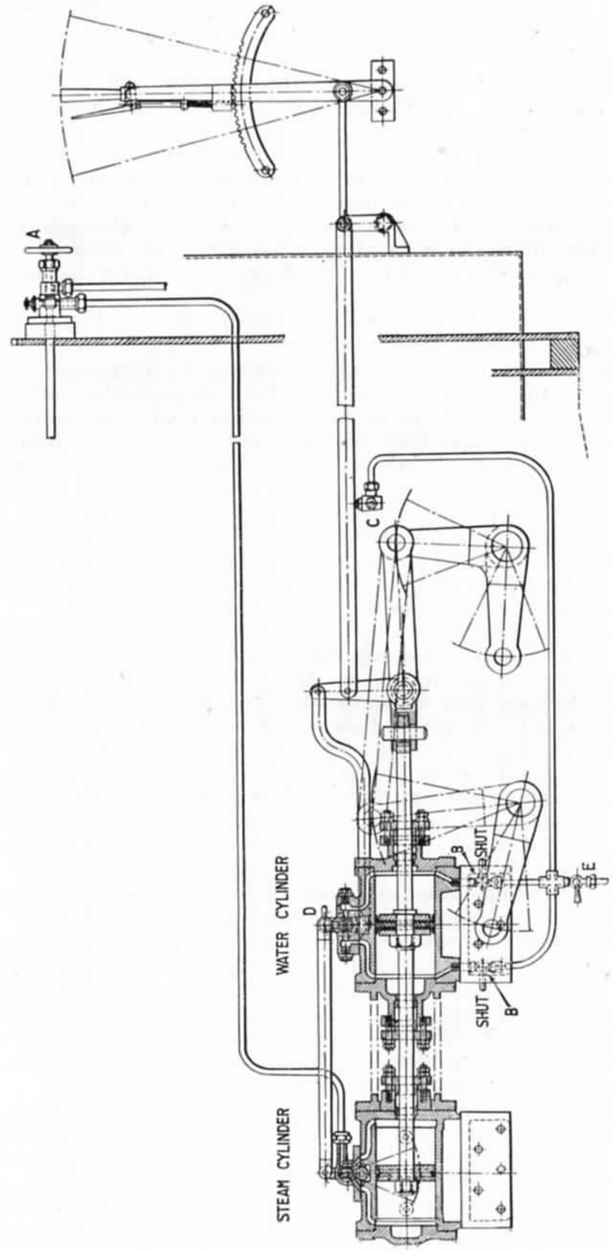


Fig. 96.—Details of Steam-Operated Reversing Gear for 0-8-4 Type Shunting Engines, L.N.E.R. (Great Central Section).

The valve L rotates on a seating with two ports, R and S. The port R is in communication with the front end of the cylinder K, and the port S with the back end of the cylinder. The exhaust ports T and U are cut in the valve L. Both communicate with the atmosphere through the hole V in the spindle of the valve L. The pressure ports W and X are cut through the valve L.

Two holes Y and Z are cut right through the valve L, and when gear is in running position (as illustrated) place both ends of the cylinder K in communication with each other through the ports R and S, and with the air reservoir P through the pipe *a* which enters the body of the casting *b* at the back of the valve L, viz., on the opposite side of the valve L to the ports R and S.

The air reservoir P is divided into two parts, *c* and *d*, which communicate with each other through the non-return valve *e*.

Air is supplied from the Westinghouse brake pump through the pipe *f* to part *c* of the reservoir, then through the valve *e* to part *d*. The brakes are in communication with the pipe *g*. Consequently, they can draw air from both part *d* and part *c* through the non-return valve. A considerable quantity of air is required to release the brakes, etc., on a long train. Air for use with the reversing gear is drawn from part *c* only. The valve *e* prevents any air being taken from the side *d* for this purpose; and all chance of a reduction of air pressure in the reversing gear and brake section (*c*) of the main air reservoir bringing about an unintentional operation of the brakes is thus eliminated.

The stopcock *h* shuts off air from the reversing gear altogether, should it be at any time necessary to do so.

To prevent the possibilities of the half nut J jumping the screw I, a locking gear is provided. The pawl *i* engages the lever *j*, which is loose on the shaft O and connected to the pin *k* by the link *l*.

When the handle B is moved either way, it rotates slightly on the pin *m* before moving the cam M, and lifts link *n* by means of one of the pins *o* or *p*, according to the way in which handle B is moved. The link *n*, in its turn, rotates bell-crank lever *q*, and, by means of the link *r*, throws pawl *i* out of gear.

The method of connecting the link-motion to the valve spindle is determined by the size and shape of the cylinders.

Inside cylinders up to a certain diameter are usually designed with the steamchest between them; but with the demand for more powerful engines, and the consequent increase in the diameters of the cylinders, it became increasingly difficult to arrange the steamchest in the restricted space between the frames, and the steamchest was therefore placed either above or below the cylinders, and the valve connections altered accordingly.

Outside cylinders are not affected by the limited room between the frames, as they are fixed on the outside of the frame plates, with the steamchests either projecting through the frames to the inside, or on the top of the cylinders.

When placed above or below the cylinders, the valve faces are often inclined in such a manner that it is possible to connect the valve spindle or rod directly to the block in the expansion

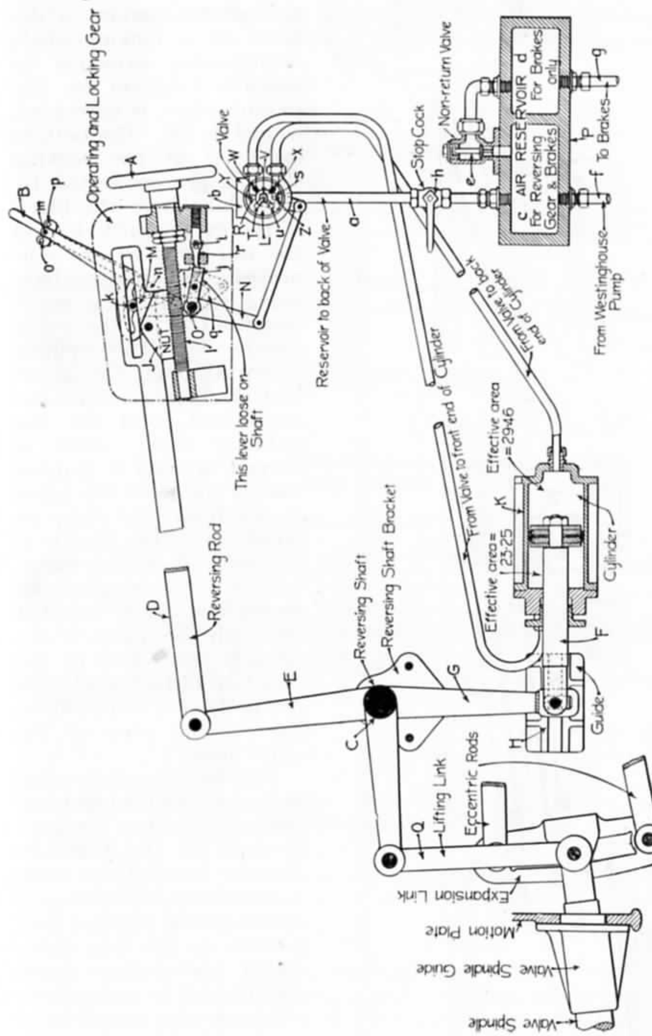


Fig. 97.—Compressed-Air Reversing Gear, L.N.E.R. (Great Eastern Section).

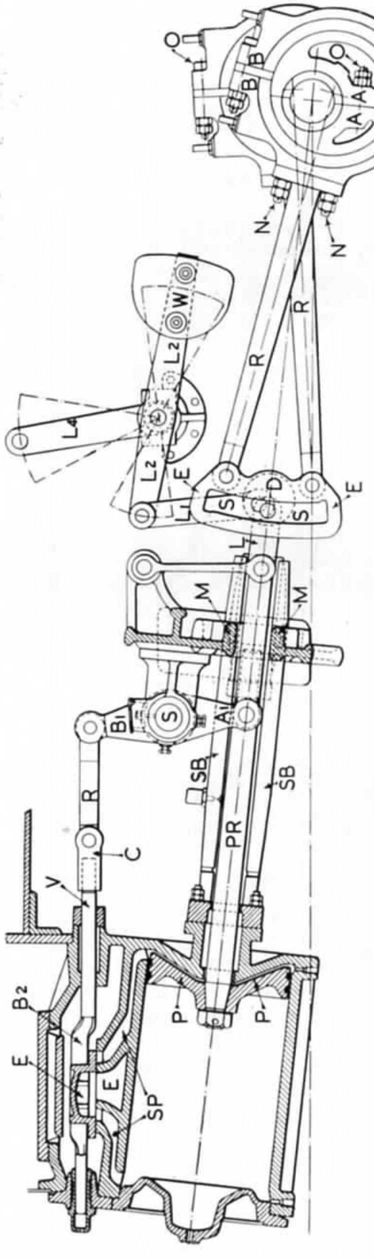


Fig. 98.—Valve Gear with Rocking Shaft for transferring Motion from Lower to Higher Plane.

link. Assuming that the steamchest is on the top of the cylinder, and that the valve facing is parallel to the centre of the engine, an indirect motion, in the form of a rocking shaft arrangement attached to suitable brackets on the motion plate, is necessary, as in Fig. 98. The bottom arms A^1 of the rocking shaft S are connected by drag links L to the block in the expansion link, and the top arms B^1 are connected by intermediate valve rods R to a small crosshead C on the valve spindle V. This spindle passes through the gland and stuffing-box into the steamchest, and for the ordinary slide valve is shaped in such a manner that it embraces the valve in the form of a strap or buckle B^2. The buckle is not secured to the valve, but is made a good fit round the back, so that although the valve is absolutely controlled in the direction of its travel, it is not prevented from following up the wear of the valve face.

Fig. 99 brings into comparison typical old and new pattern cylinders for locomotives on the L.M.S.R. Modern locomotives must be handled with due regard to the special features they possess, as the long valve travel and better steam distribution in general enable a shorter cut-off to be employed than with older engines when working under similar conditions of load and speed. In practice, this is reflected in the details embodied in

the design of cylinders and valves, and indicates that more work is being extracted from the steam, so that less steam is used per stroke.

A notice is exhibited in the cab of all the new locomotives of the L.M.S.R., and also some other classes employing long travel valves, stating that when coasting, the reversing lever must be placed in the "drifting" position, corresponding to about

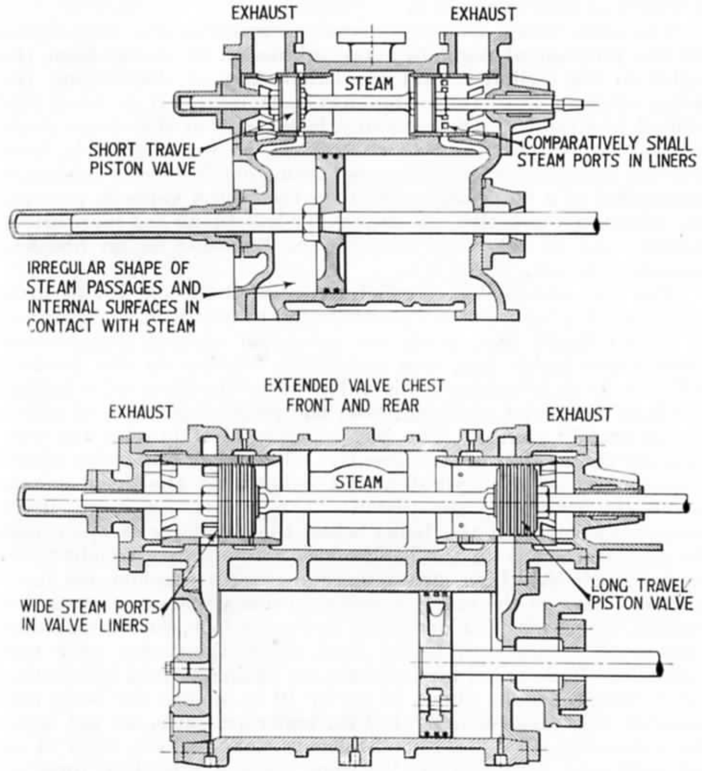


Fig. 99.—Above: Old Pattern Cylinder and Valve. Below: Cylinder Valve and Piston of New Standard Locomotives, L.M.S.R.

45 per cent. cut-off, which is marked with a letter "D" on the sector plate. When coasting, the cylinders of a locomotive operate as an air pump, and tend to create a vacuum in the steamchest. The effect of this is to cause a suction at the blast pipe, down which smokebox gases and cinders may be drawn into the cylinders. Air or anti-vacuum valves are fitted to the steamchests to break this vacuum and eliminate the tendency to draw foreign matter from the smokebox into the cylinders, but the large port areas and steam passages in modern cylinders so

greatly increase the pumping efficiency of the pistons, particularly at high speeds, that, with the valves operating at full travel, the quantity of air pumped would be so great that the air valves could not admit sufficient air to destroy the steamchest vacuum and the suction at the blast pipe.

By notching up the gear to "drifting" position the port openings are reduced sufficiently to cut down the pumping action to a point at which the air valves can neutralise it, and suction at the blast-pipe is avoided.

The slide valve, as will be shown subsequently, is designed for the purpose of regulating the admission of steam from the boiler to the cylinder, and for exhausting or discharging the steam after some of its energy has been used. It is faced and bedded accurately to prevent any leakage from the steam ports to the exhaust port, and to cut off the steam completely from entering the cylinder after its proper period of admission. Although superseded to a very large extent by the piston valve in present-day locomotive practice, the slide valve has a long and meritorious history, and is not, even now, to be regarded as an obsolete feature of design.

The first slide valve, "which superseded the old lift or drop valves worked by tappets," is attributed to Murdoch, an assistant of James Watt, and, with the exception that it had neither outside nor inside lap, was practically similar to the modern ordinary D slide valve. This valve takes the form of a hollow cast-iron or special gunmetal box, the projecting edges of which are accurately planed. The box is made to slide over the port faces by the motion of the eccentric, alternately admitting steam to each end of the cylinder, and exhausting the spent steam before the return of the piston. The steamchest is in direct communication with the boiler when the regulator is open, and the steam pressure on the back of the valve keeps it tight upon its face. Modern high steam pressure exerts considerable force upon the back of the valve, causing, in many instances, excessive friction, which may cut or groove the valve face, with a resultant leakage of steam and heavy load upon the valve gear and eccentric. If we take, for instance, an ordinary-sized locomotive valve, which may be about 15 in. by 10 in. across the back, and multiply this area even by 180 lb. boiler pressure, we get upon the valve face $15 \times 10 \times 180 = 27{,}000$ lb. load, which, with ·1 as the minimum coefficient of friction, gives a retarding force of 2,700 lb. Of course, some little reduction should be allowed for on account of the pressure exerted through the comparatively restricted area of the port from the cylinder to the front of the valve, yet it will still be evident that a large frictional resistance due to pressure must be overcome before the valve can be moved. Modern increased cylinder diameters, with the accompanying larger valves and higher steam pressures, have therefore necessitated various types of valves for relieving the wear and tear caused by excessive valve-face friction. Fig. 100 shows a type that was at one time extensively used. This is known as the Allan or Trick valve. With this design, a much smaller throw of the eccentric was permissible. One or more portways P are cast, which pass behind the exhaust cavity, giving a greatly increased

steaming area. The portways open to steam beyond the edge of the cylinder face F at the same time that the port begins to open at the steaming edge of the valve at S. A large amount of port opening is thereby obtained with a small amount of travel. The valve is not used so much as formerly, as a slight error of adjustment or lost motion due to wear in the valve gear has a serious effect on the efficiency of the valve.

An efficient method of relieving the heavy pressure on the valve face, known as the Richardson balanced valve, is shown in Fig. 101. Cast-iron strips S are let into the back, and are held tight against an adjustable back plate B, or the back of the

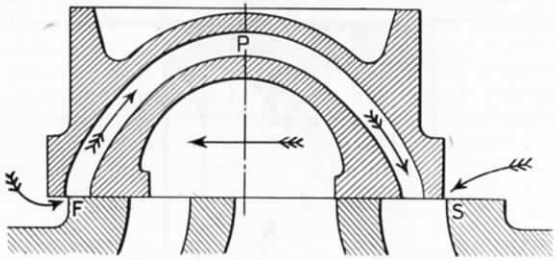


FIG. 100.—LOCOMOTIVE SLIDE VALVE (ALLAN OR TRICK PATTERN).

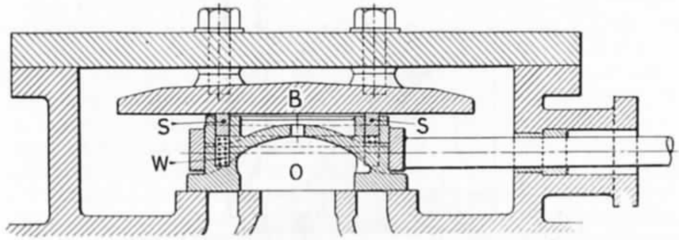


FIG. 101.—RICHARDSON BALANCED SLIDE VALVE FOR LOCOMOTIVES.

steamchest cover, by means of steel spiral springs W. The strips are made a good fit and bedded carefully so that steam is prevented from passing behind the back. Circular rings are sometimes fitted in place of the strips, and these are also held up to the back plate by springs. When the strips or rings begin to wear, a certain amount of steam is liable to leak behind the valve, and this is discharged by the hole O directly into the exhaust cavity. This valve was extensively used, and undoubtedly reduced the friction on the valve face, thereby relieving the valve gear and eccentrics of a large amount of work. This type of valve was usually applied only to cylinders with the steamchest above or below. Although the ordinary D slide valve can be balanced to a certain extent, such valves are only applicable when the location of the steamchest is suitable. It will also be evident that as they increase in size, so does the area of the lap pieces which are unbalanced.

A cylindrical slide valve, known as the piston valve, was therefore introduced. This is usually in the form of two pistons secured to one valve spindle, and fitted in such a manner that they uncover the steam ports at each end of the cylinder alternately, as with the ordinary D valve. The faces against

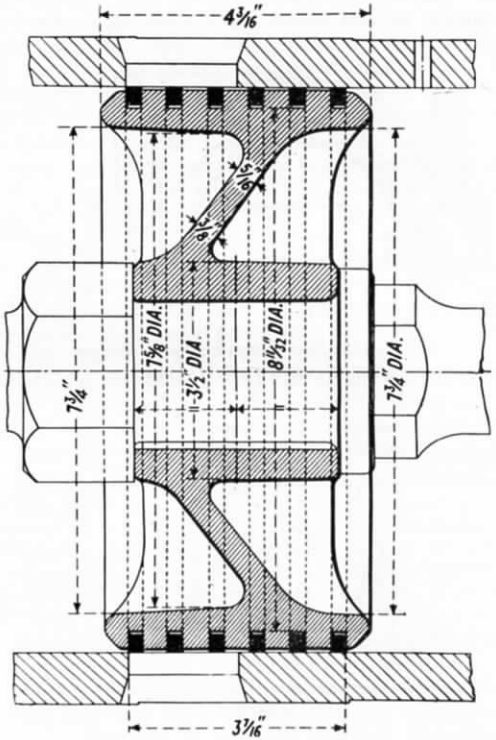


Fig. 102.—Latest Type of Piston Valve, L.M.S.R.

which the valves work are bored accurately, and are usually in the form of a hard, cast-iron bush, which is bored and fitted into the cylinder casting. The ports are cast or cut into the bush, and the valves are made steamtight by annular rings made from good cast iron or special gunmetal. These packing rings are held against the inside circular face of the bush by means of internal springs, and diagonal bars are cut or cast across the ports to prevent the rings spreading and fouling the port edges. Two distinct types of piston valves are in use. One

type is for outside admission, in which the steam is admitted to the cylinder by the outside edges of the valves at S and S^1, which have outside lap pieces as in the case of an ordinary slide valve (see Fig. 92). The second type is for inside admission, and the steam is admitted to the cylinder by the inside edges. The lap pieces are placed between the valves, and the exhaust controlled by the outside or ends of the valves (Fig. 93). It is claimed for piston valves that a greater port area is obtained than with the D valve, and a shorter travel is possible. The steam pressure, instead of pressing heavily upon the faces, is exerted endwise upon the pistons, which are therefore practically in equilibrium, so that the wear and tear on the valve gear is considerably reduced. With inside admission piston valves, it is also claimed that the valve spindle stuffing-box and gland are much more easily maintained steamtight, because there is only exhaust steam pressure to contend with. In the older types of piston valves, a certain element of danger was always present, owing to the water due to condensation or priming being trapped in the cylinder. This danger is to a great extent obviated in the later patterns. The principal advantage claimed for piston valves is that they can be worked with about one-sixth the energy that is taken from the engine in working the ordinary slide valve. On the other hand, it is suggested that this saving is in a great measure counter-balanced by the increased cost of upkeep from breakages and repairs due to the more complicated construction of the piston valve. Modern practice has robbed this contention of whatever value it may have possessed.

An excellent example of modern practice in the design of locomotive piston valves is that shown in Fig. 102. This shows the type of piston-valve head adopted on the L.M.S.R. for modern express locomotives. The valve is 9 in. in diameter, and has a maximum travel of $7\frac{1}{32}$ in. It is of simple design, with six narrow rings, and has superseded the many complicated forms of valves which have been tried in the past. Experience has shown that piston valves of the kind illustrated are capable of running more than 30,000 to 36,000 miles express service between examinations and with a high degree of steamtightness.

Improvements in the design and construction of locomotive valves for controlling the admission and exhaustion of steam to and from the engine cylinders have been concerned mainly with endeavours to avoid the liability to wire-drawing, or throttling, the steam, during both admission and exhaustion, reduction of steam leakages, low maintenance costs, and the use of a minimum effort in opening and closing the valves. This has resulted in the application of steam distribution valves, which may be of the semi-rotary type, somewhat after the manner of the Corliss valve, or approximately similar to the ordinary mushroom type, but with two seats whereby each valve is placed in equilibrium. These are described as "double-beat" valves. These latter types may have either a vertical or "drop" movement, or a horizontal motion, controlled by cams, and are often referred to as "poppet" valves. The Caprotti and Lentz types are probably the most notable examples of modern developments in this direction.

Poppet valves have been in use on locomotives for a number of years past, and Fig. 103 shows the poppet valve arrangement as developed by Associated Locomotive Equipment Ltd., formerly known as Lentz Patents Ltd., London. The general arrangement is as follows: four poppet valves A are provided for each cylinder, these are disposed in pairs of one admission and one exhaust at each end of the cylinder casting. A central annular chamber B is provided in the casting through which a camshaft C runs at right angles to the valve spindles D and carries two cams E and F. One, E, operates the steam and the other, F, the exhaust valves. The cams may come into direct contact with the valve spindles, which, in such cases, are fitted with a roller and pin, the former bearing upon the cam profile. Alternatively, intermediate levers G, shown in the illustrations (Figs. 103 and 104), are arranged on suitable fulcrum supports. This design not only enables high lifts to be obtained for a given shape of cam, but at the same time enables lighter valve spindles to be employed. Both these features are of advantage, more especially for fast-running locomotives. Oscillating movement is imparted to the cam spindles by means of a rocker arm, seen in the photographic view (Fig. 104), which is coupled by the link, also shown, to the valve gear system.

The main principles underlying the design of poppet valves as arranged in the above manner are a slow opening followed by a quick movement of the valve, a rapid closing followed by a slow movement at the time of actual closure, and also the fact that up to the actual seating of the valve on its face, the valve spindle, either directly or indirectly (through the intermediate lever system) is in contact with the cam profile. In this way absolutely noiseless operation is assured, and there is no drop action whatsoever.

It should be understood that expansive working and reversing are accomplished by the usual means, *i.e.*, through the agency of the ordinary types of valve motion as usually applied, but the port openings are improved for any given running conditions. This feature, together with the improvements obtained by the more direct passages, especially for the exhaust, reduces losses due to throttling of the steam in the ports and passageways. The control springs pressing on the outer ends of each valve spindle are provided to preserve contact with the cams when the engine is running with steam shut off.

With the idea of obtaining a poppet-valve system having separately controlled steam and exhaust valves, so that opening and closing of the exhaust valve can be entirely independent of the steam-valve events, the gear illustrated in Figs. 105 and 106 has been designed. In this instance, the valves, spindles and control springs, together with their housings and steam ports, are arranged precisely as in the case of the previous application, the difference being that the cams H and J, instead of oscillating, are made to revolve continuously. They are mounted on a camshaft K, one set controlling the steam valves L, and another set the exhaust valves M. Owing to the contours given to these various sets of cams, it is possible to preserve a constant timing for the exhaust valves, while that for the steam valves is varied,

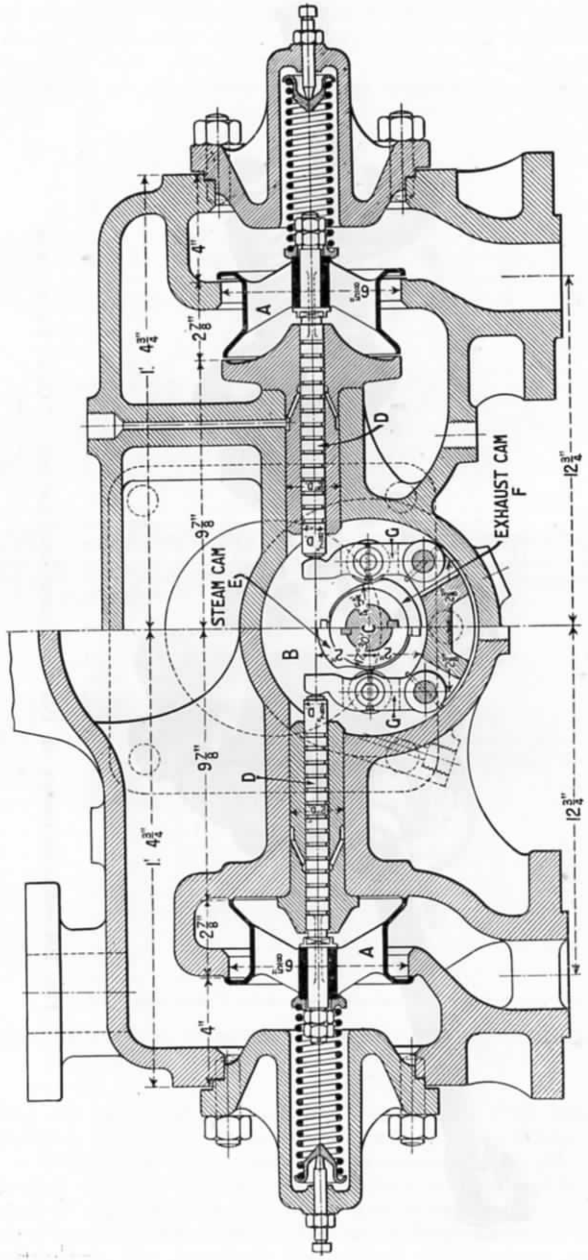


Fig. 103.—Longitudinal Section through "A.L.E." Valve Gear; "O.C." Type.

FIG. 104.—ARRANGEMENT OF POPPET VALVES AND LEVERS; "O.C." TYPE GEAR.

so that for any cut-off the points of release and compression remain the same. Reversal and expansive working are obtained by moving the camshaft, together with the cams, in a transverse direction, so that the steam-valve spindles are brought into contact with varying sections of the steam-cam profile corres-

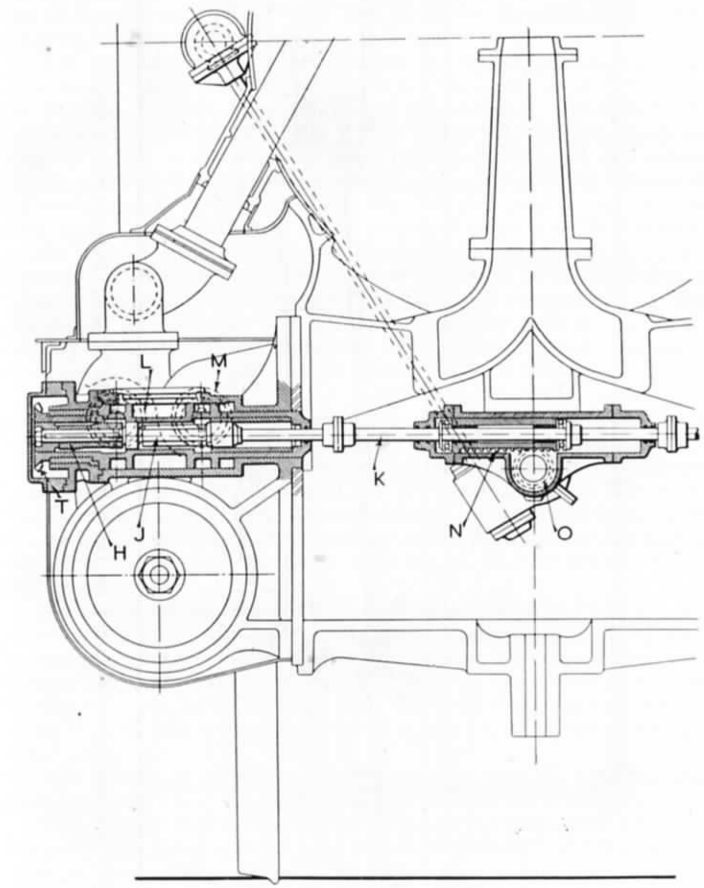


FIG. 105.—SECTION THROUGH TRANSVERSE CAMSHAFT AND CAMS; "A.L.E." ROTARY CAM POPPET VALVE GEAR.

ponding to the various cut-offs required. This transverse movement is effected by means of a rack N and pinion O, engaging with a worm and wheel, and the arrangement is self-locking. The initial drive for the rotating camshaft is obtained by means of a pair of skew gears mounted in a suitable casing P, fixed to a return crank Q, as shown. The drive from the skew gears is transmitted to the camshaft by a shaft R, carrying universal

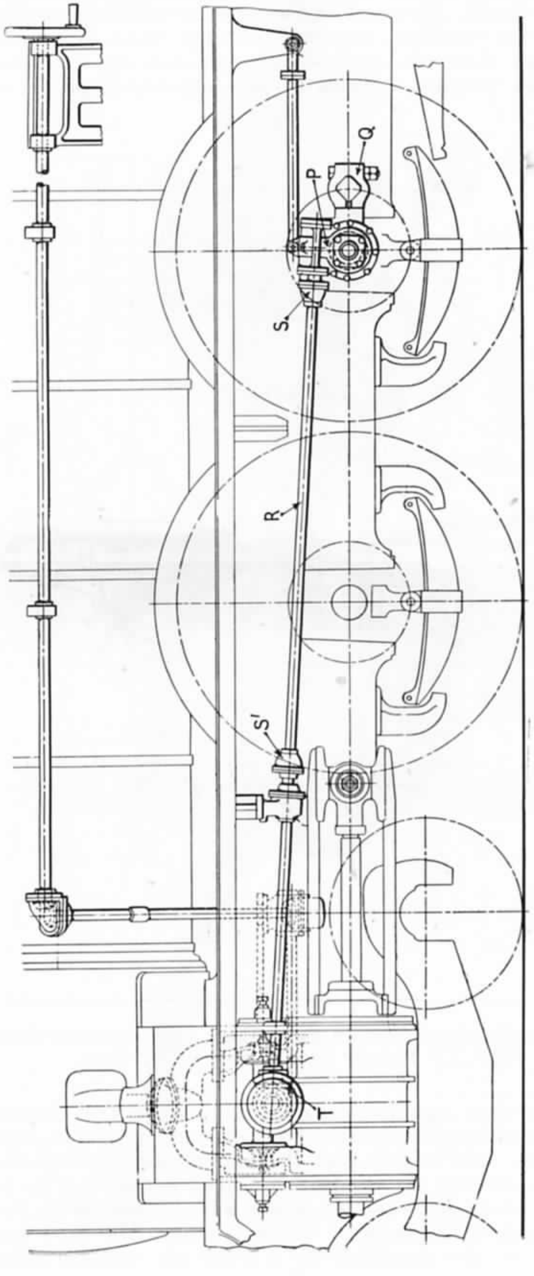


FIG. 106.—GENERAL ARRANGEMENT OF DRIVE FOR "A.L.E." "R.C." POPPET VALVE GEAR.

couplings S and S[1], and thence through two spiral bevels T, one of which is securely keyed to a sleeve, which drives the camshaft by means of splines. It is claimed that this arrangement gives a more perfect steam distribution than is possible with ordinary reciprocating valve motions common in practice, and at the same time, preserves the simplicity and accessibility which are characteristic features of the ordinary Lentz poppet-valve gear with horizontally placed valves.

The Caprotti valve gear, employing poppet valves operated by rotating cams, has been evolved for the purpose of improving the thermo-dynamic performance of the steam locomotive. The principal disadvantages of the valve gears usually employed are centred in the fact that when an early cut-off is used, the corresponding points of release and of compression are similarly advanced. An early cut-off is obtained and the point at which the exhaust port opens is also early. This causes considerable restrictions in the length of the expansion curve, and the pressure at the moment of exhaust is higher than it would be were the point of release delayed. Further, since the point of compression is also advanced, in order to run at early cut-offs, it is necessary to employ relatively large clearance volumes to prevent excessive pressure at the end of the stroke due to compression.

The Caprotti system, by employing separate means for operating the steam and exhaust valves, makes it possible to maintain the periods of release and compression constant for any degree of cut-off. Thus the dual advantage is secured of obtaining more work from the expansion of the steam, and at the same time enabling a considerable reduction in clearance volume to be effected. These two features taken together result in a considerable improvement in the efficiency with which the steam is utilised in the cylinders.

A further advantage is the reduction of frictional losses. The gearing, which for the most part runs in ball bearings, is encased in oiltight dustproof boxes, and the poppet valves are free from surface friction. About 2 h.p. is sufficient to operate the gear in the heaviest locomotives. The total oil consumption over a series of tests has proved to be very much less than with ordinary valve gear.

The above summarises briefly the advantages obtainable with any valve gear functioning after the manner described.

The valves and gear, as arranged on the Caprotti principle, are shown by the accompanying illustrations. Fig. 107 is a section through the cylinder showing the admission valves, and Fig. 108 is a section showing the exhaust valves. It must be understood that each cylinder is equipped with four poppet valves A, working in the vertical plane. There are two valves at each end of the cylinder, one operating the admission and the other the exhaust. The cams for controlling the valve movements are mounted so that they may be turned by a revolving shaft driven by any suitable means from one of the coupled axles. The angular velocity of this shaft must be, as in any form of valve gear of this particular type, exactly the same as that of the driving axle. The Caprotti system employs three cams for operating the four valves for each cylinder. Two cams, B, B[1], control the steam valves, and one, C, the exhaust. The plan view of the operating arrangement is shown by Fig. 110. It will be observed that a crankshaft D is employed, and this, by means of the links E, is coupled to sleeves F, which are very similar to the familiar eccentric straps. These sleeves embrace cylindrical pieces G, G^1, also shown separately in Fig. 109, cut to conform to a quick-pitch screw

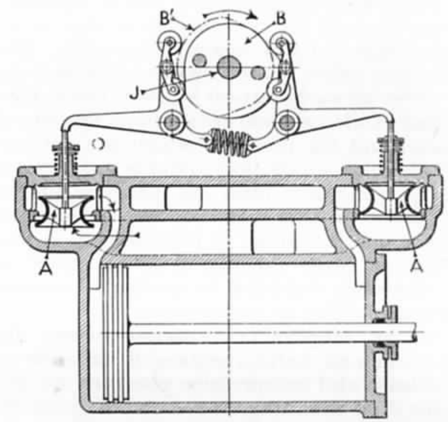


FIG. 107.—SECTION THROUGH CYLINDER AND INLET VALVES.

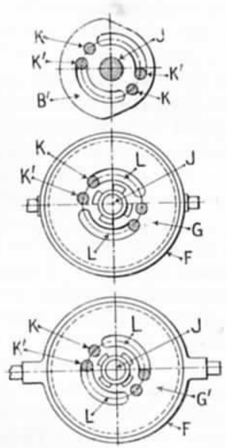


FIG. 109.—CAMS AND CAM RODS.

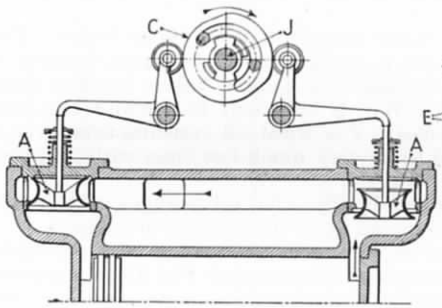


FIG. 108.—SECTION THROUGH EXHAUST VALVES.

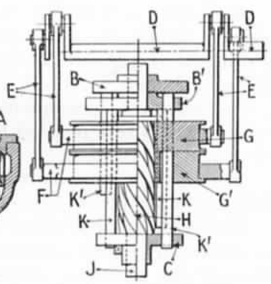


FIG. 110.—CAMSHAFT ASSEMBLY IN PLAN.

H, which forms part of the revolving shaft J. The two steam cams are located next the crankshaft D, and the exhaust cam is shown on the outer end, remote from the crankshaft. The cams are loosely fitted on the revolving shaft. They are, however, given a rotary motion by means of cylindrical bars K, K, K^1, K^1, which are driven by the cylindrical pieces engaging on the quick-pitch screw. Slots L, L (Fig. 109), cut in the cylindrical pieces,

allow the direction of motion and the functions of the cams to be reversed, the cylindrical pieces again taking over control when they have been turned through a sufficient angle.

Referring to Fig. 107, it will be noticed that the valves are actuated by bell cranks, the ends of which, next the cams, are fitted with equal arm levers carrying rollers bearing directly on the two steam cams. When running in the direction of the arrow, the cam shown by the continuous line is acting as the admission cam for the valve on the left hand, which, it will be noticed, has been opened, while the cam, shown by means of chain dots, is acting as the cut-off cam. When it is desired to reverse the engine, movement of the crankshaft by means of the links E (Fig. 110) has the effect of reversing the functions of the two steam cams. The position of the exhaust cam relative to the valve-operating levers is not altered in so far as the time of the opening and closing of the valves is concerned, until the reversing gear is in mid-position. Therefore, the points of release and compression remain the same whatever degree of cut-off is employed. It will be noted that the valves work in housings which are part of the cylinder castings, and that they work in cages which form the valve seats.

The valve-control springs, shown in Figs. 107 and 108, are no longer used. Instead, live steam is taken directly from the regulator through a pipe connected to passages in the cylinder casting. This allows the steam to act on extensions of the valve spindles, and so lifts them up to their seats, as shown in Fig. 111. The extension of the exhaust valve spindles is fitted with a frictionless type of spindle packing, which prevents live steam entering the steam port and suffers practically no wear.

Immediately the regulator is opened, the first steam taken lifts the valves into their correct running position, as controlled by the cambox. When the regulator is closed, the valves drop back off their seats, and remain in the fully open position. A perfect by-pass is thus provided when the engine is coasting. No by-pass valves are required with this valve gear.

Fig. 112 shows in perspective all the units of the gear with their titles. The drive for the camboxes is taken from one of the coupled axles, and the self-contained unit at the axle is known as the drive-off axle. From this axle a rotating shaft is connected to the cross-driving gear, which is usually situated between the camboxes, and connected to them by cross-driving shafts. The main driving shaft is fitted with universal joints to allow for the rise and fall of the driving axle, and universal joints are fitted to the cross-driving shafts to ensure very free running of the gear.

The reduction gearbox is placed immediately behind the cambox, and the reversing shaft from the hand wheel in the cab is connected directly to it. By this means, the turning movement of the reversing shaft is reduced, as a small gear wheel transmits the motion to a gear wheel segment of larger diameter. This also makes the reversing of the engine particularly easy. The lever on the shaft of the large segment connects with a lever on the reversing crankshaft of the cambox, and transmits the movement of the reversing shaft to the cambox. One turn only of the reversing hand wheel moves the gear from the full forward gear position to the full backward gear position, and the engine can be reversed easily in any position whether standing or moving. A lever on the rear end of the shaft of the large segment in the reduction gearbox is connected to a cross-rod, which transmits the reversing motion to the opposite side of the engine, where the cross-

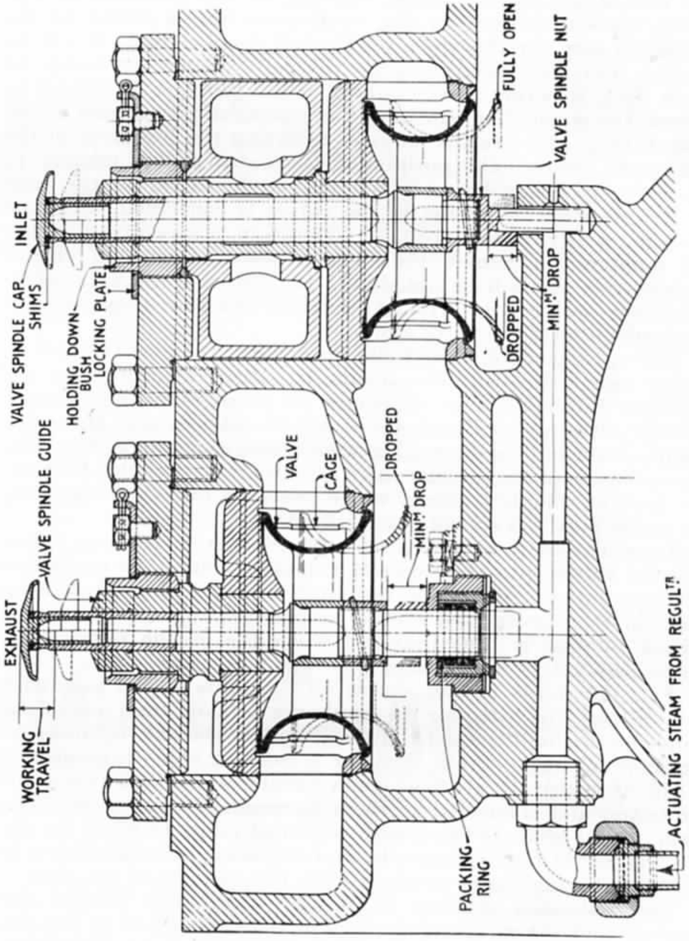


FIG. 111.—SECTION THROUGH STEAMCHEST SHOWING STEAM-ACTUATED POPPET VALVES.

rod (known as the reversing rod) is connected to a lever on the reversing gear support. This is coupled to the other cambox in the same way as the reduction gearbox.

The camshafts rotate at the same number of revolutions as the driving wheels of the engine. If necessary, the driver can satisfy himself readily that the gear is in order, and correctly set, by the following simple observations :—

In the case of an engine with the reversing hand wheel on the right-hand side, the left-hand crank must always move in the same angular position as the asterisk marked on the graduated disc on the outside end of the left-hand cambox ; *e.g.*, left-hand

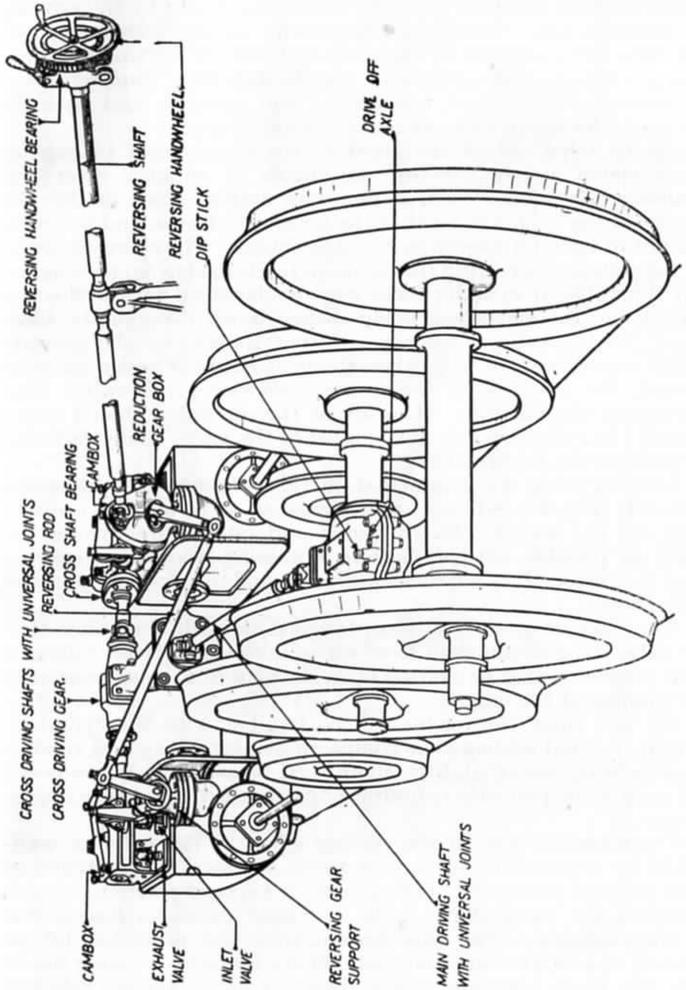


FIG. 112.—PERSPECTIVE VIEW OF CAPROTTI VALVE GEAR APPLIED TO A TWO-CYLINDER LOCOMOTIVE.

crank on front dead centre, asterisk on left-hand cambox on front dead centre. In the case of an engine with the hand wheel on the left-hand side, the right-hand crank synchronises with the asterisk on the graduated disc of the right-hand cambox ; *i.e.*, right-hand crank on back dead centre, asterisk on right-hand cambox on back dead centre.

The valve spindles need no lubrication at all, and are better if kept clean and free of oil. The camboxes must be filled up to the middle of the oil-level indicator glass with best superheater cylinder oil. The self-contained units, drive-off axle, cross-driving gear, reduction gearbox, and reversing gear support, etc., should be oiled regularly with the standard oil used by the railway for journals, etc. Suitable oil boxes and oil plugs are provided, and these are indicated in Figs. 113 and 114. The Caprotti valve gear permits a high degree of standardisation; camboxes are interchangeable between one engine and another, and between right- and left-hand cylinders on the same engine.

Air or relief valves are fitted to the steamchests of engines using piston valves. When an engine is running after the regulator has been closed, a pumping action is set up by the pistons in the cylinders, so that the air is withdrawn, and a certain amount of vacuum formed in the steamchest. The energy exerted by the pistons in creating this vacuum tends to slow up the engine, and the valve or cylinder faces may be damaged by the floating particles in the smokebox being sucked down through the blast pipe. The air valve is maintained upon its seat by the pressure in the steamchest, so that when steam is shut off and a vacuum formed, the pressure of the atmosphere raises the valve, thus destroying the vacuum. The lift of the air valve should never exceed $\frac{3}{8}$ in., otherwise there is danger of the valve being fractured by striking the face too heavily.

Leading from the steamchest to the cylinders are the steam ports SP (Fig. 98). These are designed so as to provide a direct path for the steam. Sharp bends and curves are avoided as much as possible with a view to obtaining a pressure exerted upon the pistons P as nearly as possible equal to the steam pressure in the boiler.

The exhaust port E is also designed in such a manner that the exhausting steam shall have a free outlet, otherwise sufficient back pressure would be exerted upon the pistons to retard seriously the running of the engine.

By this time, the reader will be familiar with the cylinders, so that, beyond adding that compactness, durability and rigidity are absolutely essential, little more need be said. They are bored out so as to be perfectly cylindrical and finished with every degree of care.

Condensation due to the cooling effect of the cylinder walls would be responsible for serious losses of steam if the cylinders were not well protected. Owing to their exposed position, outside cylinders are particularly liable to cause excessive losses, due to condensation. For this reason, they are protected by an efficient non-conducting material. Many kinds of covering are in use, the most common being silicate cotton, special asbestos composition, or wood lagging. This protection, however, does not prevent a certain amount of condensation when steam is first admitted to the cylinders after an engine has been standing. Since water is practically incompressible, if it is present in the cylinder, either from priming or condensation, there is a danger of knocking out the cylinder ends when the piston approaches the end of its stroke. The cocks which are fitted to the lowest

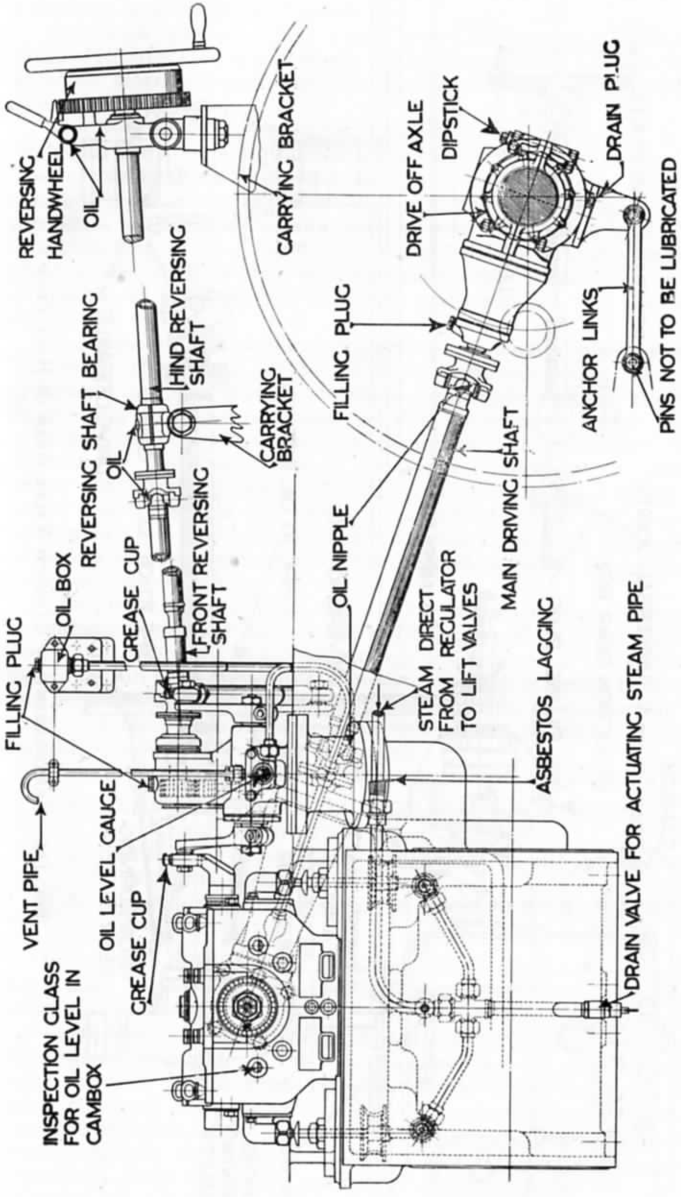


FIG. 113.—ARRANGEMENT OF CAPROTTI VALVE GEAR IN ELEVATION.

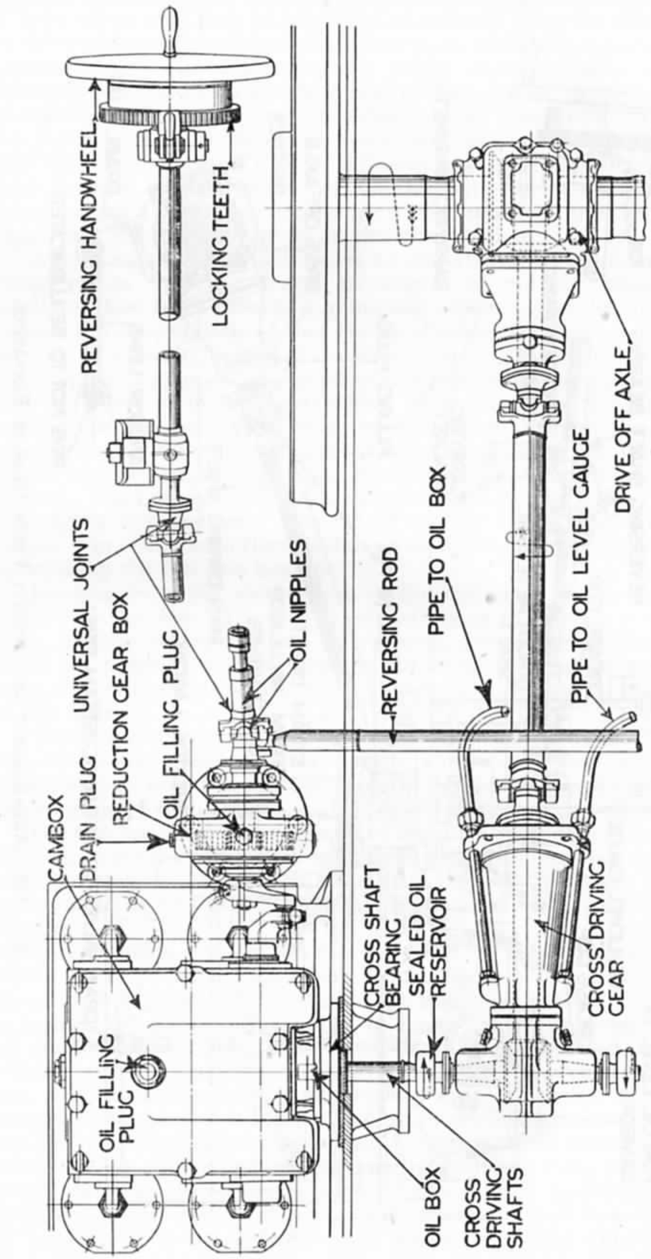


Fig. 114.—Arrangement of Caprotti Valve Gear in Half Plan

part of the cylinders for draining the water are therefore important adjuncts. They are controlled by rods and levers from the footplate, as already mentioned.

Spencer's patent relief and drain valve for locomotives (Figs. 115 and 116) is a modern device designed to act as a relief valve for trapped water, and also to take the place of the ordinary cylinder drain cock.

The valve has six passages, 1-6, which are connected to the back and front ends of the cylinders and steamchest respectively. These passages open downwards into one common chamber through ports in a faced surface, and a central passage *b* is also provided, which is in communication with the atmosphere. The faced surface of the ports is covered with a properly bedded plate or disc *d* (Fig. 116), which is maintained in position by the admission of steam direct from the main pipe to the underside of the disc at *e*.

The area of the surface exposed to the main pipe pressure is greater than that of the ports in communication with the cylinders, and the disc is therefore held tight against the port faces until an excessive pressure, due to trapped water in the cylinder, occurs, when the disc is forced from the face, thus discharging the water through the central port into the atmosphere. A specially designed three-way cock is fixed upon the boiler front plate in the cab, by means of which the pressure underneath the disc may be relieved, whereupon both ends of the cylinders and steamchest may be drained, as with the ordinary cylinder drain cocks.

The piston head P (Fig. 98, p. 176) is turned slightly smaller in diameter than the bore of the cylinder, so as to be an easy fit. The steam, when admitted alternately to each end of the cylinder, exerts its full pressure against the piston, which is forced backward and forward, so that it is directly instrumental in converting the energy of the steam from pressure into a motion which is transmitted by means of rods to the crank.

The chief desiderata for an efficient piston are as follows :—

1. Ability to prevent the leakage of steam from one end of the cylinder to the other.
2. Sufficiency of strength to withstand the pressures to which it is subjected.
3. Suitability of design for a secure attachment to the piston rod.

In order to fulfil the first condition, many kinds of piston rings have been tried. The Ramsbottom rings, which are invariably fitted in this country, are perhaps the simplest and most effective for locomotive purposes. They are generally made of cast iron. The outside diameter of the rings is made from $\frac{1}{8}$ to $\frac{3}{8}$ in. larger than the bore of the cylinder, and a piece is cut away, so that when the ends are pressed together, it is possible to spring them into the cylinder. Two or more grooves are turned in the piston block, and the rings fitted in such a manner that they are not prevented from springing outwards. The pressure brought to bear by the tendency of the rings to spring outwards to their normal diameter is found sufficient to resist the steam pressure.

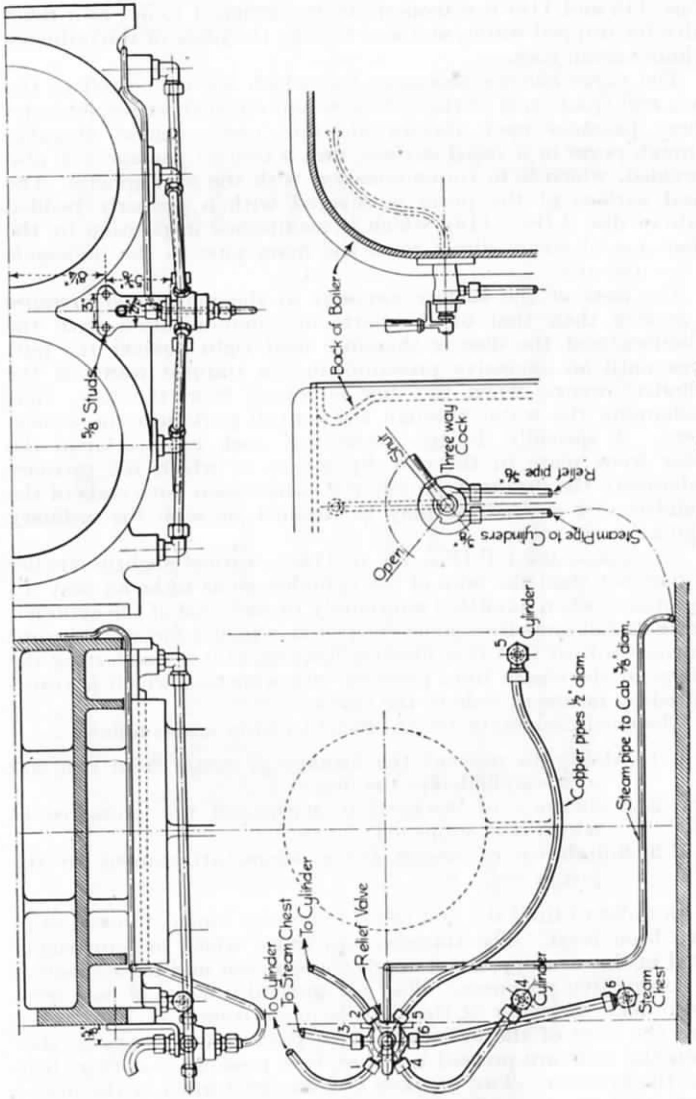


FIG. 115.—SPENCER'S RELIEF AND DRAIN VALVES.

Excessive friction would absorb a large percentage of the power of the engine, and the cylinder would be cut or grooved if the rings were made too strong, so that the most efficient rings are those that will remain steamtight with the least amount of friction. By cutting away a portion of the rings, an opening is left where the ends meet, and these openings must be staggered or broken, *i.e.*, placed on opposite sides of the piston, and away from the port openings so that two joints do not come together. Otherwise the steam will have a straight path past the piston and a considerable leakage will take place. To prevent the rings from turning after they have been forced into the cylinder, pegs are often fitted inside the grooves. The weight of the piston head is reduced as much as possible consistent with a safe margin of strength.

The momentum of a moving body increases rapidly with the weight and speed of the body, so that in modern high-speed engines heavy stresses are passed through the rods to the crank-pin, when the piston is changing its direction of travel. Cast-iron piston heads are often used, except in large cylinders, for which steel is sometimes employed, to obtain a comparatively lighter and stronger piston. On account of the smoother running qualities of the metal, cast-iron heads are not so liable to damage the cylinders as steel heads, and whenever possible, the iron casting is adopted. In locomotive cylinders, it is usual to allow about $\frac{3}{8}$ or $\frac{7}{16}$ in. space between the piston head and the inside of the cylinder covers at the limit of the stroke. This space, which, with the addition of the port volume, is known as the cylinder clearance, is an important factor in the consumption of steam, and the smooth running of an engine. A certain amount of clearance is necessary to allow for any alteration in the position of the rods when wear takes place, and also to allow room for any water that may be in the cylinders, due to condensation or priming. When properly designed, the clearance is of great assistance in arresting the momentum of the moving parts by allowing room for a certain amount of compressed steam. The time of exhaust and admission is specially set for this purpose. This compression is known as cushioning, and acts in such a manner that the piston is, comparatively speaking, brought gradually to a standstill before the return stroke is commenced. At the same time, too much clearance would result in an excessive consumption of steam, as the clearance spaces are refilled with live steam at every stroke of the engine.

A strong boss is cast in the centre of the piston head, which is bored out to an accurate taper for the attachment of the piston rod PR (Fig. 98). The rod is carefully turned and made a good fit in the taper hole. It is often ground in position to ensure a first-class job. The end of the rod is also turned and screwed in the lathe for the reception of a strong, well-fitting nut, which, when fully tightened, secures the piston head firmly to the rod.

A hole is drilled in the nut and rod end, through which a pin is fitted, and riveted at both ends, to prevent the nut from working back. Before its final attachment to the piston head, the rod is turned so as to be perfectly true throughout its length,

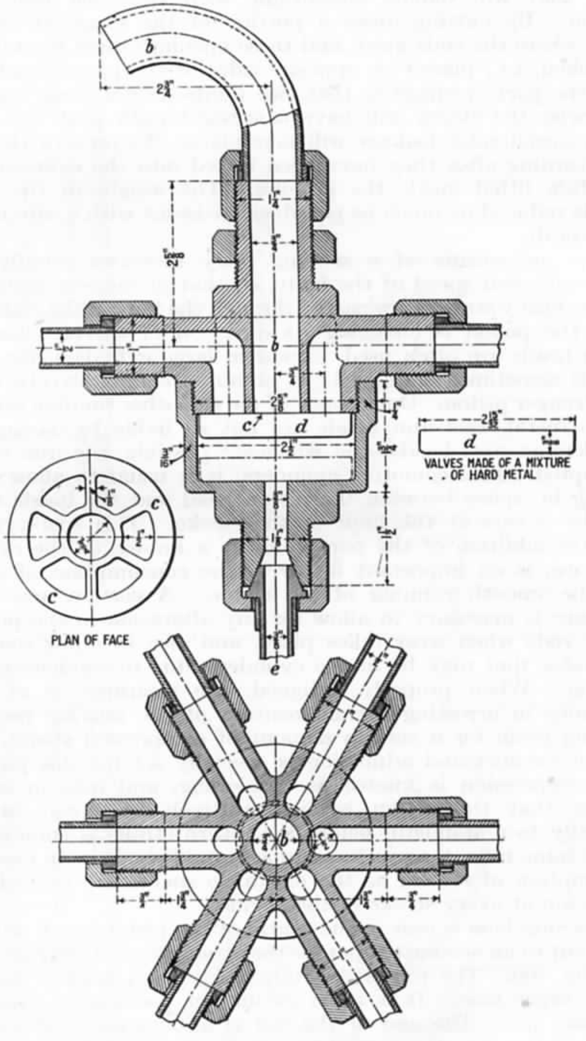


Fig. 116.—Further Details of Spencer's Cylinder Relief Valves.

and is left $\frac{1}{4}$ to $\frac{3}{8}$ in. larger in diameter than is absolutely necessary, to allow for turning up true after wear has taken place. This saves the cost of a new rod. It is made from forged steel of a known and approved breaking strength, and is prepared at the opposite end for the reception of the crosshead.

To provide additional support for heavy pistons in large cylinders, the piston rod is often extended on the front side of the piston, and passed through a stuffing-box in the front cylinder cover similar to the back-cover gland and stuffing-box.

The rod is maintained steamtight in passing through the covers by means of the gland packings, of which many types are in use. The requirements of a good gland packing are that it shall maintain the gland steamtight, with a small amount of friction, and without injury to the surface of the piston rod. The old-fashioned hemp rings soaked in tallow soon became a constant source of trouble when steam pressures, and consequently temperatures, were raised. For resisting the heat, and at the same time reducing the friction, special asbestos packings, sometimes interwoven with rubber for flexibility, and with graphite, soapstone, or metallic fibres for lubrication and smooth running, were introduced. This form of gland packing is still used extensively, and under certain conditions fulfils all the requirements. It is placed in the stuffing-box in rings very similar to the old hemp rings, with the joint of each placed on opposite sides of the stuffing-box. When using this kind of packing, it is essential to take care that the rings are cut to a proper length, put in evenly, and tightened up equally all round with the gland nuts. If the stuffing-box is improperly packed, steam leakage will give constant trouble, and the rod will become overheated or damaged by grooving. It is surprising to find what a small amount of pressure is required to maintain the packing steamtight in a well-packed stuffing-box. Notwithstanding the state of proficiency attained by the manufacturers of fibrous packings, the high steam temperatures and piston-rod speeds of a modern engine soon affect seriously the durability and efficiency of the packing. Many forms which are entirely metallic have therefore been designed, and these have superseded the fibrous packings almost completely. They are made in so many different forms that it is impossible to give here more than a general description.

Metallic gland packings may be divided broadly into two types, viz.: (1) Those that depend upon end-on pressure exerted by the gland nuts, somewhat as shown in Fig. 117, and (2) those that are maintained steamtight by the action of springs fitted inside the stuffing-boxes, sometimes assisted by the pressure of the steam in the cylinder, as in Fig. 118. In the older forms of the first type the packing rings are usually made of white or Babbitt metal. Two of these rings form a pair, with the conical sides of each in contact, so that together they form a square packing ring. In order that the rings may tighten against the piston rod by the pressure exerted through the gland nuts, they are split or sawn and placed in the stuffing-box with the joints broken or "staggered" to prevent steam leakage. As will be seen, the packing rings are held rigid in the stuffing-box, and should there be any lateral or vibratory movement of the rod,

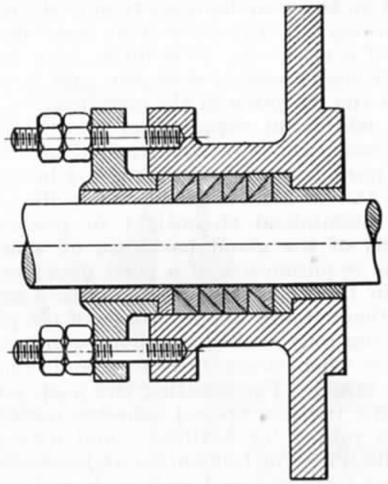


Fig. 117.—Metallic Packing for Piston Rods.

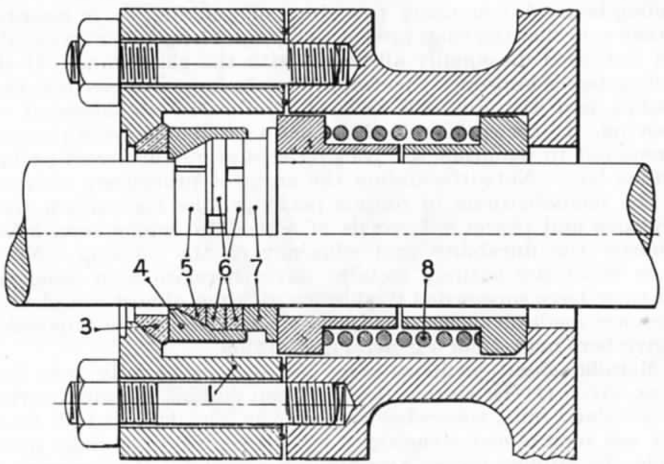


Fig. 118.—Spring-Controlled Metallic Packing.

due to faulty alignment or wear at the slide bars, the rubbing surfaces of the rod and rings soon become grooved or worn. This entails fairly frequent renewals.

The Britimp packing ring for locomotive piston rods and valve spindles is illustrated in Fig. 119. It consists of three segments encircled by a garter spring. The joints between the segments are overlapped in a manner that prevents leakage,

and steamtight glands are ensured. These rings are usually manufactured from a special wear-resisting grade of high-duty cast iron, which quickly acquires a highly polished surface, and a similar surface is produced on the rod.

When the packing ring is first fitted to the rod, there is a gap of $\frac{3}{32}$ in. between each segment, and as wear takes place in the

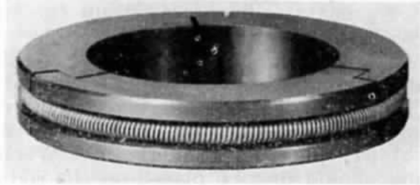


Fig. 119.—Britimp Packing Ring for Piston Rods and Valve Spindles.

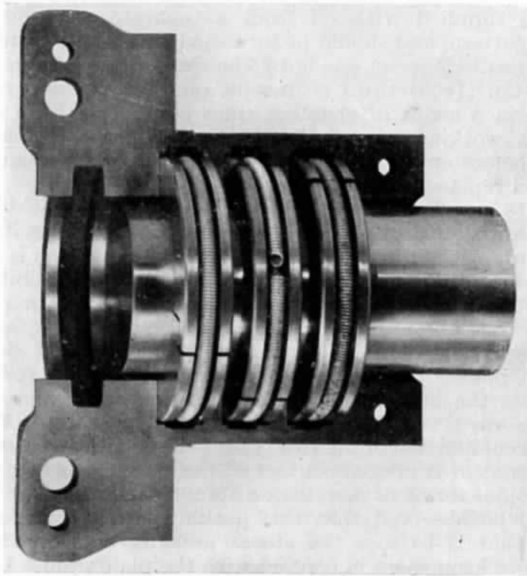


Fig. 120.—Housing for Rings of Britimp Packing.

bore, these gaps close until, after a lengthy period of service, the segments are butting. When this occurs, leakage will take place, but it is necessary only to dismantle the packing and file or grind $\frac{3}{32}$ in. off the end of each segment to secure a further period of effective service. Spare rings, bored smaller than the originals, and suitable for fitting to a worn rod, are supplied. The rod should be ground or skimmed up, to ensure that it is truly circular and parallel throughout its length. Each packing ring can be set up in the lathe for boring to suit the rod by chucking it with the spring in position, and a $\frac{3}{32}$ in. diameter distance piece between each segment.

It should be noted that the rings must be fitted with the tongues facing the outside of the box in order to allow the steam to have access to the backs. The garter springs are only required to prevent the segments falling away from the rod, and have no connection with the prevention of leakage.

The housings for the rings are made in a wide variety of patterns to suit existing stuffing-boxes. A typical arrangement is shown in Fig. 120. The housing is made in halves with ground and lapped joints, and the two halves are registered together with dowel pins or fitting bolts. When fitting, the rings and springs should first be placed on the rod, and the two halves of the housing placed over them and bolted together. A little thick oil should be used on the joint faces. The whole assembly is then pushed into the stuffing-box and secured with the gland studs and nuts. If an external swab-box is fitted, it should be supplied with oil from a separate reservoir of the drip-feed pattern, and should be furnished with a soft cotton swab.

The Britallic housing made by the same firm (British Metallic Packings Co. (1933) Ltd.) is unsplit, and the packing rings are contained in a series of chamber rings secured with an external flange. A working life of 150,000 to 200,000 miles should be obtained before spare rings are required, and the housing should never need replacement.

Fig. 118 is a flexible and modern type of gland packing made by the United States Metallic Packing Co. Ltd. at its works in Bradford, Yorkshire. The particular packing shown is adapted specially for locomotives, and consists of three Babbitt metal rings (5, 6) placed in a vibrating cup (4), the interior of which is partly conical or has double conical sides. The vibrating cup (4) rests against a ball and socket ring (3), and the whole is kept in place by a follower (7) and one or more springs (8), which press the ball ring against the socket in the head of the case and form there a steamtight joint. Reverting to Figs. 117 and 118, a comparison of the two types will show the comparatively small amount of frictional contact of the latter type as compared with the older forms of metallic or fibrous packings.

It will be observed that this packing is a "steam-setting" packing, that is to say, the steam pressure acts on the rings, and helps to keep them in contact with the piston rod. It follows therefore that this pressure is exerted only on the ring during a portion of the steaming stroke, and that there is no pressure on the rings during the exhaust stroke beyond the small amount due to the spring pressure. The packing does not depend upon the spring, as this is only required to keep the parts in position. The reduced area of the ring in contact with the rod, taken in conjunction with the reduction in pressure due to the steam-setting principle of the packing, ensures the minimum of friction on the rod.

The constant pressure exerted by packings that are adjusted by gland nuts is always an unknown quantity, and, when

excessive, may be equal to as much as two fully loaded wagons. The large amount of friction which is present throughout both strokes, together with the rigidity of the packing, has often resulted in hot rods, more especially when the lubricating properties of the steam are not available, as when running down a bank with the regulator closed. When the latter conditions have obtained for any considerable length of time, drivers have often been forced to admit a little steam to the cylinders for lubricating the rods, notwithstanding the fact that the brakes have been applied. The greater sense of security due to the advantage of a minimum amount of piston-rod friction with the regulator closed will be fully appreciated by the many locomotive drivers who have had anxious times with hot rods and melted whitemetal gland liners. By referring again to Fig. 118, it will be seen that the follower spring (8) automatically feeds up the follower (7), thus taking up the wear of the Babbitt rings (5, 6), and lateral

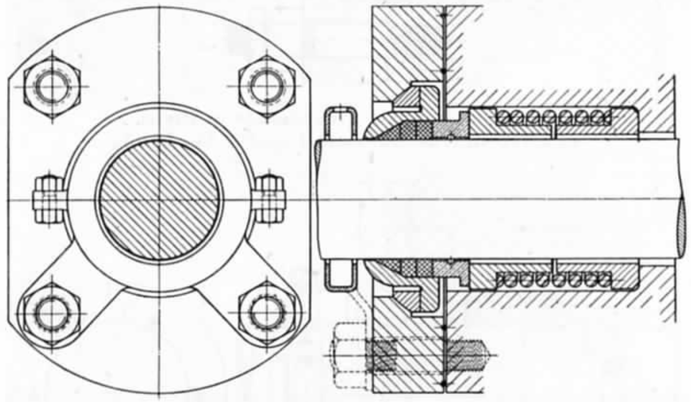


FIG. 121.—UNITED STATES METALLIC PACKING (AIR-COOLED TYPE).

movement is provided for by the space between the inner surface of the case (1) and the vibrating cup (4). This permits a direct sliding movement upon the face between the vibrating cup (4) and the ball ring (3), or a rocking motion between the ball rings and the socket in the head of the case (1), or a combination of both movements at the same time. The possibility of the packing producing a lateral strain on the rod is thus prevented. The foregoing remarks are applicable also to valve spindle glands.

During recent years, it has become almost standard practice to fit locomotives with superheaters, and this has entailed a modification in the arrangement or the material of the metallic packing to suit the increased temperature. One method, which has been employed to a considerable extent, has been in the nature of an air-cooled design, as shown in Fig. 121. This packing follows the general arrangement shown in Fig. 118, except that the vibrating cup, which holds the white-metal rings, is air-cooled. This reduces considerably the temperature to which the packing rings are subject, and permits the use of

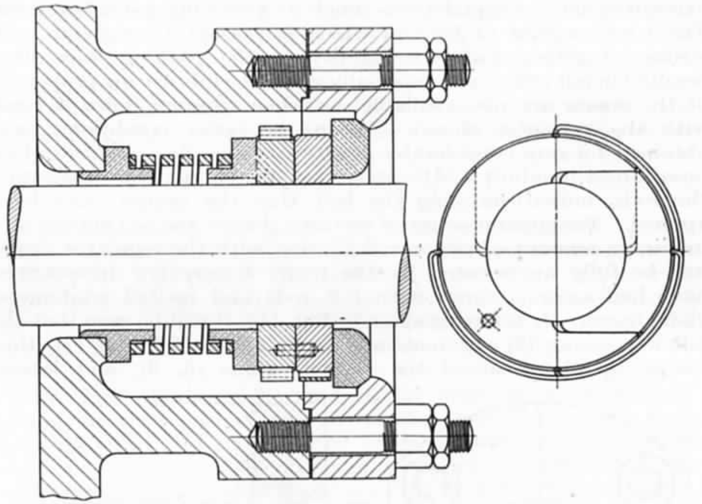


FIG. 122.—PACKING WITH CAST-IRON RINGS.
(UNITED STATES METALLIC PACKING CO. LTD.)

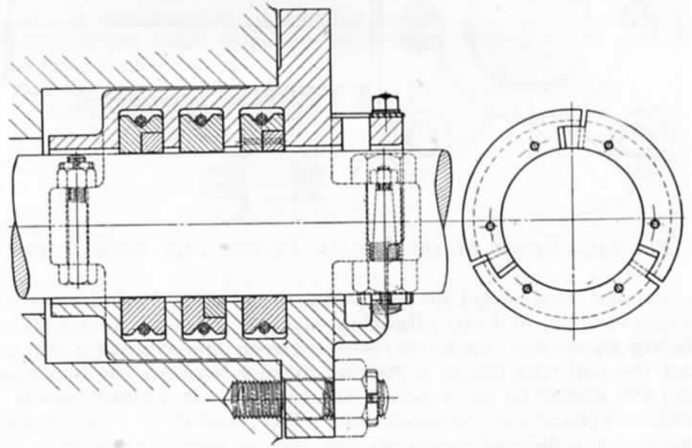


FIG. 123.—ANOTHER TYPE WITH CAST-IRON RINGS.
(UNITED STATES METALLIC PACKING CO. LTD.)

a whitemetal alloy for the packing rings. As an alternative to the air-cooled type of packing, many railways have adopted gland packings in which cast-iron rings are employed. Such packings are illustrated in Figs. 122 and 123.

The type shown in Fig. 122 is in use to a considerable extent on main-line engines in Great Britain. The packing blocks, which are of cast iron, are arranged in two rings, with the joints in one ring placed at right angles to the joints in the other.

Each ring consists of two pieces which are held together and kept in contact with the rod by clip springs. Apart from the cast-iron blocks or rings, the general arrangement corresponds approximately with the type shown in Fig. 118. When using metallic packings with cast-iron blocks or rings, it is essential that the piston rods should be of high tensile steel.

Fig. 123 shows another arrangement of cast-iron blocks. In

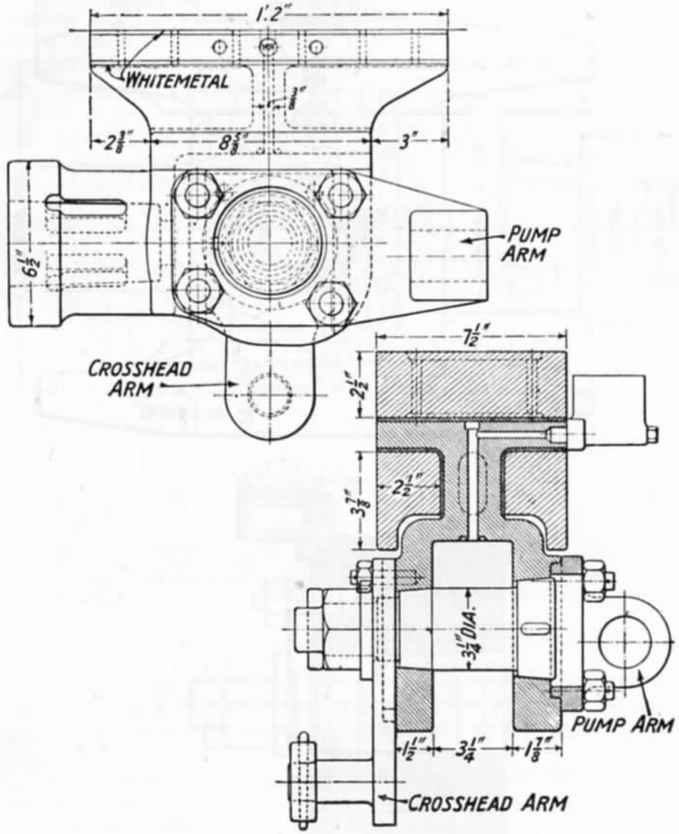


FIG. 124.—THREE SLIDE-BAR CROSSHEAD, SOUTHERN RAILWAY.

this arrangement, there is a split housing with three chambers. The cast-iron blocks or rings are each made in three segments and encircled with a garter spring. Cast-iron packings of this type have been used to a considerable extent by the Indian State Railways.

The crosshead is secured to the piston rod in much the same manner as the piston head. The rod end is turned accurately to suit the taper hole which is bored in the crosshead, and the two are ground together with fine emery powder, to ensure the best possible fit. After being finished to the proper length, a slotted hole is cut through the end of the rod, and another through the shank of the crosshead, for the reception of a forged-steel cotter, which is tapered, so that when driven home the rod is tightened very securely into the taper socket. A split pin or solid cotter

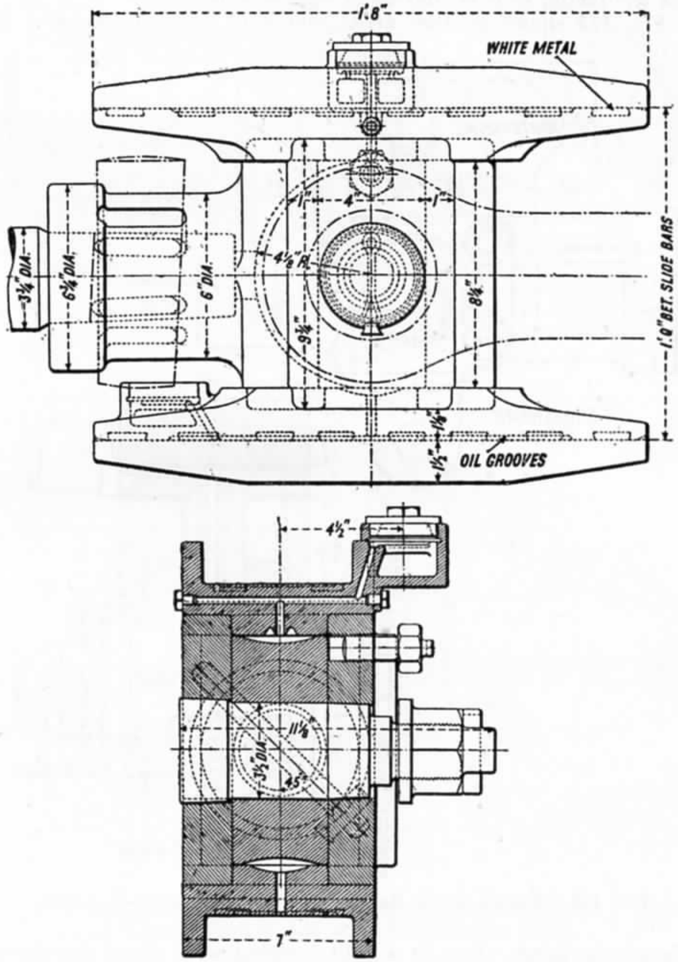


Fig. 125.—Crosshead for Outside Cylinders with Two Slide Bars.

is fitted through the small end of the piston-rod cotter to prevent slacking back. In some few instances, the rod end is screwed, and nuts are used instead of the cotter.

From one to four slide bars may be used to each cylinder, and the number of the bars determines the shape or form of the crosshead. These bars are necessary for guiding the small end

of the connecting rod in a straight path, which must be absolutely true and parallel with the centre of the cylinder, and to take up the angular thrust and pull transmitted by the rod in forcing the crank-pin through its circular path.

The type of crosshead shown in Fig. 124 is used on express engines where lightness is of importance. One upper slide bar and two lower bars are required in conjunction with it. The body of the crosshead is a steel casting with whitemetal applied to the surfaces which work on the slide bars. The attachments for the piston rod and gudgeon pin are the same as in the preceding example. One crosshead on each engine is fitted with a lug to take the vacuum pump rod.

The type of crosshead used generally with outside cylinders and two slide bars is shown in Fig. 125. The centre portion is a steel forging, and has circular seats at the top and bottom to carry the cast-steel slippers, which have whitemetalled wearing surfaces.

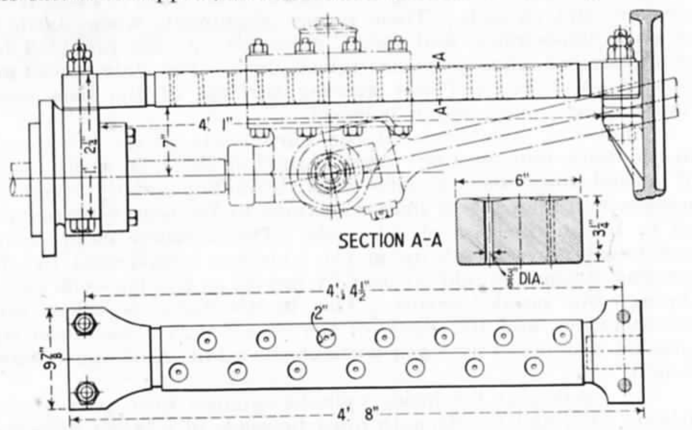


Fig. 126.—Crosshead for Single Slide Bar.

One side of the crosshead has a register to take the crosshead arm of the valve gear, which is secured by the gudgeon pin end nut. Attachment of the piston rod is by means of a coned and tapered cotter.

When only one bar is employed, it is usually fixed above the crosshead, and the slide block is fitted with a cover or cap to embrace the bar completely (see Fig. 126). When running forward, the upward thrust would be transmitted through the slide to the underside of the bar, and when running backward the downward pull would be sustained by the bar through the cap.

Two slide bars, one above the crosshead and one below, are often used, especially with outside cylinder engines. The bars are placed well apart, to make room for the angular swing of the connecting rod. The slide blocks may be fitted upon the crosshead in the form of a slipper, or secured by gudgeons specially forged and turned upon the crosshead for this purpose.

Another common form of crosshead is used for inside cylinders, and fitted with slide blocks on each side. For this type, four slide bars are necessary, and a certain amount of space is saved by bringing the top and bottom bars fairly close together. The slide blocks are fitted between each pair of bars and bored for the reception of the projecting ends of a strong gudgeon pin, which is fitted through accurately bored holes in the forked end of the crosshead. Cast-iron slide blocks, with recesses cast in the sliding faces for the reception of white or antifriction metal, are in general use, and brass plates are sometimes fitted to the side strips which come into contact with the sides of the slide bars. Crossheads in the form of steel forgings or steel castings are now adopted generally because of their combined strength and lightness.

The ends of the slide bars are supported by brackets cast upon the back cylinder cover, and, when possible, by facings cast upon the motion plate. They are usually made of steel, and are machined accurately and finished with care, to make them straight and smooth. Their proper alignment, when fixed, is of great importance, and special arrangements are provided for re-adjustment when wear has taken place. The slide blocks are bedded carefully, and the wearing surfaces of the bars case-hardened and re-ground or polished.

Connecting rods transmit the movements of the crossheads to the crank-pins, and are made of mild steel, or, in many cases, of special alloy steels capable of withstanding greatly increased stresses and allowing of lighter sections to be used, as explained on p. 152 in the case of side rods. The alternate compression and tensile stresses set up in the rods are complicated by the bending strains brought to bear by inertia as the big ends swing through the crank centres. This inertia force is taken into consideration, and the shape of the rods designed to obtain the greatest amount of strength without the addition of unnecessary weight.

The crank-pins for inside cylinder engines form part of the driving axle, and for strength must be made of a larger diameter than is necessary for the crank-pins fitted into the driving wheels for outside cylinder engines.

The big ends of the rods for inside cylinders are therefore larger than those for outside cylinders. There are, as already explained, many different types of rod ends, and the method of securing the bearing brasses in the rods varies considerably on the different railways. Constant modifications are necessary for transmitting the greatly increased power of modern engines.

The connecting rod shown in Fig. 127 has been in use for many years, and is known as the marine type. The middle portion is of circular section, and is therefore cheaper to manufacture than one of I section, but is a little heavier for equal strength. The big end bearing has whitemetal inserts which occupy most of the wearing surface. Lubrication is by means of a siphon trimming feeding on to felt pads at the top, and a similar number of felt pads are provided at the bottom of the bearing. These pads retain the oil and wipe the journal, so that a film is maintained on the surface. The small-end bearing is a split gunmetal bush working on the gudgeon pin, which is fixed permanently in the crosshead.

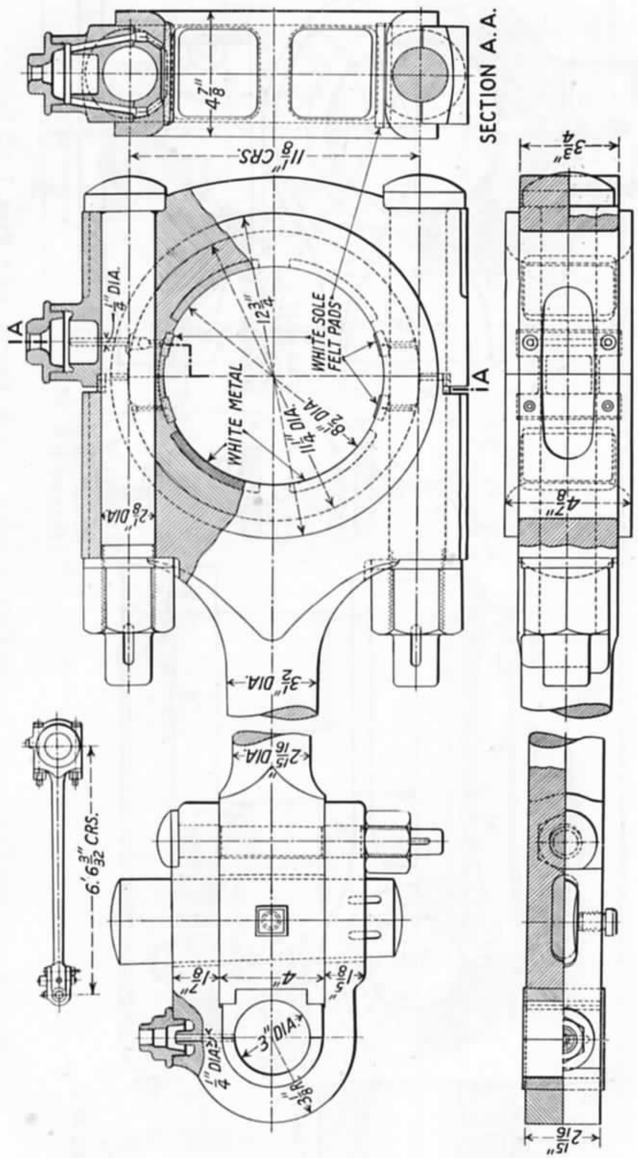


Fig. 127.—Marine Type Connecting Rod, Southern Railway.

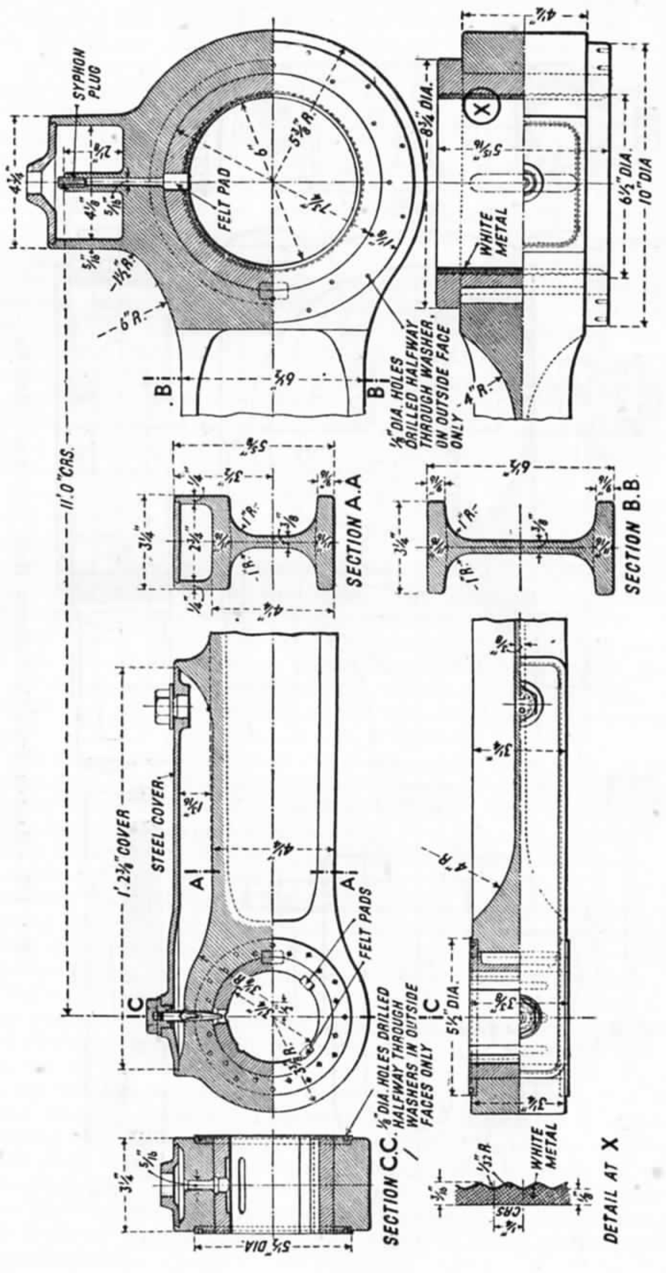


Fig. 128.—Outside Connecting Rod of Four-Cylinder Express Engine, 4-6-2 Type, L.M.S.R.

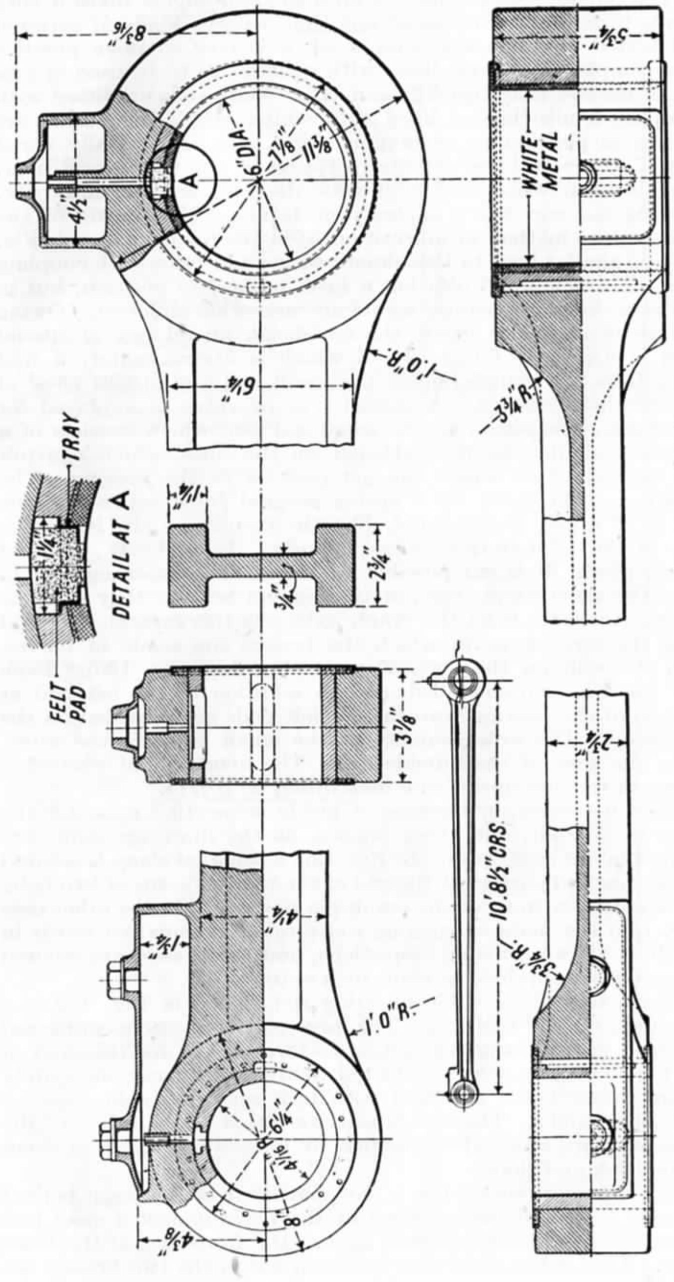


Fig. 129.—Outside Connecting Rod, G.W.R.

The outside connecting rod on a modern engine takes a very simple form, and, whereas at one time various kinds of cottered and bolted big ends were employed, it is now common practice for a simple brass bush lined with whitemetal to be used at this end of the rod (see Figs. 128 and 129). Both rods are fitted with phosphor-bronze bushes lined with whitemetal. The bushes are secured in position by rectangular keys, and are specially bored with a coarse traverse for the reception of the whitemetal liner. The oil cups, which are solid with the rod, are of ample size. The big-end cup has a capacity of 1 pint. The nature of the bush and its method of lubrication is, in the case of the rod (Fig. 128), on similar lines to that described in connection with coupling rods. The small end also has a bush pressed in position, but in this case the oiling arrangements are somewhat different. Owing to lack of clearance inside the crosshead, an oil box of special form is used, the filling cap of which is approximately a foot away from the centre line of the small end and stands clear of the crosshead casting. A special type of valve is employed for introducing the oil on to the small-end pin, which consists of a circular spindle slightly flattened on the sides, which controls the amount of oil which can get past on to the bearing. The spindle is held down by a spring secured by a cap nut. The rod is of fluted section, and, like the coupling rods, is, in the case of the "Coronation" class engine of the L.M.S.R., made of Vibrac steel. It is not possible for the inside connecting rods to be of the same simple form at the big end because they must be made detachable from the crank axle. In this case, the big end is of the strap type in which the brasses are made in halves, with the split on the vertical centre line (see Fig. 130). Each half brass is whitemetalled, and in addition to the felt pad at the top of the bearing, two further felt pads are provided on the underside. The arrangements at the small end are the same, as in the case of the outside rod. The attention of readers is drawn to the description and illustration on p. 214.

It is necessary, in the case of inside connecting rods, for the brass to be split, and these brasses, as the drawings show, are secured in different ways. In Fig. 130, a separate strap is secured to the enlarged portion at the end of the rod by means of two bolts and a cotter in front of the crank-pin opening. In the other case (Fig. 131) the main connecting rod forging extends rearwards in the form of two arms or projections, and the brasses are secured by a separate clip held in place by a cotter.

The partly dissected connecting rod shown in Fig. 132 is a type used on the L.M.S.R. The large end of the connecting rod is forged in a rectangular section to form a seat for the jaws of the big-end strap, which is bolted to the rod by two accurately ground taper bolts, provided with lock nuts and split pins for additional safety. The two brasses are fitted to the inside of the strap, and are retained in position by flanges machined on them at the back and sides.

The cotter is inserted in a slot machined in the strap behind the rear bolt, and passes down at the back against a steel pad known as the glut, which rests against the front face of the front brass. Thus, when the cotter is driven down, the two brasses are

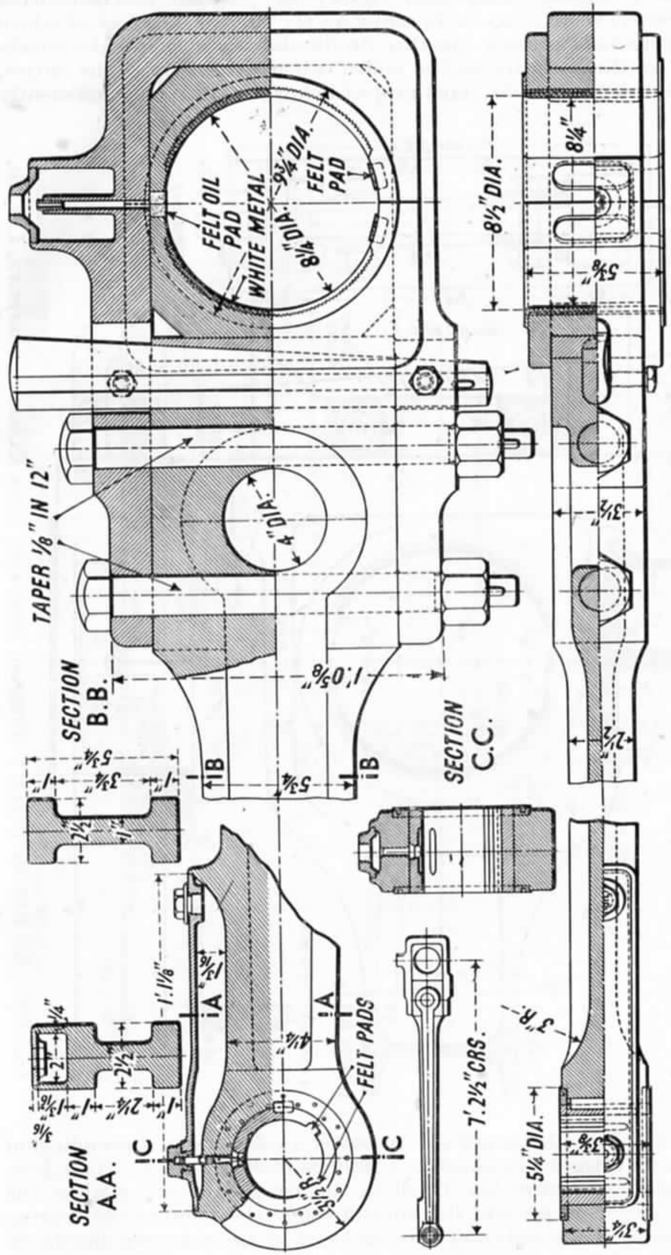


FIG. 130.—BIG END OF INSIDE CONNECTING ROD FOR 4-6-0 TYPE ENGINE, L.M.S.R.

pressed together and held tightly in position. When fitted correctly, there must be no draw on the brasses, the feet of which must be held pressed together firmly above and below the crank-pin by the pressure of the cotter when driven up. The cotter, when driven up tight, must project below the strap only sufficiently

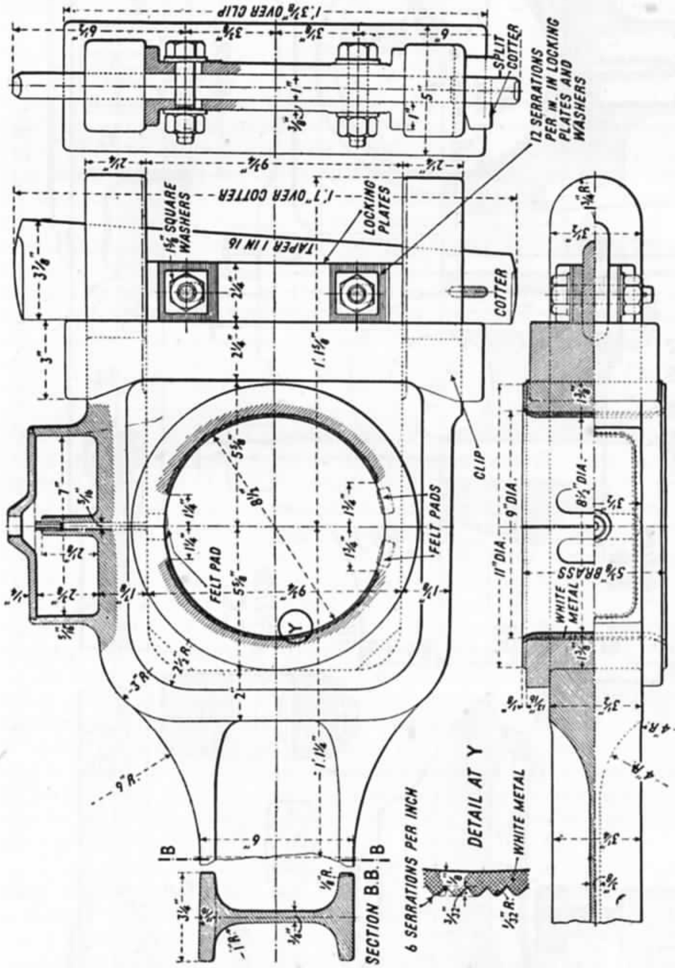


Fig. 131.—Big End of Inside Connecting Rod, 4-6-2 Type Express Locomotive, L.M.S.R.

far to enable the small safety cotter to be driven through, and must be a tight fit against the underside of the strap. Two $\frac{5}{8}$ in. diameter set-screws are fitted in the strap to clamp against the main cotter, to prevent it from shifting in the event of the bearing becoming disturbed, and the tightness of these screws should be checked during engine preparation. If during examination it is

found that draw has developed on the brasses, or that the main cotter is projecting too far through the strap, so that the safety cotter is loose, the big end should be reported for attention, because other troubles and knock are liable to develop rapidly when such conditions exist.

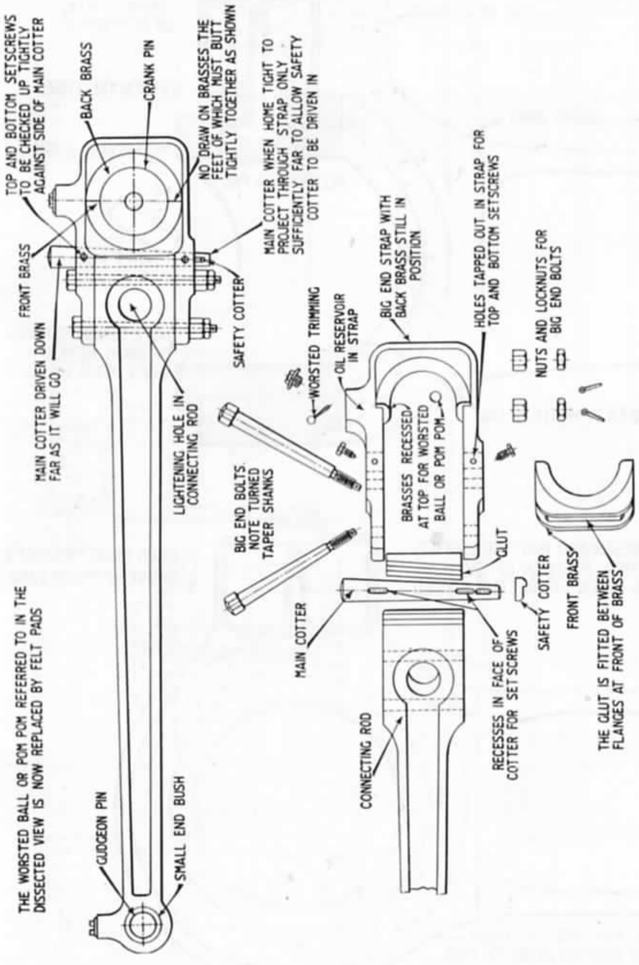


Fig. 132.—Method of Uncoupling Big-End Bearing, L.M.S.R. Locomotive.

The most suitable setting for uncoupling a big end of this type is with the crank slightly in front of the bottom quarter position; but in a breakdown on the road, where no pit is available, front centre, or even higher, may be found more convenient, as it permits a better blow with the hammer for driving out the bolts. It should be remembered that two or three firm

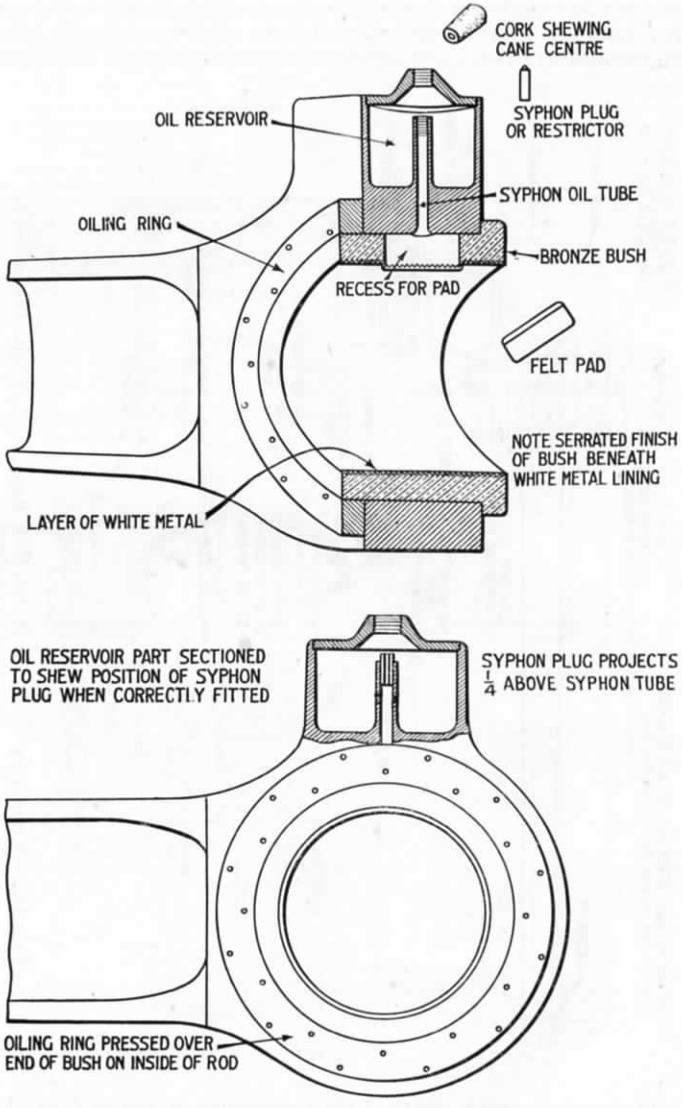


FIG. 133.—BIG-END BEARING; PLAIN BUSH TYPE.

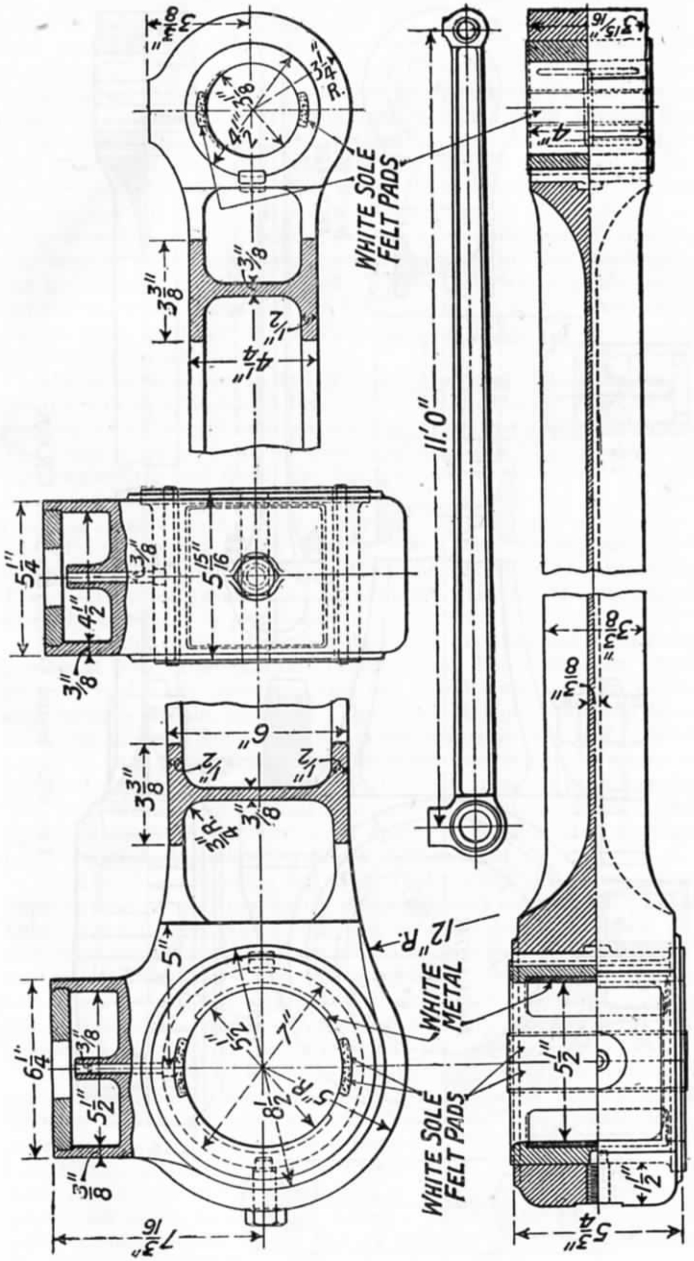


FIG. 134.—CONNECTING ROD FOR OUTSIDE CYLINDER ENGINE, L.N.E.R.

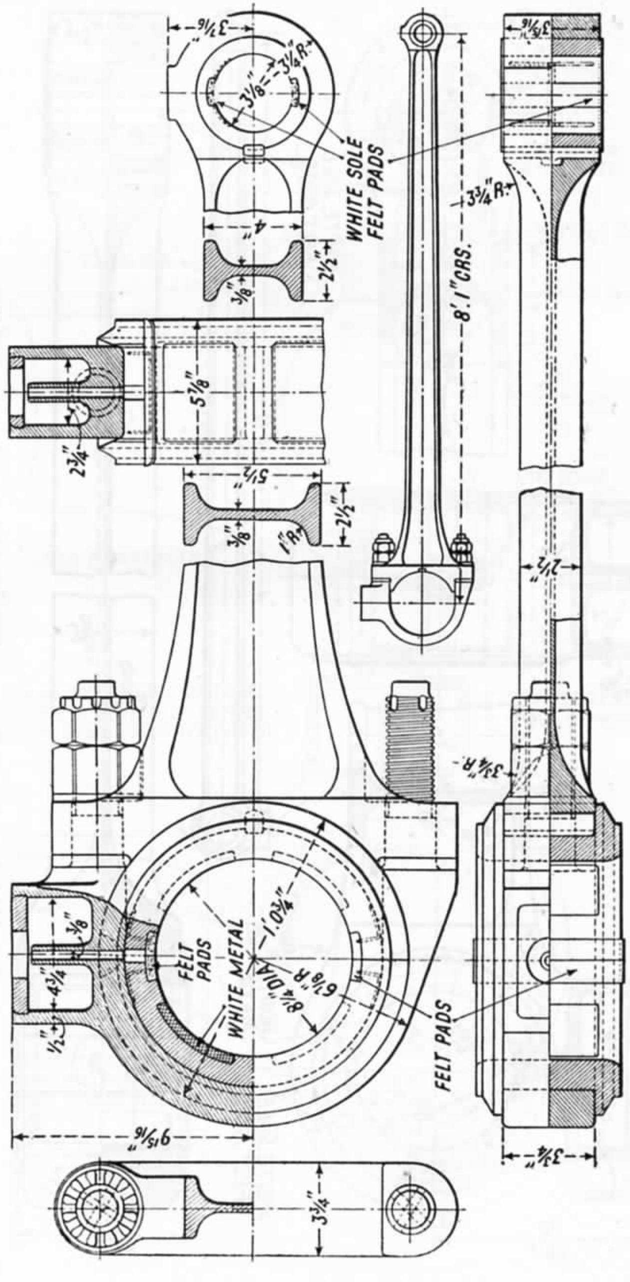


FIG. 135.—INSIDE CONNECTING ROD, L.N.E.R.

and well-directed blows with a heavy hammer will be more effective in starting an obstinate bolt than many blows with a light one, and will be less likely to damage the bolt ends. The sequence for dismantling the various portions of the big end should be as follows: First loosen the main cotter, but do not remove it from the strap; then loosen big-end bolts, leaving them in position. Disconnect the connecting rod from the gudgeon pin, and lower the front end into the motion plate, or on to a support placed across the slide bars. Then return to the big end; remove the bolts, lever the end of the rod out of the strap, and lower it to the ground, taking care to keep well clear of the strap and brasses which may swing round quickly on the crank-pin as the connecting rod comes clear. Finally, withdraw the cotter, remove the glut, and work the front brass out of the strap, which should then be lowered carefully to the ground with the back brass still in position.

The illustration on p. 216 (Fig. 133) shows a big-end bearing of the plain bush type which has been in use for many years on both passenger and freight engines, and has given complete satisfaction. The bush is made from special bronze alloy and is pressed into the connecting rod from the front at a predetermined pressure. As an additional precaution against the possibility of the bush rotating in service, a key and keyway are provided on the centre line of the bearing. The bush is lined with whitemetal, which is applied on to a series of serrations machined on the inside face. These serrations provide a more secure grip for the metal, and assist in keying it in position.

The outside connecting rod shown in Fig. 134 has solid bronze bushes at both crosshead and crank ends. The bushes are pressed in with hydraulic pressure, and are fitted with keys to prevent any turning within the rod. The bush at the crank end is also held transversely by means of a set screw in the rod. White-metal is cast into pockets in the main bearing, and white sole felt pads are fitted on the vertical centre lines of both bearings. The rod is made of nickel chrome steel, which allows a much lighter section to be used, and shows a considerable saving in total weight over rods of ordinary carbon steel.

The inside connecting rod (Fig. 135) is that of a three-cylinder express engine, and has at its crank-pin end circular split brasses held to the forked end of the rod by a semicircular strap. The rod is of nickel chrome steel of fluted section. The strap is of carbon steel bent to shape to ensure continuous grain. The bolts are integral with the strap and the lock nuts secured by cotters are fitted. The thread of the bolts is of knuckle form. The brasses are prevented from turning in the rod by a steel key.

The bearing is of bronze, split vertically, and provided with pockets into which whitemetal is cast. Bars of bronze are left to take the weight and thrust. White felt sole pads, held in position by wires, retain the lubricant. The oil is fed through a pin trimming from an oil box integral with the strap. The cross-head end of the rod is fitted with a bronze bush pressed in, and prevented from turning by a key. It is lubricated from the gudgeon pin, and felt pads and oil grooves in the bush distribute the oil over the bearing surface.

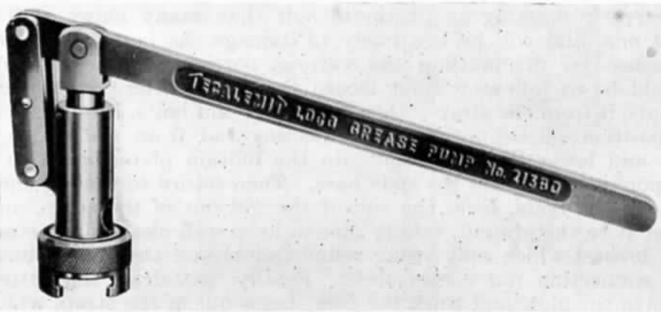


FIG. 136.—GUN FOR TECALEMIT HARD-GREASE LUBRICATION.

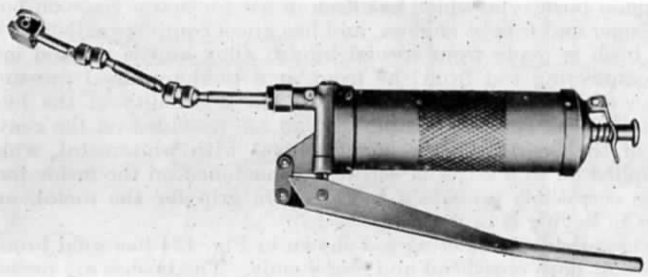


FIG. 137.—TECALEMIT GUN FOR SOFT-GREASE LUBRICATION.

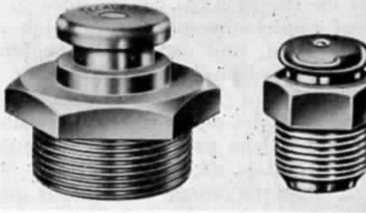


FIG. 138.—NIPPLES FOR HARD AND SOFT GREASE.

During recent years, grease lubrication for locomotives has progressed steadily. As a rule, hard grease is used for coupling and connecting rods and gudgeon pins, and soft grease for all valve-motion pins and brake and spring rigging. Lubricant is applied to the bearings by means of grease guns and special nipples, in a manner similar to that adopted for motorcars. Inevitably, some of the points to be lubricated are somewhat inaccessible, but this difficulty is overcome by using jointed flexible connections between the gun and the nipple. The guns,

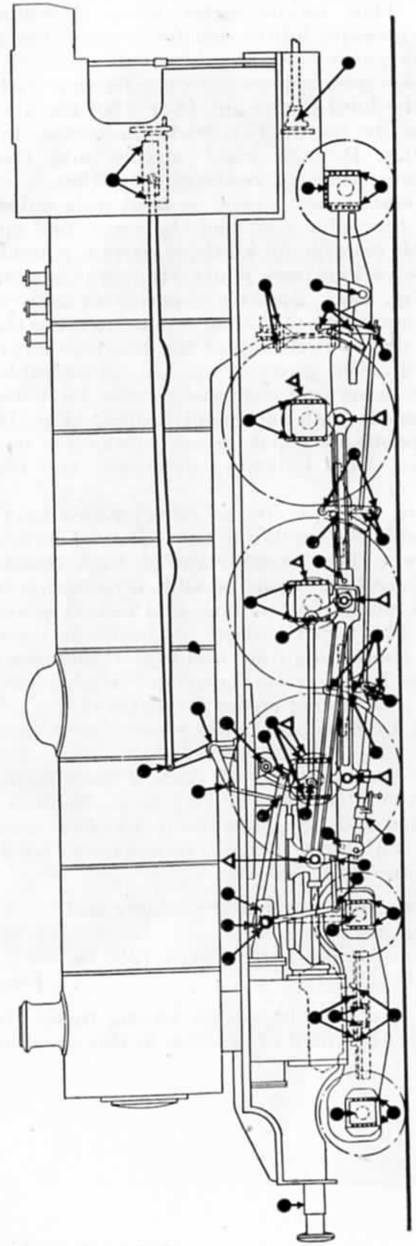


FIG. 139.—DIAGRAM OF LOCOMOTIVE SHOWING POINTS ADAPTABLE FOR GREASE LUBRICATION, TECALEMIT SYSTEM.

which are extremely simple to operate, are illustrated in Figs. 136 and 137. They represent the latest development of the Tecalemit high-pressure lubrication for locomotives, and by their use the various parts can be lubricated positively by feeding hard grease under great pressure to the friction surfaces. As an alternative to the hard-grease gun (Fig. 136) the Tecalemit hard-grease pump can be used. This feeds the grease, in the form of sticks or candles, through giant nipples into the locomotive coupling and connecting rod bearings (Fig. 138).

As already stated, soft grease is used as a substitute for oil for all parts of the valve gear and the brake and spring rigging. The grease nipple suitable for all these parts is a small steel fitting screwed into the various pins, joints, etc., and the gun used is that illustrated in Fig. 137. Suitable channels or grooves are cut in the rod bushes, and those of the valve gear, in order that the grease may be evenly distributed around the bearings when it is forced in at pressure by the grease gun. A considerable number of locomotives for home and overseas service have been provided with this equipment with successful results. Fig. 139 illustrates the numerous points at which grease lubrication can be applied to a locomotive. Dots indicate soft-grease, and triangles hard-grease application.

During recent years, considerable advances have been made in connection with the metallurgical aspect of locomotive design and construction. The introduction of high tensile and other special types of steel has made possible a reduction in the weight of certain parts, while maintaining, and indeed increasing, resistance to stress. This is particularly noticeable in the web portions of coupling and connecting rods, and in the thickness of the plates used in boiler and firebox construction. Higher driving stresses in the one case, and higher steam pressures in the other, are provided for amply by rods and plates which are thinner than those formerly used.

It cannot be over-emphasised that, if these lighter materials had not been available, certain very large modern locomotives would have exceeded the maximum weights permitted. An example from the latest British practice—a 4-6-2 high-speed streamlined engine—is as follows :—

Thickness of web portion of coupling and connecting rods	$\frac{3}{8}$ in.
Thickness of boiler barrel plates (250 lb. pressure)	$\frac{5}{8}$ and $\frac{11}{16}$ in.

These are only two examples from among many that could be cited to illustrate the trend of practice in this direction.

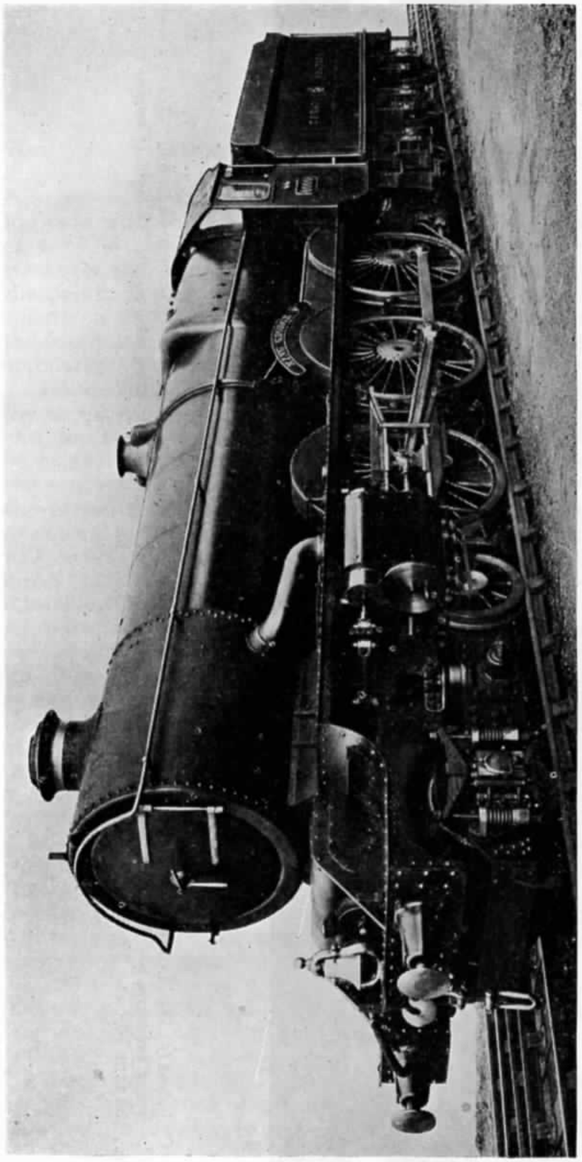


Fig. 140.—"King" Class 4-6-0 Type Four-Cylinder Express Locomotive, G.W.R.

Mr C. B. Collett, O.B.E., Chief Mechanical Engineer (*retired*).

Cylinders (4), 16¼ in. by 28 in. Coupled wheels, 6 ft. 6 in. diameter. Coupled wheelbase, 16 ft. 3 in. Total engine wheelbase, 29 ft. 5 in. Boiler pressure, 250 lb. per sq. in. Total heating surface, 2,514 sq. ft. Grate area, 34·3 sq. ft. Weight of engine in working order, 89 tons. Total weight of engine and tender in working order, 135 tons 15 cwt. Tractive effort (at 85 per cent. b.p.), 40,300 lb.

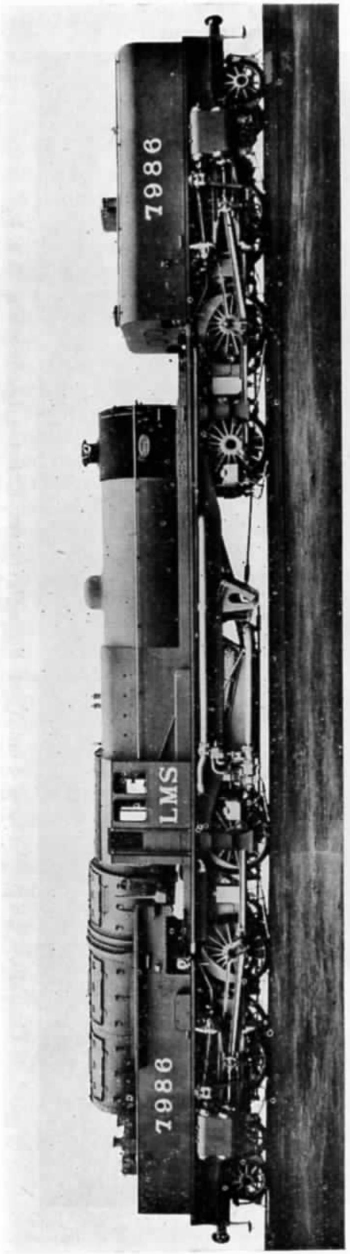


FIG. 141.—FOUR-CYLINDER GARRATT LOCOMOTIVE, 2-6-0+0-6-2 TYPE, L.M.S.R.

Built by Beyer, Peacock & Co. Ltd., Manchester.

Cylinders (4) 18½ in. by 26 in. Coupled wheels, 5 ft. 3 in. diameter. Coupled wheelbase (each group), 16 ft. 6 in. Total wheelbase, 79 ft. Boiler pressure, 190 lb. per sq .in. Total heating surface, 2,637 sq. ft. Grate area, 44·5 sq. ft. Weight of engine in working order, 155 tons 10 cwt. Tractive effort (at 85 per cent. b.p.), 45,620 lb.

CHAPTER 9

VALVE EVENTS AND SETTING

A SLIDE valve without either outside or inside lap is shown in Fig. 142 with the full throw of the eccentric at 1 and the crank at 4. The piston must therefore be at T in the cylinder. The stroke of the engine is represented by the distance ST between the points 2, 4 in the circle described by the crank. The valve spindle is shown connected directly to a single eccentric without the complication of a link motion or rocking shaft, and the angularity of the eccentric rod will be neglected.

Immediately the crank begins to turn in a forward direction, the throw of the eccentric will begin to move the valve forward, and the steam-way or port SP^1, as well as the port SP^2, will be opened by the valve at S and O, admitting steam at S from the steam or valve chest VC through SP^1 to the cylinder, and the pressure exerted will force the piston in the direction of F, as shown by the arrow in the cylinder. At the same time, SP^2 will be opened to E, the exhaust cavity of the valve, which is in direct communication through E^1 with the blast pipe, thus releasing the steam used in the preceding stroke.

With the full throw of the eccentric at 2 and the crank at 1, one quarter of a revolution will have been turned, so that with this type of valve the ports are full open to steam and to exhaust at half-stroke of the engine. Immediately on leaving the point 2 the eccentric will begin to recede, thereby closing the ports, until at 3 the valve will have returned to its middle position, with the piston at F and the crank at 2, completing the stroke, or one-half a revolution. From 3 the eccentric will begin to open the port SP^2 to steam at S^1, the pressure returning the piston towards T in the cylinder with the exhaust escaping at SP to E, so that with the eccentric at 4 and the crank at 3 the ports are fully open, three-quarters of a revolution having been turned. From 4 the eccentric will be closing the ports until 1 is reached, when the valve will have returned to the first position with the crank at 4, thus completing two strokes and one revolution.

The points 2 and 4 are known as the dead centres, because at these points the valve is in its middle position, and prevents any movement by covering the steam ports at both ends of the cylinder.

When two cylinders are used in the locomotive the cranks are generally placed at right angles, so that when in fore or back gear it is impossible to have both valves in the middle position at the same time, as one is always well open and sufficient to start the engine.

In following the movements of this early type of valve, which has been quoted for the sake of simplicity, it will be seen that steam was admitted for the full length of the stroke. This could only obtain for very low speeds, on account of the momentum of the piston and other moving parts, which, at higher speeds, would cause a violent shock to pass through the rods and crank-pin or axle when brought up by the crank at the end of the stroke. Moreover, the engine would soon " get out of breath."

A certain amount of valve lead was therefore introduced by advancing the eccentric upon the axle, so that the steam edges of the valve would be open a little when one crank was at 2 or 4, and admit steam before the piston had reached the limit of its stroke at T or F, and arrest the momentum by cushioning the steam in the clearance spaces. Thus the amount that the steam edges of the valve are open to the ports with the crank exactly at 2 or 4 is known as " outside lead," and is spoken of as the lead of the valve. This may be anything up to $\frac{1}{16}$ in., according to the lap.

In moving the eccentric forward the exhaust edges of the valve at O and O^1 would also open sooner, thereby giving an earlier release, and so reducing the back pressure on the piston. The valve, having no lap, would require to travel twice the width of the ports to give a full port opening.

To measure the amount of valve travel that an eccentric will give, take the distance from the centre of the axle to the centre of the sheave and multiply by two. If fixed upon the axle, subtract the narrow from the wide part of the sheave, and the difference will give the amount of valve travel.

Slide valves as used today are always prolonged at S and S^1, so that they overlap the steam ports at each end with the valve in its middle position. The amount of this overlap from the outside edges of the steam ports is known as outside lap or the lap of the valve. The elastic properties of steam have already been mentioned, and full advantage is taken of this in the use of the lap by cutting off the steam at an early part of the stroke. The economical results obtained with high-pressure steam and an early cut-off will be referred to subsequently.

It will be seen from Fig. 143 that the position of the eccentric relative to the crank has been altered to obtain the proper point of admission with the added lap on the valve, and as a consequence, the cycle of valve operations or events will be considerably changed. The amount by which the eccentric is advanced from its position at right angles to the crank, as in the old valve, is known as the angle of advance, as shown at AN.

The effect of the lap should be studied carefully, and before proceeding to follow the valve through its operations, the names that are given to the various events should also be noted. The point at which the valve begins to open the port to steam is known as the point of admission. The point of cut-off is therefore at the end of the period of admission, when the valve cuts off the steam from the cylinder. A certain time elapses between the point of cut-off and the opening of the exhaust or point of release, during which the steam is expanding. This is known as the period of expansion. The period of release is ended by the point of compression, when the valve has returned and closed the exhaust, so that the period of compression is from the time

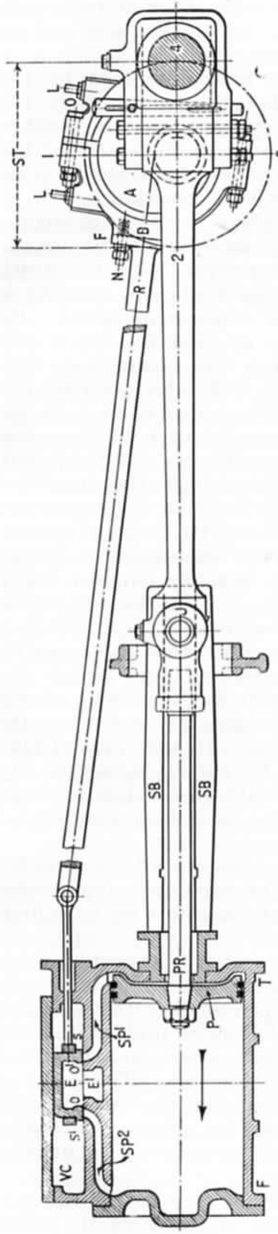


Fig. 142.—Slide Valve without Outside or Inside Lap.

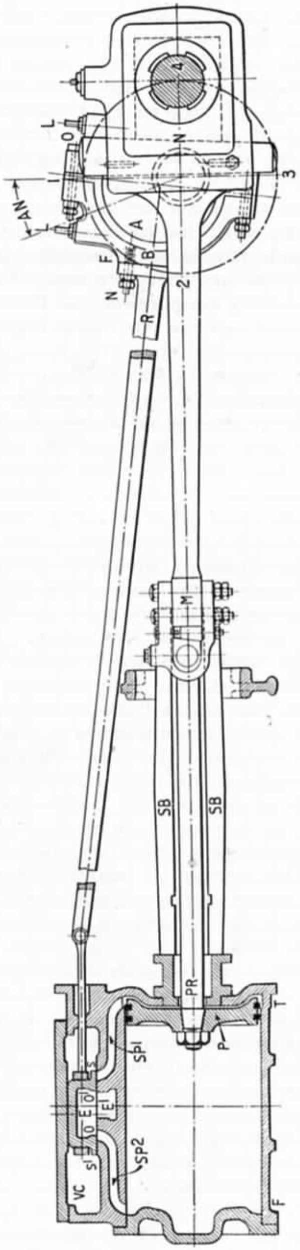


Fig. 143.—Slide Valve provided with Lap.

the exhaust has closed to the time that the valve opens to steam at the point of admission. All these events occur at both ends of the cylinder during the course of one revolution, and will be further explained by the use of a diagram later.

The length of the valve from S to S[1] is increased by the addition of lap, so that to uncover the steam ports fully the throw of the eccentric will need to be proportionately greater, and the travel of valve required will be twice the width of the ports plus the amount that the outside edges of the steam ports are overlapped when the valve is in its middle position.

The work due to valve face friction, which has to be overcome at each revolution, increases with the amount of the travel. The ports are therefore made as long as possible, with the width reduced in proportion, so that a large area of port opening is obtained with a correspondingly smaller amount of travel. By advancing the eccentric upon the axle, so that the lap S will allow steam to enter the cylinder from the steamchest with the piston at T and the crank at 4 (Fig. 143), the eccentric will begin to recede relatively earlier in the course of the stroke. This gives the early cut-off. The increased length of the valve face from the steaming edge S to the exhaust cavity E will prevent the valve from opening to exhaust until this increased distance has been travelled, which gives the time for expansion to take place between the point of cut-off and the point of release. In the old valve, the point of release did not occur until the piston had reached the end of the stroke. In fact, the exhaust began at one end of the cylinder simultaneously with the opening of the port to steam at the other. In the valve with lap, however, release must take place earlier by the amount that the eccentric is advanced, and the exhaust will therefore begin before the piston has reached the end of the stroke at F. This early release is of great assistance in a high-speed engine as it reduces the back pressure upon the returning piston. It also follows that the exhaust or period of release will be ended earlier, as the point of compression takes place before the piston has returned to T, so that a certain amount of steam is retained and compressed for cushioning behind the piston.

The amount of lap that is sometimes employed in valves for high-speed engines is sufficient to give the necessary compression without the use of lead, and the valves are therefore set with little or no lead.

Valves are sometimes designed to give what is known as inside lead. This means that the distance between O and O[1] is increased, so that the exhaust cavity E will be open slightly to the inside edges of both steam ports with the valve in its middle position. With inside lead, the release will take place earlier, and the period of expansion will be shortened by that amount. The point of compression would also be later, so that for engines with excessive back pressure inside lead would be useful by allowing an earlier release of the steam from the cylinder, and by reducing the amount of compression.

Inside lap is the opposite to inside lead, because the distance between O and O[1] is shortened so that the face of the valve overlaps the inside edges of the steam ports with the valve in middle position. The point of release would therefore be delayed, and the point of compression would occur earlier, giving a longer period of expansion and a correspondingly higher compression. For high-speed engines this late release would result almost invariably in excessive back pressure. Inside lap is therefore usually to be found only on the lower-speed engines.

Drivers are not called upon to set the valves, though a certain amount of familiarity with some of the methods adopted, and the points which determine the proper position of the eccentrics, will be of great assistance in cases of valve motion failure or slipped eccentrics by making the fault at once apparent. The eccentric sheaves are usually secured to the driving axle at the required advance before they are sent into the erecting shop, so that, after the engine is wheeled and coupled, it is necessary only to adjust the valves to equalise the lead at each end of the cylinder. There are two methods of setting valves, one by equalising the full port openings and the other by equalising the lead. The compression is more regular at each end of the cylinder with an equal lead, which is an important factor in a high-speed engine. The equal lead method is undoubtedly the best, and any slight irregularity in the full port opening may be neglected.

For measuring the lead of the valves with the cranks on the centres, wood wedges tapered from $\frac{1}{2}$ in. at the thick end to a fine point at the thin end, and 3 in. long by about $\frac{3}{4}$ in. wide, are used frequently. After the wedges have been planed smooth, they are marked for a definite port and gear; for instance, the RH front port fore gear RF/FP, or the LH front port back gear LB/FP, etc., as the case may be, so that there will be four wedges marked for forward and four for backward gear. Means are usually provided in the erecting shop for turning the driving wheels without moving the engine, although a short piece of straight road will suffice for obtaining the centres. The axleboxes should be in their proper working position in the horn blocks, to give little or no alteration in the obliquity of the rods, which might change the relative positions of the valves and eccentrics under working conditions.

For setting the valves by the lead the dead centres 2 and 4 (Figs. 142 and 143) must be found. These should be obtained carefully, as the valves travel rapidly when opening, and a slight error in the centres would affect the position of the valves seriously. To obtain the dead centre, say, for example, at 4, the crank should be turned a little above the centre. A mark should then be made upon the face of the tyre by means of a trammel with one leg at a centre pop mark upon the frameplate or underside of the top footplating. To denote the position of the slide block, a line should be scribed carefully across the side of the slide block and bar. Next, turn the wheel past the centre so that the slide block has travelled to the end of the stroke and returned exactly to the mark upon the slide bar, when the crank will be just the same distance below the centre that it was above when the mark was first made. Another mark should now be scribed upon the tyre with the trammels from the fixed point upon the frame. Bisect the two lines upon the tyre with dividers, and put a centre pop mark upon the division line.

The wheel should now be turned so that the centre pop mark upon the bisection comes exactly to one trammel leg with the other leg in the fixed point, and the crank will be accurately upon the dead centre 4.

The other dead centres are obtained in the same manner, and should be marked to their respective centres in chalk upon the tyre RF, RB, LF, LB. Thus, for two cylinders with cranks at right angles, the tyre will be divided exactly into quarters if all the centres have been ascertained correctly.

When the centres have been found the valves may be set. Commencing, for instance, with the RH fore gear, front centre, place the driving wheel with the trammels so that the RH crank is at the centre 2, with the reversing lever or screw in full forward gear. Insert the wedge marked RF/FP in the front port, pressing it in so that the edge of the port will make a mark, which will denote accurately the amount of lead. The driving wheel must now be turned in the same direction as when running forward until the crank is exactly on the centre 4, and the back port wedge inserted in a similar way. By placing the wedges together upon a surface plate any inequality of the lead will be shown by the difference in the thickness of the wedges at the marks. Assuming that the RF/FP measures $\frac{1}{16}$ in., and the wedge for the back port $\frac{3}{16}$ in., the lead allowed in the fixing of the eccentrics will be $\frac{1}{4}$ in., and the valve will therefore require adjusting to be equal. To do this, take down the fore gear eccentric rod, and shorten it by $\frac{1}{16}$ in., thus increasing the opening at the front end to $\frac{1}{8}$ in. and decreasing the back opening to $\frac{1}{8}$ in. This will give an equal lead.

In some cases, the valves are set with the reversing screw or lever placed at the notch at which it is intended that the engine shall work with an average load. By having the lever in full forward or full backward gear the valves will be seen at their smallest amount of lead, which is important when the Stephenson link motion is used.

In some instances, a difficulty is experienced in getting at the ports with the valves connected up, especially when the steamchest is between the cylinders, as with inside cylinder engines. To overcome this difficulty the valve spindles are disconnected, and with the steamchest covers removed, the desired lead is obtained by inserting a piece of sheet metal or feeler in the ports, or by adjusting the valve for a full port if setting by the opening.

It is not suggested that Figs. 142 and 143 represent modern practice, but together with their text from p. 225 to this point, they have a considerable educational value.

With the valve set for lead or port opening in this manner, a clearly marked line is scribed upon the valve spindle, or the drag link from any fixed point upon the stuffing-box, by means of the trammels. A mark is made for each end of the valve, and when these have been checked carefully with the trammels, the steamchest covers can be replaced. The valve spindle is connected up, and the setting is done with the trammel, the lines representing the valve position at its proper amount of lead or port opening.

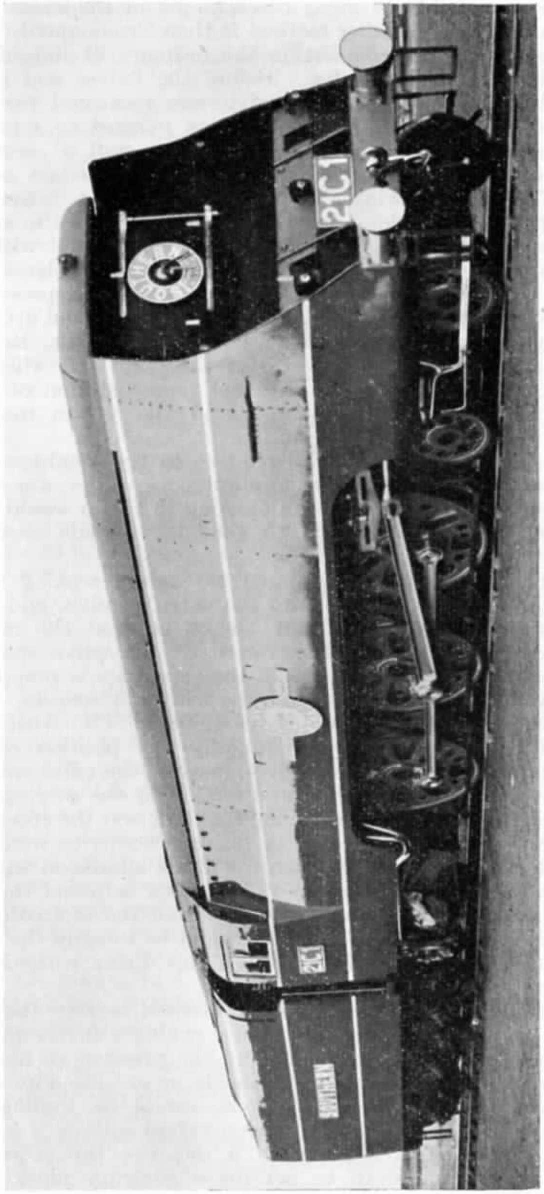


Fig. 144.—Southern Railway Streamlined Three-Cylinder Single-Expansion 4-6-2 Type Express Locomotive, "Merchant Navy" Class.

Mr O. V. Bulleid, Chief Mechanical Engineer.

(See p. 501 for Dimensions of Locomotive.)

When the steam is admitted into the cylinder by means of the inside admission piston valve, the feeler cannot be used, as it would be impossible, in many cases, to get at the inside edges of the steam ports. Another method is therefore adopted, which is also used frequently for setting the ordinary D slide or the outside admission piston valve. Before the valves and covers are placed in position, the port edges are measured carefully and a wood staff or an iron template is marked to represent exactly the position of the ports. Another staff or template is made, upon which are marked the steaming edges of the valves. The staff showing the ports is fixed in a convenient position upon the outside of the cylinder or steamchest in such a manner that the port edges upon the staff correspond with the ports in the steamchest. After the valves and covers have been fixed with the valve spindle connected up, the staff representing the edges of the valves is laid alongside the port staff and attached temporarily to the outside end of the valve spindle, so that the valve staff is made to travel over the port staff when the wheels are turned. This gives an exact representation of what is taking place in the steamchest, and the valves may be set to it.

The position of the eccentrics relative to the cranks will be altered considerably when inside admission valves are used, since the travel of the valve when opening to steam would have to be in an opposite direction to that for outside steaming valves.

Many piston valves are actuated through a rocking shaft, which has arms above connected to the valve spindles, and arms below connected to the quadrant blocks, so that the motion derived from the eccentrics is reversed at the valve spindles. In this case, the angular advance of the eccentrics is practically the same as for outside admission valves without rockers. This intervention of a rocking shaft (see Fig. 98, p. 176) with arms above and below also affects materially the position of the eccentrics for outside admission valves, because the valve spindles will be travelling backward in the direction of the driving axle when the eccentric rods are travelling forward, and the eccentrics have to be set accordingly. In short, the eccentrics would be approximately in the same position for inside admission without a rocker as for outside admission valves when actuated through a rocker. On the other hand, the position of the eccentrics for inside admission valves with a rocker would be roughly the same as for outside admission, when coupled up direct without the intervention of a rocker.

These last few points have been emphasised because they are important, and if noted carefully would enable a driver to tell, from the position of the eccentrics and the presence or absence of a rocker, whether his valves are inside or outside admission. The fore gear eccentrics, for instance, would be leading the cranks in fore gear for outside admission valves without a rocker, and also for inside admission with a rocker. The eccentrics would, however, require to be set for a contrary motion for inside admission without a rocker and outside admission with a rocker, and would therefore appear to be following the cranks.

When the changed eccentric positions due to these various conditions are grasped properly, a slipped eccentric would easily be apparent by its position in relation to the crank.

The following details show the effect upon the valves when notching up with a Stephenson link motion in a passenger engine :—

Throw of eccentrics, $6\frac{3}{4}$ in.
Lap of valves, 1 in.
Inside lead of valves, $\frac{1}{32}$ in.
Travel of valves in back gear, $4\frac{5}{32}$ in.
Travel of valves in fore gear, $4\frac{7}{32}$ in.
Angle of eccentrics in fore gear, $106\frac{1}{2}°$.
Angle of eccentrics in back gear, $106\frac{1}{2}°$.

Gear.	Lead.		Opening.		Cut-off.	
	B.	F.	B.	F.	B.	F.
	in.	in.	in.	in.		
Forward full . .	$\frac{3}{16}$	$\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{32}$	$73\frac{1}{2}$	$75\frac{1}{2}$
Forward 3 . .	$\frac{7}{32}$	$\frac{3}{16}$	$\frac{3}{4}$ f.	$\frac{11}{16}$	$62\frac{1}{4}$	65
Forward 2 . .	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$46\frac{1}{2}$	$48\frac{1}{2}$
Forward 1 . .	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{1}{4}$ f.	$25\frac{1}{2}$	$25\frac{1}{2}$
Backward full . .	$\frac{3}{16}$	$\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{1}{32}$	$74\frac{1}{2}$	76
Backward 3 . .	$\frac{7}{32}$	$\frac{3}{16}$	$\frac{13}{16}$ f.	$\frac{3}{4}$	$64\frac{1}{2}$	$65\frac{3}{4}$
Backward 2 . .	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{9}{16}$	$\frac{7}{16}$	$47\frac{1}{2}$	$48\frac{3}{4}$
Backward 1 . .	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{11}{16}$	$\frac{1}{4}$ f.	$26\frac{1}{2}$	26

When setting valves with Joy's gear (see p. 165) it should be remembered that the height of the axleboxes in the horn blocks has a more direct effect upon the valve positions than with the link motion, and care should be taken to fix the axle at the proper height for which the gear was designed. The dead centres are obtained as before, but the method of adjusting the lead is altogether different, as there are no fore and back gear eccentric rods, and only one valve rod, to each cylinder. Assuming that the front port required closing in forward gear and opening for the backward gear, the impossibility of altering the single valve rod to suit both cases will be evident. The adjustment is therefore done by varying the height of the reversing shaft, in conjunction with the alteration to the length of the valve rod.

The effect of raising or lowering the reversing-shaft may be summed up thus :—

To close the front port and open the back port in forward gear, or to open the front port and close the back port in backward gear—drop the shaft.

To open the front port and close the back port in forward gear, or to close the front port and open the back port in backward gear—raise the shaft.

The following are approximately the usual port openings when using Joy's gear with a lap of 1 in. and a constant lead of $\frac{3}{16}$ in. :—

Travel of valves in fore gear, $4\frac{1}{2}$ in.
Travel of valves in back gear, $4\frac{5}{8}$ in.
Fore gear, front port, $1\frac{5}{16}$ in.
Fore gear, back port, $1\frac{3}{16}$ in.
Back gear, front port, 1 in.
Back gear, back port, $1\frac{3}{8}$ in.

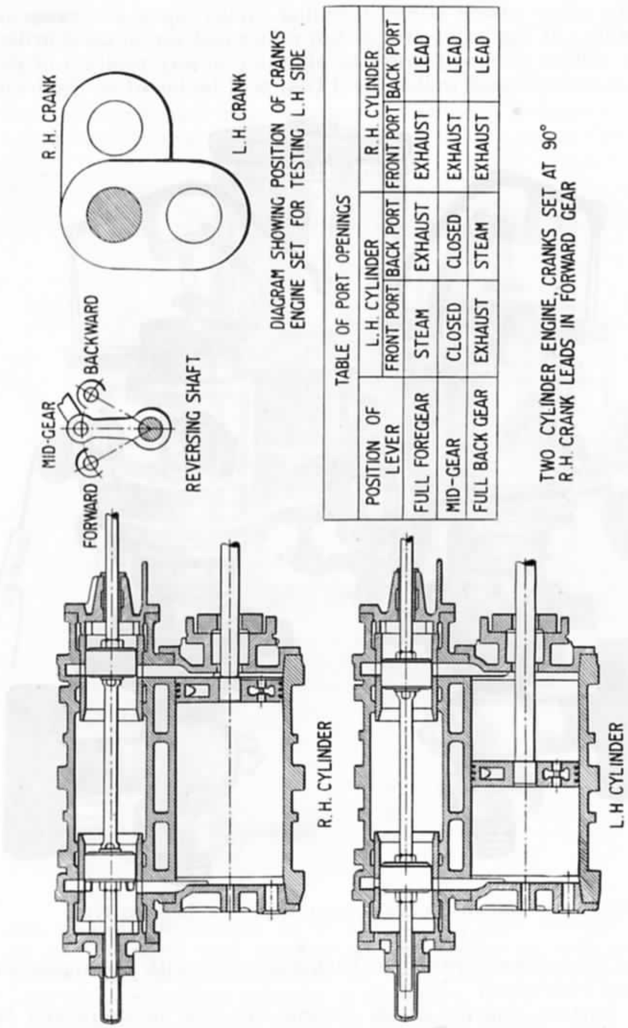
It is necessary sometimes to test the valves and pistons of locomotives for leakage, and what is known as the mid-stroke method of setting, *i.e.*, with the crank under test on the top or bottom quarter, may next be described. This setting, used on the L.M.S.R., is probably the most reliable that can be devised for two and three-cylinder simple engines, because only one cylinder is tested at a time and the chances of error are reduced accordingly.

To give complete reliability, however, it is important that all cylinders should be tested in turn, for under certain conditions, conclusions drawn from a test made on one cylinder only may be quite incorrect, due to the presence of defects in the other cylinder. In the case of four-cylinder engines, the adjacent inside and outside cylinders will be tested simultaneously by this method, and it is therefore difficult to locate the exact cause of trouble from the indication given, without considerable experience. In fact, with this type of engine, whatever crank setting is employed for testing purposes, at least two cylinders will have to be taken into account.

The principle of this test is that with the piston at mid-stroke and the reversing lever in mid-gear position, both cylinder ports will be covered by the valve. In full forward and full backward gear, the front or back cylinder port will be opened to steam and the opposite port to exhaust. If the bottom quarter setting is used, placing the lever in forward gear will open the front port to steam and the back one to exhaust, and with the lever in backward gear the back port is open to steam and the front to exhaust. When the crank is on top quarter, the order of port opening to steam and exhaust is the reverse of that given above. It is quite immaterial and largely a matter of opinion which crank setting is used, but some prefer to use the bottom quarter setting, because it is considered to be a more straightforward arrangement to have the front port open to steam in forward gear and the back port in back gear. For this reason the bottom quarter setting will be considered in the following paragraphs.

The drawing, Fig. 145, shows the relative positions of the pistons and valves in a two-cylinder engine set for testing the L.H. side with the L.H. crank on bottom quarter and the reversing lever in mid gear. The R.H. crank, it should be noted, is on the back dead centre. To carry out the test, close the cylinder cocks, apply the steam brake, and open the regulator to about first valve position. When the reversing gear is moved, if a blow occurs up the chimney in full forward gear, ceases when in mid-gear, and starts again in full back gear, leakage past the L.H. piston is indicated. If

the blow occurs in forward gear but not in mid or back gear, a cracked front port bar on a slide valve engine, or a damaged front valve liner in the case of a piston valve engine, is indicated.



POSITION OF LEVER	L.H. CYLINDER FRONT PORT	L.H. CYLINDER BACK PORT	R.H. CYLINDER FRONT PORT	R.H. CYLINDER BACK PORT
FULL FOREGEAR	STEAM	EXHAUST	EXHAUST	LEAD
MID-GEAR	CLOSED	CLOSED	EXHAUST	LEAD
FULL BACK GEAR	EXHAUST	STEAM	EXHAUST	LEAD

FIG. 145.—METHOD OF TESTING VALVES AND PISTONS, L.M.S.R.

Similarly, a blow obtained in back gear only indicates a defect in the back port bar or valve liner respectively.

A continuous blow up the chimney obtained in all positions of the lever generally indicates that the valve under test is blowing through, but a similar indication will be obtained on two-cylinder engines arising from a defective piston on the opposite side, where the back port will be open to lead and the front to exhaust, as shown, for all settings of the lever with the engine in this position. Consequently if this indication is obtained, reset the engine to test the opposite side in order to prove the other piston before deciding finally upon the cause of the trouble. If the valve and piston under test are in good order, no blow will be obtained from the chimney in any position of the gear, but a single and well-defined beat will be heard as the lever

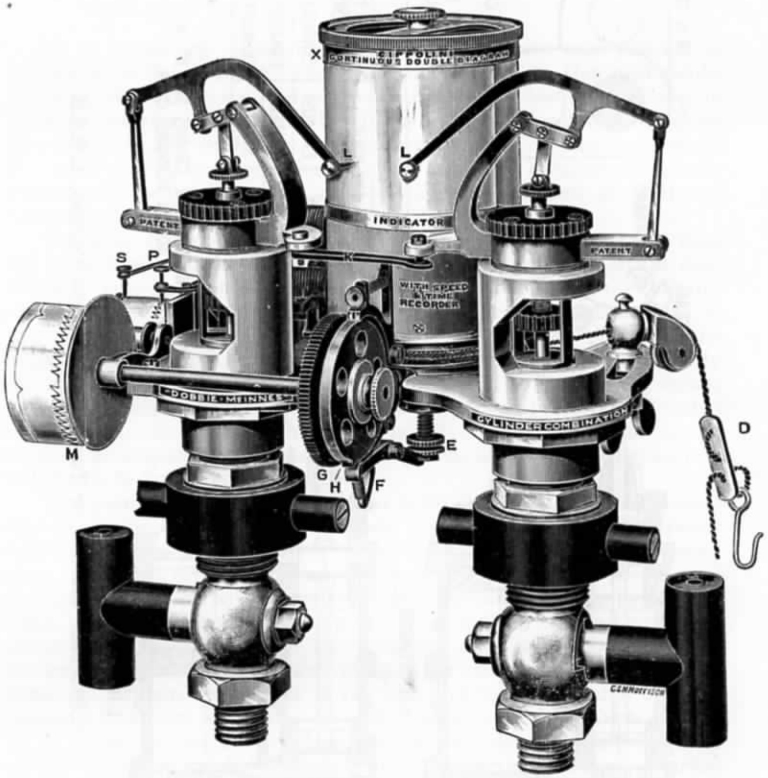


Fig. 146.—Dobbie-McInnes Indicator for Locomotives.

is pulled over from forward to backward gear with the regulator open, and vice versa.

The bottom quarter crank setting can also be employed to detect and locate a broken valve lap. In this case, close the cylinder cocks, open the regulator with the brake applied and the lever in mid-gear position. If on releasing the brake the engine moves forward, a front lap is broken, and if it moves backwards a back lap will be defective.

The results of "notching-up," or increasing the lap, will best be explained by the use of the indicator diagram.

This diagram is a record of the actual distribution of the steam at one end of the cylinder during one revolution, and is obtained by connecting the indicator to suitable cocks, which are fitted into holes specially drilled to communicate with the clearance spaces at each end of the cylinders.

The indicator shown in Fig. 146 is specially designed for use on locomotives and other high-speed engines.

This instrument is supplied by the firm of Dobbie McInnes Ltd., Glasgow, and is known as the "Dobbie-McInnes Cippolini" continuous double diagram indicator. The apparatus automatic-

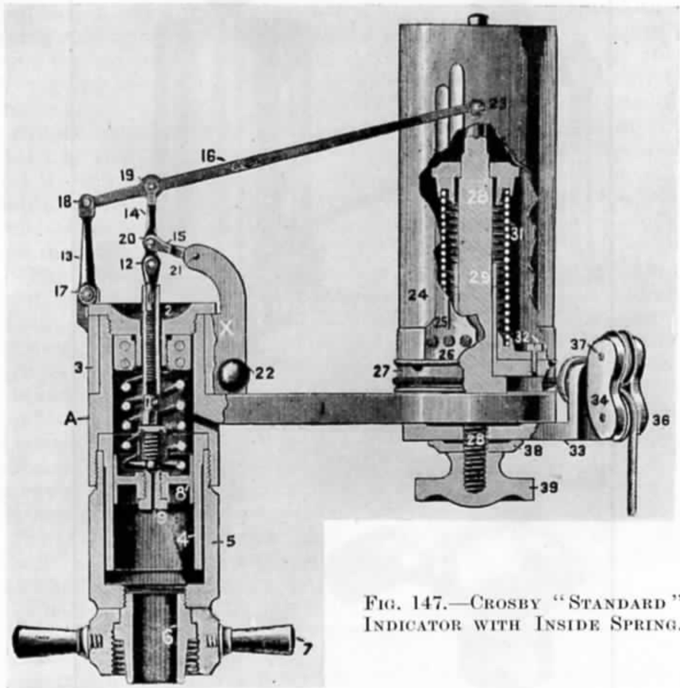


Fig. 147.—Crosby "Standard" Indicator with Inside Spring.

ally records, by means of diagrams, the true average pressure in the cylinder, and consists of two indicator cylinders, with pistons and parallel motions of the "Dobbie-McInnes" type, with pressure springs exterior to the steam cylinders.

Both pencil arms L point to the same drum, which contains a roll of metallic paper carried from a spindle, between rollers, round the drum and re-entered to another spindle.

The cord D is attached to some suitable moving part of the engine so that the drum reciprocates at each stroke, and the pencils rise and fall when the indicator cocks are opened.

By means of an internal mechanism the spindle E is lifted upward, and thus imparts a motion to the cam F, which thereby propels the ratchet wheel G one tooth forward for every revolution.

The mechanism is so arranged that the length of the paper occupied by the diagram previously obtained is drawn forward

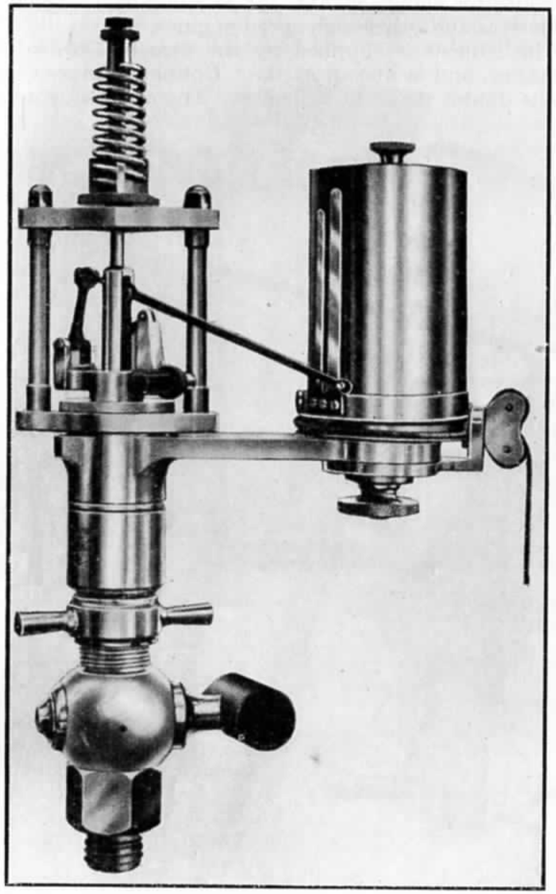


FIG. 148.—CROSBY "NEW NO. 2" TYPE INDICATOR WITH OUTSIDE SPRING.

into the drum, thus automatically leaving another portion of the same paper ready for the next set of diagrams.

The cam H determines the diagram intervals, and each indicator is supplied with interval wheels to give diagrams at every 25, 50 and 100 revolutions. On the indicator shown, with the engine running at 100 revolutions, double diagrams would be taken automatically at every half-minute.

Arrangements are also made whereby the time occupied during the test is electrically registered by means of a simple timing apparatus in conjunction with the electrical contact connection provided for the purpose.

It will be evident that, by the use of this type of indicator, pressure diagrams may be taken simultaneously and automatically from both ends of the engine cylinder, together with time and revolution diagrams. Since these diagrams are automatically repeated at exact intervals, any variation in the running conditions is shown by comparison, and a true average is therefore obtained.

The special feature of the Crosby indicator is the use of a double-coil spiral spring very carefully calibrated. This form of spring enables the strains to which it is subjected to be transmitted from the centre of the piston through a ball-and-socket joint. The spring is made of a single piece of wire wound from the centre into a double coil, the ends of which are securely held in a suitable head-piece. The Crosby "Standard" indicator (Fig. 147) has the piston of cylindrical shape provided with grooves, and the spring is fitted inside the housing. The instrument, as manufactured for standard service, has a drum $1\frac{1}{2}$ in. diameter, which is the correct size for high-speed work, and answers equally well for low speeds.

The "New No. 2" outside-spring type indicator (Fig. 148), as its name implies, has the spring mounted outside the cylinder, where it is detached and replaced easily, and where it is removed from any effect of heat. This makes the instrument specially suitable for use on superheated steam. Another novel feature in this indicator is the piston. It is spherical in shape, an arrangement which practically eliminates cylinder friction. The piston is connected to the pencil mechanism by a rod ending in a ball-and-socket joint in the centre of the piston. With both types of instrument, adjustment is provided for altering the position of the pencil lever on the paper.

It is of interest to note that Crosby indicators of the "New No. 2" outside-spring type have been used by both the L.N.E.R. and the L.M.S.R. for tests with streamlined locomotives.

Fig. 149 is a diagram taken from an engine running at 50 revs. per min. The piston has travelled in the direction shown by the arrow.

The line F, T is made by the pencil upon the paper held by the rotating drum before the steam is admitted to the indicator cylinder, and therefore represents the atmospheric pressure. The length of this line also denotes the length of the stroke, since the motion of the drum is obtained from some reciprocating parts of the engine-levers, or drums of different diameters are used for reducing correctly the amount of movement, to give a convenient length of diagram. It will thus be seen that two independent movements are recorded upon the paper. One is longitudinal and due to the stroke, and the other vertical at the pencil point, due to the pressure in the cylinder. The line drawn by the pencil upon the paper therefore denotes the pressure exactly relative to the stroke, if a vertical line is drawn through the diagram from the atmospheric line F, T.

At the point of admission, or 1′ on the diagram, the slide valve admits steam to the cylinder and instantly compresses the spring, thus forcing the pencil point upward until the full, or initial, pressure is reached at 2′. The valve is still opening and closing until the point of cut-off occurs at 3′, when the valve is closed to steam, so that from 2′ to 3′ gives the period of admission relative to the stroke. From 3′ to 4′ is the period of expansion, with the pressure falling gradually as the steam, in following up the piston, is expanding and filling the increasing volume of the cylinder, until the exhaust opens at 4′, which gives the point of release. The pressure immediately falls to near the

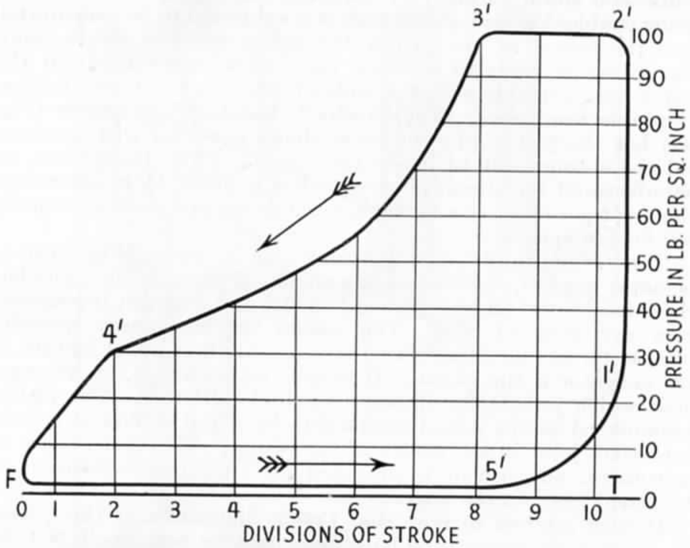


Fig. 149.—Diagram taken from Engine at Low Speed.

atmospheric line, and remains there until the piston has returned to 5′, where the exhaust closes and gives the point of compression. From this point the pressure rises during compression until 1′ is reached with the valve again opening to steam.

In Fig. 149 the admission line rises until 100 lb. pressure per sq. in. is indicated, and the divisions in the diagram represent a sufficiently accurate method of obtaining the average pressure. The height of the diagram is measured with a proper scale; and the heights added together and divided by 10 (the number of the divisions) give an average pressure of 58·6 lb. The point of cut-off occurred at 25 per cent., or one quarter of the stroke. If steam were admitted during the whole stroke at 100 lb. the average pressure would be 100 lb., which, instead of being four times greater, is not even double the average pressure which was obtained when only one-fourth the amount of steam was used.

The application of the foregoing is obvious and demonstrates that the higher initial pressures combined with an early cut-off must tend to economical working. Many drivers, for instance, do not believe that the best results are obtained with the regulator full open. That engines differ is well known, and notching up too near mid-gear with the regulator full open may cause pounding in the rods, boxes, and journals. It should be remembered, however, that the modern engine is designed specially to withstand these high initial pressures, and the driver should adjust the point of cut-off by means of the variable lap placed at his disposal in the reversing gear.

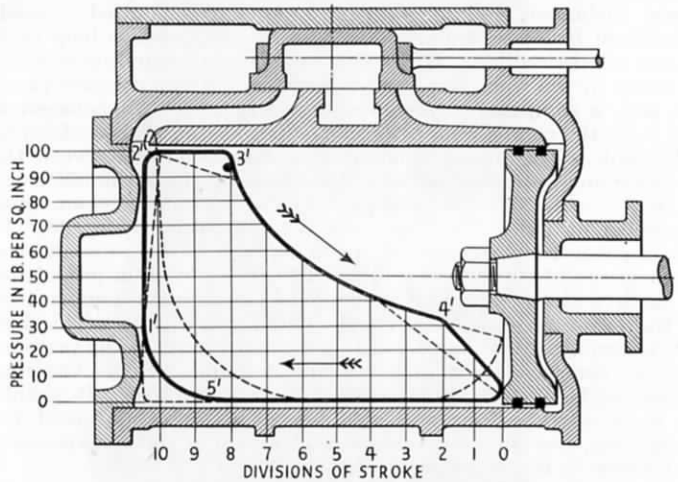


Fig. 150.—Indicator Diagram Superimposed on Locomotive Cylinder showing Action of Steam.

The comparative efficiencies of the various points of cut-off are approximately as follow :—

$\frac{3}{4}$ of stroke	. . . . .	1·26	relative	efficiency.
$\frac{1}{2}$,,	. . . . .	1·62	,,	,,
$\frac{1}{4}$,,	. . . . .	2·13	,,	,,
$\frac{1}{8}$,,	. . . . .	2·51	,,	,,

Provided that the average pressure is sufficient to do the work required, a cut-off at $\frac{1}{8}$ stroke is approximately twice as efficient as a cut-off at $\frac{3}{4}$, so that the earlier cut-off should result in a substantial saving in coal.

The dotted lines in Fig. 150 show the defects due to inefficient admission of steam or faulty valve setting exposed by the indicator. The sloping dotted admission line from 1′ to 2′ would occur if the valve were too late, the piston having commenced the stroke before the full initial pressure was reached; and a valve that was too early would show a line rising from the compression at the point of admission sloping in the other direction.

The inclined dotted line from 2′ to 3′ would be produced by wire-drawing, and denotes a throttled admission. If the point of release occurs too early, it will be denoted by the line falling abruptly from the expansion line before the point 4 is reached, and a late exhaust will be shown approximately by the dotted line leaving 4′ in such a manner that the normal back pressure is not attained until the piston has accomplished a portion of the return stroke. When the exhaust closes too early an excessive compression occurs, and causes a premature rise in pressure, as shown by the dotted line before the point 5′. In many instances the excessive compression generated exceeds the actual boiler pressure, as denoted by the peculiar loop at 2′ on the admission line. When this takes place, pounding is likely to occur in the rods, boxes, and journals. If the exhaust closes too late, a comparatively sharp curve will be shown between 5′ and 1, as the compression will be small, and imperfect cushioning will result. The proper amount of compression is between the two extremes, and has an important bearing upon the efficiency of the engine. Take, for instance, the admission of steam from the boiler at 150 lb. pressure with a temperature about 366° F. into a space which contained steam at, say, 10 lb. pressure, the temperature of which is only about 240° F. A certain proportion of the live steam would be condensed in raising the temperature of the lower pressure steam and cylinder walls, etc. This loss due to condensation is avoided to a certain extent as the pressure due to compression approaches the pressure of the entering steam, and so tends to equalise the temperatures. It should be noted that not only is an efficient compression good for cushioning, but that the compressed steam is again expanded, and assists in the following stroke.

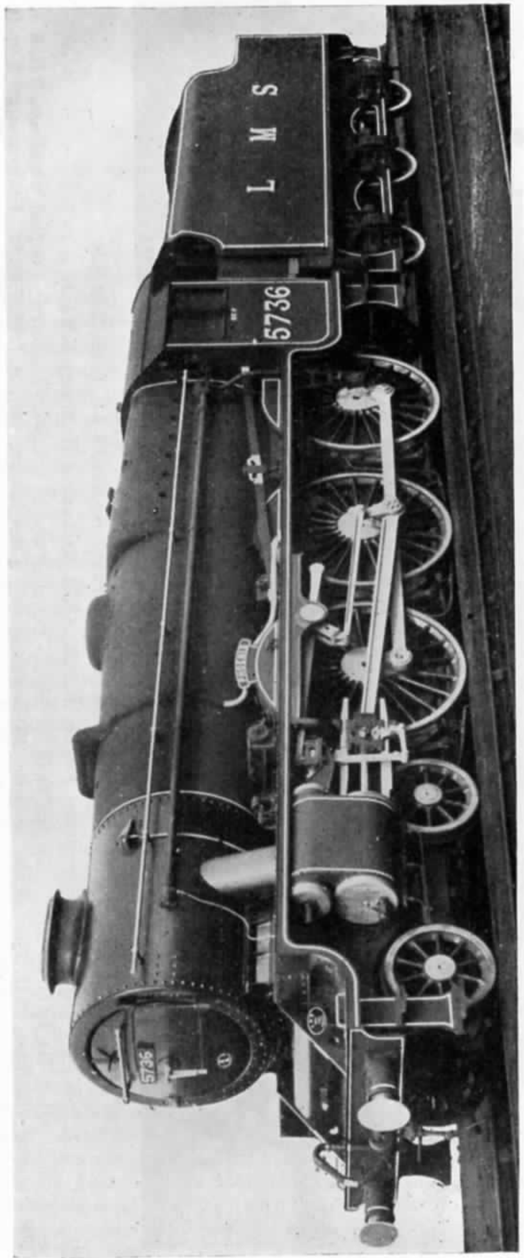


Fig. 151.—L.M.S.R. 4-6-0 Type Express Locomotive, "5 XP" Class, fitted with Enlarged Boiler and Double Chimney.

Sir William Stanier, Chief Mechanical Engineer (*retired*).

(*See p.* 497 *for Dimensions of Locomotive.*)

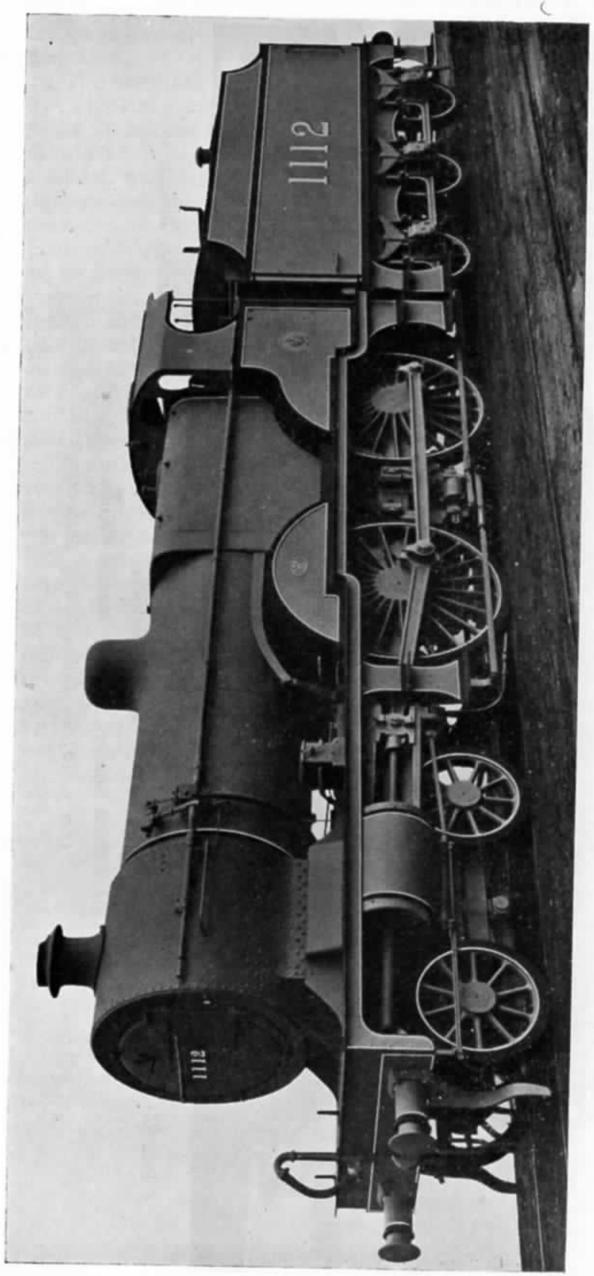


Fig. 152.—Three-Cylinder Compound Express Engine, 4-4-0 Type, L.M.S.R.

The late Sir Henry Fowler, K.B.E., Chief Mechanical Engineer, L.M.S.R.

Cylinders, h.p. (1), 19 in. by 26 in.; l.p. (2), 21 in. by 26 in. Coupled wheels, 6 ft. 9 in. diameter. Coupled wheelbase, 9 ft. 6 in. Total engine wheelbase, 24 ft. 3 in. Boiler pressure, 200 lb. per sq. in. Total heating surface, 1,607·7 sq. ft. Grate area, 28·4 sq. ft. Weight of engine in working order, 61 tons 14 cwt. Weight of engine and tender in working order, 104 tons 8 cwt. Tractive effort (at 85 per cent. b.p.), 22,649 lb.

Chapter 10

COMPOUND LOCOMOTIVES

Although compound locomotives are still used both in this country and abroad, and more particularly on certain European railways, the general tendency nowadays is to build locomotives on the single-expansion system with from two to four cylinders using steam at boiler pressure. Indeed, in modern practice, so far as new construction is concerned, the compound to all intents and purposes has disappeared from British railways.

A compound locomotive is one in which the steam at boiler pressure is admitted first to one or more high-pressure (h.p.) cylinders and exhausted into one or more larger diameter low-pressure (l.p.) cylinders, from which it is exhausted finally into the atmosphere, thus having done its work twice over. The arrangement of the high and low pressure cylinders may be varied to suit the ideas of the designer; there may be two h.p. cylinders exhausting into two l.p. cylinders, or one h.p. into two l.p., or two h.p. into one l.p., and so on, but the expansive action of the steam is the same in every case, and the end in view remains unaltered. The exhaust from the h.p. cylinder may be passed directly into the l.p. cylinder, or into a receiver which practically forms part of the l.p. steam chest. For the former method it is essential that each crank shall be set at a proper angle apart, as admission to the l.p. must be simultaneous with exhaust from the h.p. cylinder. When the h.p. exhaust is discharged into a receiver, the cranks may be set at any convenient angle apart, and the points of cut-off in both the h.p. and l.p. cylinders, therefore, may be adjusted to obtain the most efficient expansion.

This flexibility in the valve adjustment is of great importance, as the loss or fall of temperature and work performed may be divided more equally between each cylinder; hence the greater popularity of the latter method.

Then, again, steam at boiler pressure, sometimes termed "live" steam in this connection, may be admitted direct to the l.p. cylinder or cylinders for increasing the tractive effort at starting. A "change" valve is used for this purpose, which in the ordinary way does not operate, *i.e.*, when working compound. Such admission of live instead of exhaust steam from the h.p. cylinders can be indulged in only temporarily, as the l.p. cylinders are of greater capacity than the h.p. cylinders. It would be uneconomical and a severe strain on the boiler if the l.p. cylinders were supplied with h.p. steam for any length of time.

When h.p. steam is admitted to a single-expansion engine an early cut-off is necessary to obtain the advantage derived by expansive working, and for exhaust to take place at a sufficiently low pressure. A very large force of initial pressure is exerted, therefore, at the beginning of every stroke, which is diminished gradually with a corresponding fall of temperature as the point of exhaust is approached. The great reduction of loss from condensation is the most important saving in compound engines, more especially with the high boiler pressures which obtain in modern practice.

Practically the same number of expansions can be obtained with simple as with compound expansion, provided the cut-off be sufficiently early. On the other hand, this early cut-off, besides setting up excessive mechanical stresses in the engine parts, considerably increases the condensation losses.

The temperature of admission, for example, in a single expansion engine would be about 379° F., with a working boiler pressure of 180 lb. per sq. in. After cut-off takes place the pressure, and therefore the temperature, must be reduced rapidly to allow for expansion and to avoid a waste of energy at the end of each stroke by exhausting at the lowest possible pressure. The temperature at exhaust, therefore, must approach that of steam at atmospheric pressure and for the purpose of illustration may be taken at about 220° F., or 159° F. below the temperature of admission.

These variations of temperature are transmitted to the cylinder walls, and the entering steam, therefore, is brought into contact with metal which has been subjected just previously to the cooling influence of steam at exhaust temperature; hence the loss from condensation at the beginning of each stroke. It will be seen that some of the h.p. steam must be condensed in re-heating the cylinder walls, and although some portion of the condensation will re-evaporate at the lower pressures during expansion, a large amount will be discharged into the atmosphere at each exhaust in the form of moisture or heavily saturated steam.

In addition to the economy derived from dividing this fall of temperature between two or more cylinders, a further saving is effected when compounding by adopting the modern high steam pressures.

The relatively greater economy of h.p. steam may be denoted by comparing the units of heat required to raise the temperature of water and steam.

To raise the temperature of 1 lb. of steam from water at 32° to 212° F. at atmospheric pressure, 1146·1 units of heat are required, and further to raise the temperature to 327·9° F. or 100 lb. pressure, 1181·4, or only 35·3 additional units of heat, are necessary. By again adding 16·4 or a total of 1197·8 units of heat per pound of steam, 381·7° F. or 200 lb. pressure is attained, thus doubling the power available for admission to the cylinders by a very small additional expenditure of coal per pound of steam. The relatively greater economy of h.p. steam is, therefore, at once apparent, and is a fact so well established that pressures up to 300 lb. per sq. in. with triple and even quadruple-expansion engines are fairly common in marine engineering practice.

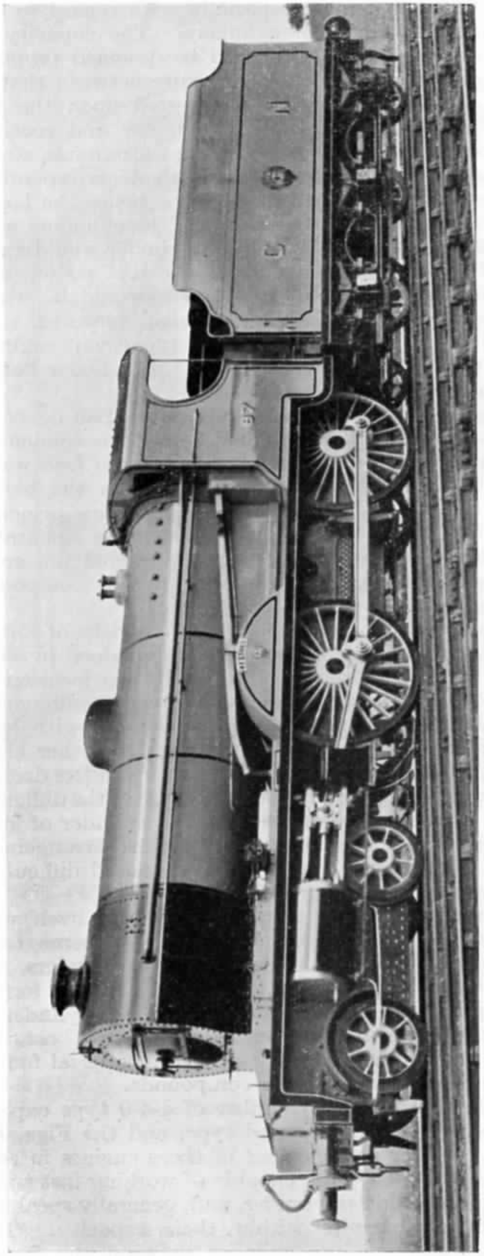


FIG. 153.—THREE-CYLINDER 4-4-0 TYPE COMPOUND LOCOMOTIVE, GREAT NORTHERN RAILWAY (IRELAND).

Mr G. T. Glover, Chief Mechanical Engineer (*retired*).

Cylinders, h.p., 17¼ in. by 26 in.; l.p., 19 in. by 26 in. Coupled wheels, 6 ft. 7 in. diameter. Coupled wheelbase, 10 ft. 8 in. Total engine wheelbase, 24 ft. 9 in. Boiler pressure, 250 lb. per sq. in. Total heating surface, 1,527·5 sq. ft. Grate area, 25·22 sq. ft. Weight of engine in working order, 65 tons. Weight of engine and tender in working order, 103 tons. Tractive effort (at 85 per cent. b.p.), 23,762 lb.

The efficiency of the compound always is dependent greatly on the design of the engine, more especially with regard to the proper ratios of the h.p. and l.p. cylinders. The capacity of the receiver or steam passages also should be designed properly for the avoidance of " drop " or loss of pressure between that of h.p. exhaust and the amount of energy exerted upon the l.p. piston. The area or volume of the l.p. cylinder and receiver is designed, therefore, with a view to receiving the exhaust steam from the h.p. cylinder at a given volume with a corresponding amount of back pressure upon the h.p. piston ; hence the larger diameter of the l.p. cylinder. If, for instance, the cylinders were made equal in area, the steam of the second cylinder would exert only a force equal to the back pressure of the h.p. piston, and the second cylinder with the whole of its gear would be worse than useless. The pressure of the h.p. exhaust, however, may be considerably higher than with simple expansion engines, as its energy is afterwards abstracted in the l.p. cylinder before being finally exhausted into the atmosphere.

It has been argued that a compound locomotive can never be really satisfactory unless used in conjunction with a condenser, by which the exhaust steam can be re-converted into feed water and the condensate used for raising more steam in the boiler. Many compound locomotives were constructed on this principle in earlier times, but the weight of the condensing apparatus and the general complication entailed were considered too great a disadvantage, and therefore in ordinary practice compound locomotives are built without condensers.

Compound locomotives have been built in a variety of forms, some with two, and others with three or four cylinders, in what may be termed " normal " practice. Similarly the location of the cylinders has been varied and practically every combination has been used ; that is to say, two-cylinder engines with both h.p. and l.p. cylinders between the frames, and in other cases outside the frames. The inside position, with the cylinders driving on the crank axle, was not very convenient, because of the difficulty of providing space between the frames for a l.p. cylinder of large diameter. The outside cylinder position, a lop-sided arrangement with one cylinder much larger than the other, caused difficulties in respect of platform clearance on the l.p. side.

The three-cylinder compound arrangement lends itself with greater convenience to locomotive conditions. In some cases engines have been built with two h.p. and one l.p. cylinders, and in others with one h.p. and two l.p. cylinders. In the former case, with the steam exhausting direct from the l.p. cylinder to the atmosphere, the somewhat curious effect of two beats for each revolution of the driving wheels instead of the usual four is obtained, as in the case of two-cylinder compounds.

The L.M.S.R. has in service a number of 4-4-0 type express engines of the three-cylinder compound type, and the Figs. 154 and 156 show the cylinder arrangement of these engines in each case from the front end. They are capable of working fast trains up to 350 tons loading behind the tender, and, generally speaking, have given satisfactory results within their capacity. This class of locomotive has one h.p. cylinder between the frames

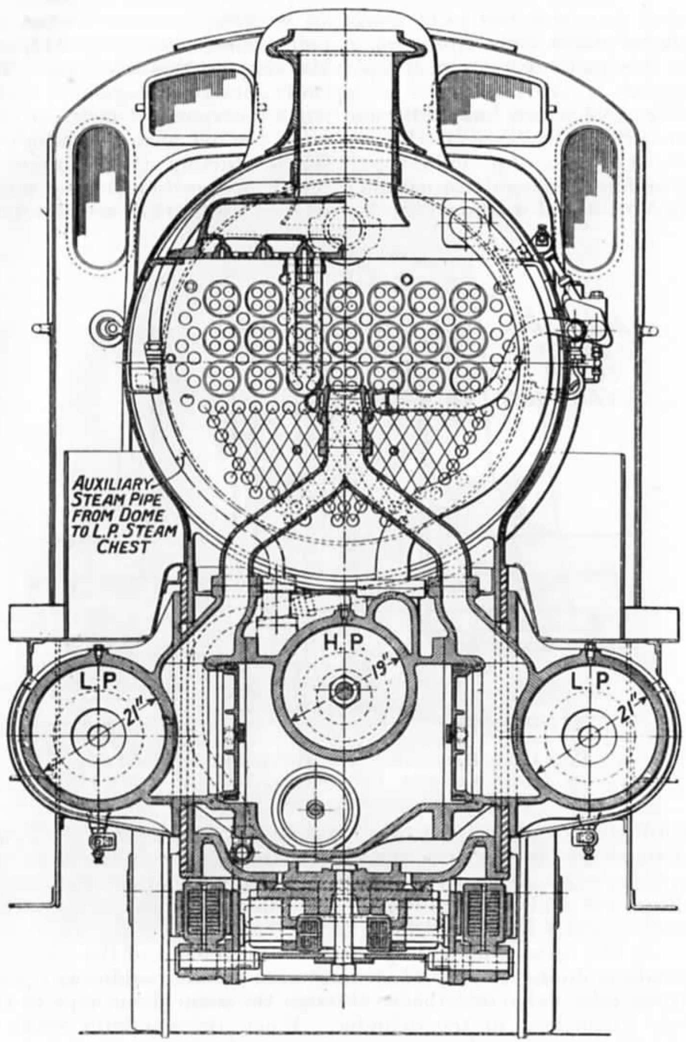


FIG. 154.—CROSS-SECTION THROUGH CYLINDERS AND SMOKEBOX, THREE-CYLINDER COMPOUND LOCOMOTIVE, L.M.S.R.

19-in. dia. × 26-in. stroke, and two l.p. cylinders outside the frames 21-in. dia. × 26-in. stroke, all three cylinders driving the leading coupled wheels. As in all compound locomotives, some provision has to be made for working "simple" when the engine starts away from rest, a point referred to on p. 245, and in this particular design it takes the simplest possible form. The engine is provided with a specially designed regulator valve (Fig. 155) which has additional ports incorporated in it, so that in certain positions of the regulator handle steam is admitted direct to the l.p. cylinders. When starting the locomotive, therefore, the regulator handle is put into a position corresponding to Nos. 3 and 4, shown on the diagram (Fig. 157), which allows

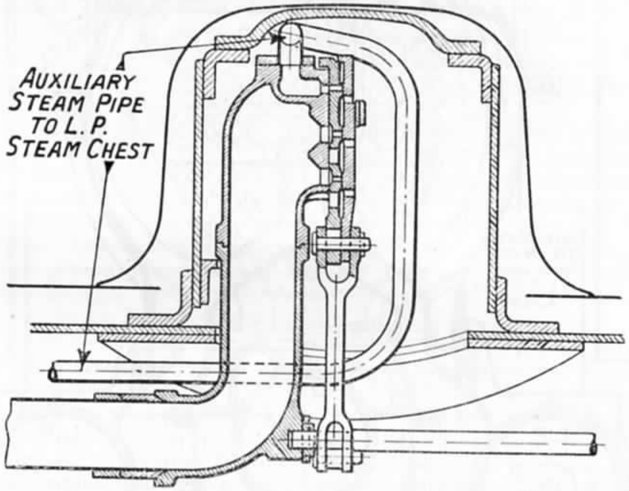


FIG. 155.—REGULATOR AND AUXILIARY STEAM PIPE, COMPOUND LOCOMOTIVE, L.M.S.R.

a full opening of the port through a pilot valve and into the upper chamber of the regulator marked A, from which it passes to the cylinder through a special auxiliary steam pipe of small diameter (Figs. 154 and 155) leading to the steamchest supplying steam to the outside l.p. cylinders.

At the same time and by the same movement of the regulator handle a limited supply of steam passes through additional ports in the pilot valve and thence through the main steam pipe to the h.p. steamchest in the cylinder. When the regulator valve is opened more fully the steam passage to the l.p. receiver through the auxiliary steam pipe is closed and the steam is admitted only through the main steam pipe to the h.p. receiver and thence by the movement of the h.p. piston valve to the h.p. cylinder. Once having done its work it is exhausted into the l.p. receiver, and finally works in the l.p. cylinder before being exhausted through the blast pipe into the atmosphere, thus establishing full compound working.

When starting, excess pressure on the exhaust side of the h.p. piston may occur from certain positions, and this is prevented by the lifting of simple non-return valves, one fitted at the front and one at the back end of the h.p. cylinder casting, so that the engine starts working as a simple engine with steam direct from the boiler acting on each l.p. piston, and steam at a

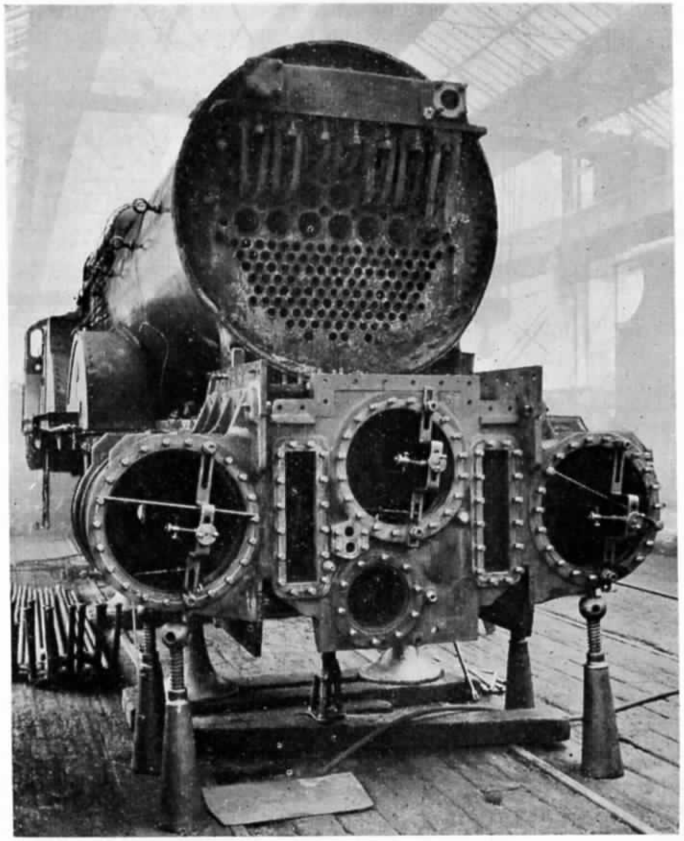


FIG. 156.—VIEW OF FRONT END, L.M.S.R. THREE-CYLINDER COMPOUND LOCOMOTIVE, SHOWING H.P. AND L.P. CYLINDERS AND STEAMCHESTS.

pressure proportionate to the difference between that in the h.p. and the l.p. receivers acting upon the h.p. piston. After starting it is important that as soon as the engine and train have gained sufficient speed the regulator handle should be put over to the fully opened position, so that full advantage is taken of compound working.

Engines built on the same system, but without the valve arrangement above referred to, were used formerly on the erstwhile North Eastern and Great Central railways. Four-cylinder compounds have been used in this country and more widely abroad, and here again the relative positions of the l.p. and h.p. cylinders have been varied.

Many times it has been demonstrated clearly under actual working conditions that for certain classes of work the compound is undoubtedly more economical in coal and water consumption than the single-expansion locomotive engine. A gradual rise in

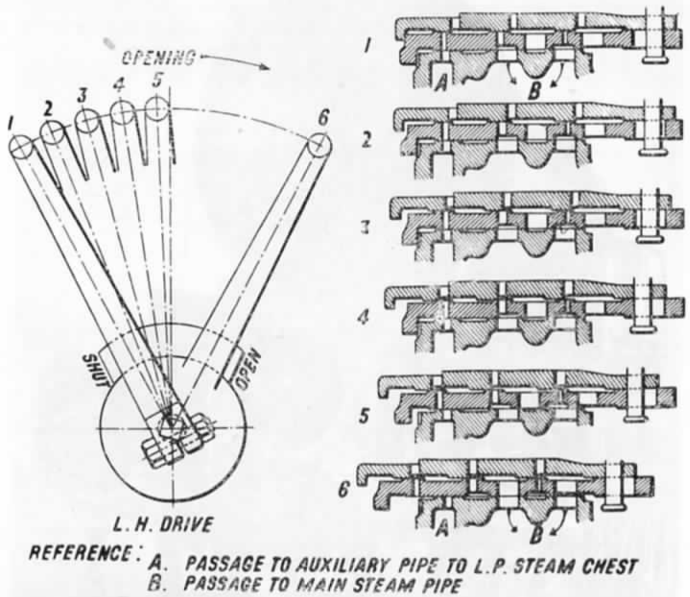


FIG. 157.—DIAGRAM SHOWING METHOD OF ADMITTING LIVE STEAM TO L.P. CYLINDERS, COMPOUND LOCOMOTIVE, L.M.S.R.

boiler pressures has been coincident also with improvements in the compound locomotive, until today working pressures of over 350 lb. per sq. in. may be found in a number of examples abroad.

The advantages derived from compounding under suitable conditions may be summarised briefly as follow :—

1. Expansion in two or more cylinders, thereby reducing condensation losses.

2. Increase of power from a given quantity of steam, which is equivalent to increased boiler capacity.

3. Reduced valve leakage losses.

4. Greater uniformity of crank effort with a resultant reduction of excessive stresses in the engine parts.

5. Lighter or more steady blast ; hence reduced loss of fuel and danger from ejected sparks, and so on.

6. Reduced amount of coal and water to be hauled in tender for a given amount of work.

In addition to several minor ones, the following are the important disadvantages of compounding :—

1. Increased cost of construction.

2. Increased risks because of multiplicity of engine parts.

3. Increased cost of upkeep and repairs.

4. Increased cost for lubricants.

5. Uneconomical cylinder ratios because of varying duties of engine.

It should be pointed out, however, that when reviewed strictly in accordance with what may be termed " modern " locomotive practice, covering three and four-cylinder single-expansion locomotives the boilers of which carry high steam pressures combined with advanced superheat, the above tabulated matter for and against the compound must be read with some reserve.

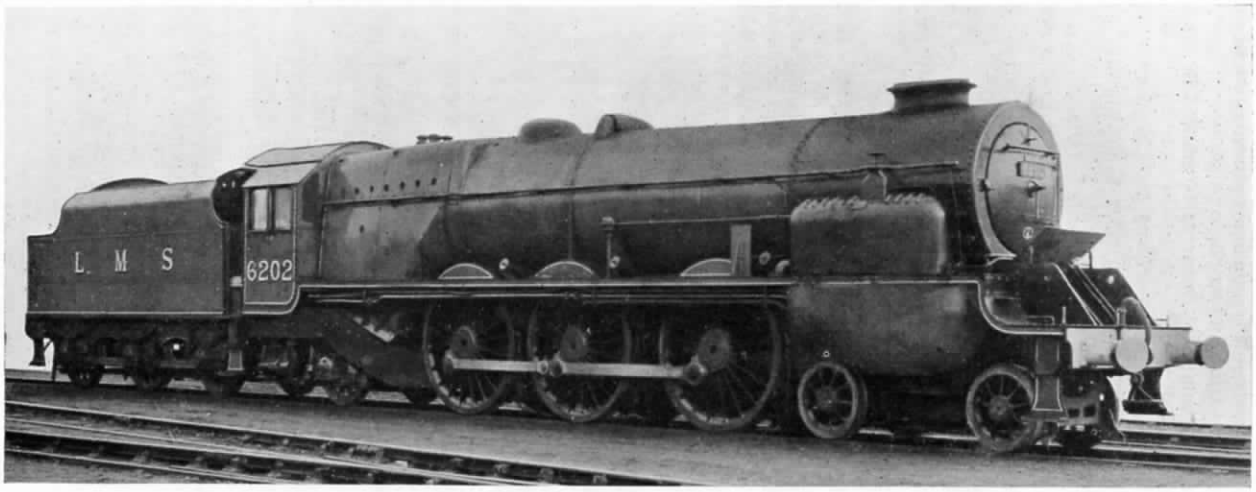


Fig. 157a.—Turbine-Driven 4-6-2 Type Express Locomotive with Geared Transmission, L.M.S.R.

Sir William Stanier, Chief Mechanical Engineer (*retired*).

Non-condensing multi-stage forward turbine and reverse turbine of the impulse type. Coupled wheels, 6 ft. 6 in. diameter. Coupled wheelbase, 15 ft. 3 in. Total engine wheelbase, 37 ft. 9 in. Boiler pressure, 250 lb. per sq. in. Total heating surface, 2,745 sq. ft. Grate area, 45 sq. ft. Weight of engine in working order, 110 tons 11 cwt. Weight of engine and tender in working order, 165 tons 4 cwt.

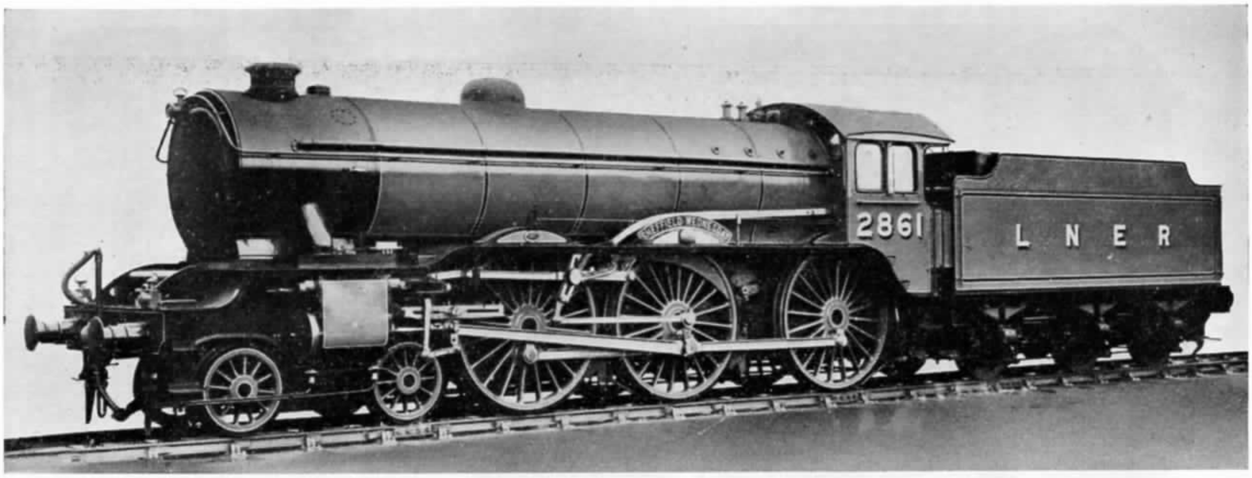


Fig. 158.—4-6-0 Type Express Locomotive, "Sandringham" Class, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 17½ in. by 26 in. Coupled wheels, 6 ft. 8 in. diameter. Coupled wheelbase, 16 ft. 3 in. Total engine wheelbase, 27 ft. 9 in. Boiler pressure, 200 lb. per sq. in. Total heating surface, 2,020 sq. ft. Grate area, 27·5 sq. ft. Weight of engine in working order, 77 tons 5 cwt. Weight of engine and tender in working order, 129 tons 15 cwt. Tractive effort (at 85 per cent. b.p.), 25,380 lb.

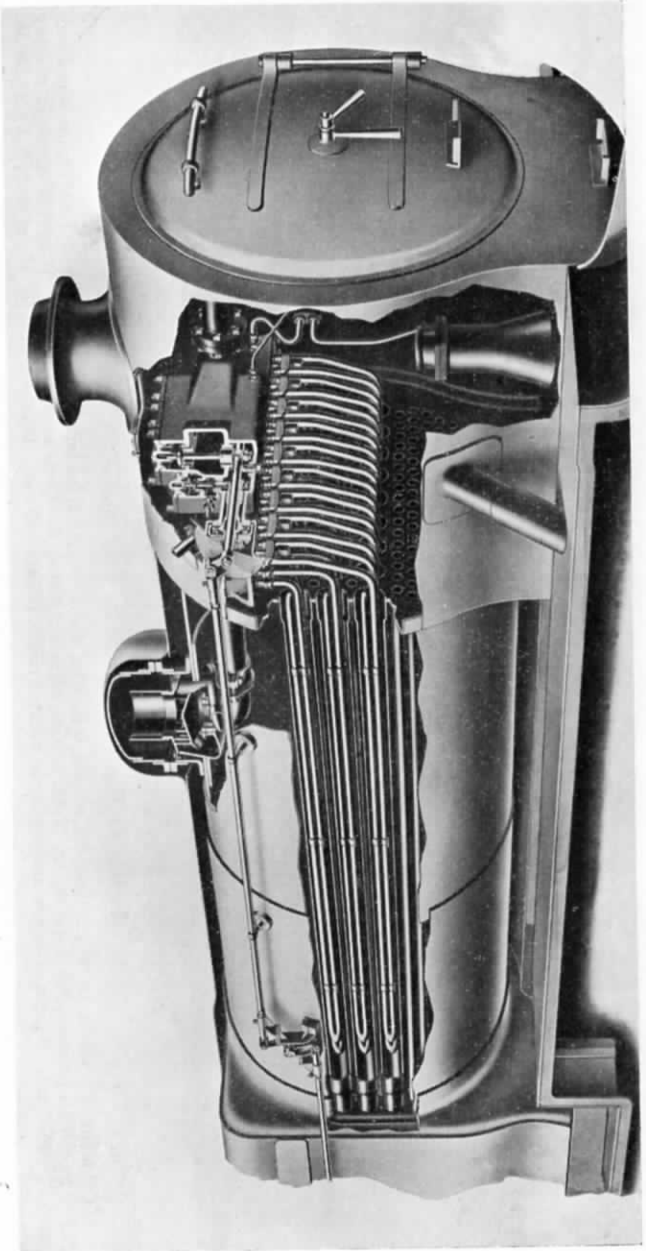


Fig. 159.—Locomotive Boiler showing "MeLeSco" Superheating Apparatus and Tangential Steam Dryer.

Chapter 11

SUPERHEATED STEAM

The economy of superheated steam now has been proved conclusively, and today the practice of equipping locomotives with superheating apparatus has become virtually standard. It is evident that the size of the largest locomotive boilers has reached the loading gauge limit, and any gain in power to meet the constantly increasing traffic demands for higher speeds and heavier trains will be dependent greatly, therefore, on a more economical use of the steam generated.

Steam is said to be superheated when its temperature has been raised above that of the water from which it is formed. The term " saturated " is applied to steam when in contact with the water in the boiler, under which conditions its temperature cannot be raised without a corresponding increase of pressure. If additional heat be applied to the steam after it has left contact with the water its temperature may be raised and a constant pressure maintained by allowing for the increase of volume. This larger volume is provided for by placing the superheater between the regulator and engine cylinders, in which case further heating of the steam occurs without an increase in pressure.

The advantages of superheating are briefly :—(1) Larger production of steam, as a given volume of saturated steam increases in volume when superheated. (2) Reduction of losses from cylinder condensation. (3) More efficient expansive behaviour of the steam in the cylinder.

1. The larger production of steam is equivalent to an increase in the size of the boiler. Experimental and practical trials have demonstrated that the volume of saturated steam delivered by the boiler may be increased by 33 per cent. with 200° F. of superheat.

2. The great reduction of losses from condensation is the most important saving effected by the use of superheated steam. It has been calculated that from 20 to 30 per cent. of the steam entering the cylinder in a simple expansion engine may be condensed by contact with the low exhaust temperature of the cylinder walls. The prevention of this large amount of condensation would be equal, therefore, to an increase in the boiler capacity according to the amount of saving effected. By superheating, the temperature of the steam above that of saturation point is available for counteracting the cooling influence of expansion, and condensation does not begin until the superheat has been extracted. If, for instance, the temperature of the steam at admission be 500° F., instead of 380° F. (the temperature of saturated steam at 180 lb. pressure), the 120° F. above saturation temperature represents the amount of heat that could be lost before liquefaction began. Modern superheating practice shows

the advisability of making the initial steam temperature sufficiently high to ensure that there is still some superheat when released from the cylinder.

Because of the elimination of initial condensation and the increased volume of steam from the water evaporated, superheating is a great saver in coal and water consumption.

3. The vapour characteristic of the steam is changed to one of a more gaseous nature, thus improving the expansive action of the steam in the cylinder. It has been found that a given weight of superheated steam will transmit a larger amount of energy than a similar weight of steam at saturation temperature. The frictional resistance of the steam as it traverses the pipe or port passages also is much reduced when in this gaseous state, with a corresponding decrease in condensation, as the flow may be much more rapid. Its heat conductivity as compared with saturated steam also is reduced considerably, hence a further reduction in the amount of heat lost by transmission to the cylinder metal.

These and other advantages may be briefly summarised as: (1) reduction of risks and losses from priming, by the evaporation of any moisture that may be carried along with the steam from the boiler; (2) reduction in the size of the boiler for a given load, or a 20 to 30 per cent. reduction in the pressure carried, with a corresponding decrease in the cost of upkeep and prolongation of the life of the boiler.

Various types of superheating equipment are in use on boilers for stationary engine plant, ships, and locomotives, and probably one of the best known and most widely used systems applied to locomotive work is that manufactured by The Superheater Co. Ltd., under the trade mark "MeLeSco." This is a header carried in the smokebox, above the level of the top row of tubes, and joined by means of a flange on the front tubeplate to the main steam pipe from the boiler. Flanges on the front of the header connect up to the main pipes leading to the steamchests. The header is divided into a series of small compartments. Half of these receive the steam as it enters the header from the main steam pipe from the boiler, and give access to the superheater elements which lead from the underside of the header into the superheater flue tubes in the boiler. The superheater elements usually are formed in such a way that the saturated steam to be superheated is fed first towards the firebox end of the flue, is returned by a bend to within a short distance of the front end of the flue, and again returns to a second bend at the firebox end. It passes back along the fourth portion of the element piping to rejoin the underside of the header and enter the remaining half of the compartments, which communicate by way of the main steam pipes in the smokebox to the valves and cylinders. During its passage from the first, or saturated steam compartments, through the elements to the second, or superheated steam compartments, the steam has been freed entirely from moisture, and the temperature has been raised or, in other words, it has become superheated. Superheating equipment arranged in the manner described is known as the smoketube type, and different types of header are used to suit various classes of smokebox.

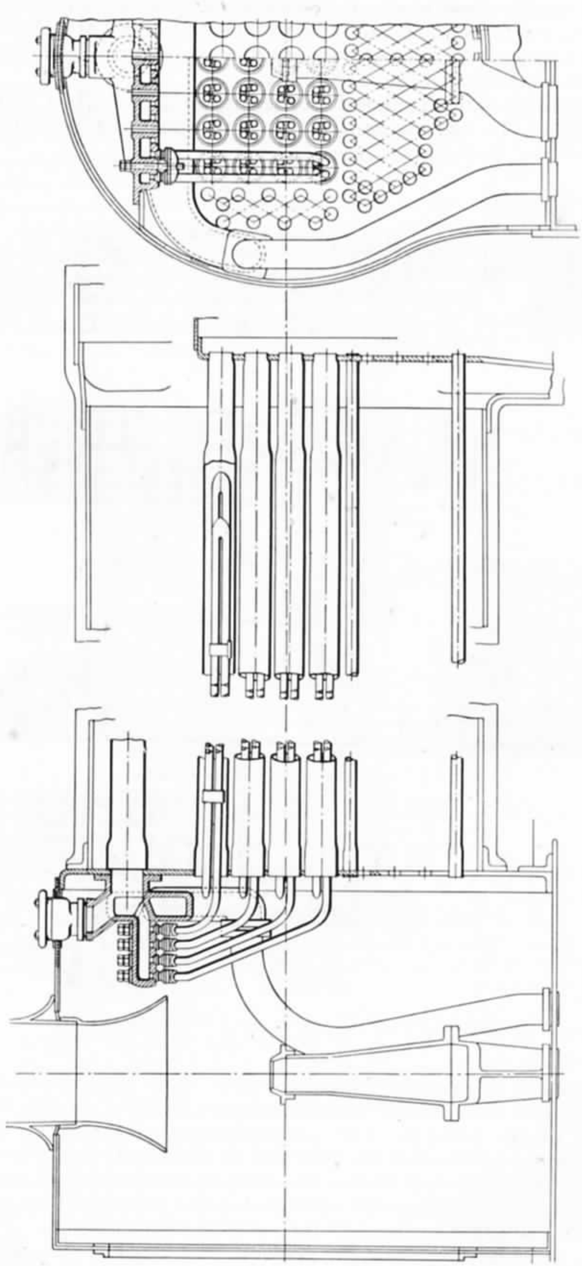


FIG. 160.—GENERAL ARRANGEMENT OF SMOKETUBE TYPE SUPERHEATER WITH BALL-JOINT ELEMENTS AND VACUUM RELIEF VALVE.

The most widely used method of connecting the element ends to the undersides of these headers is by the ball-joint attachment. A typical example of this type of superheater is shown in Fig. 160 and in the frontispiece of this chapter.

The through bolt insulated header, type "A.X.," is shown in Fig. 161. The casting is divided into transverse pockets or

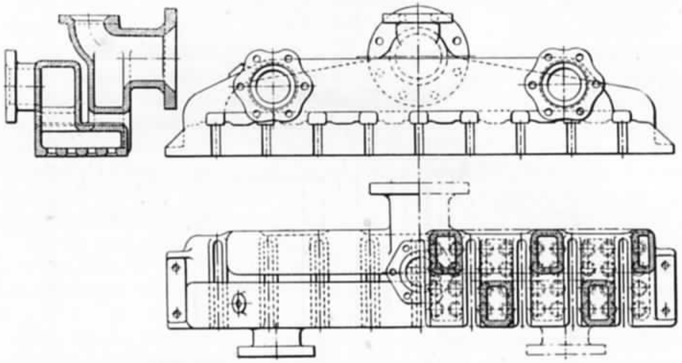


FIG. 161.—TYPE "A.X." SUPERHEATER HEADER.

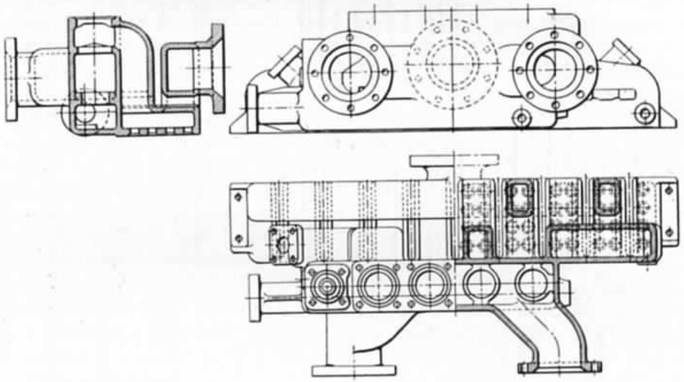


FIG. 162.—THE "MELESCO" MULTIPLE VALVE REGULATOR.

compartments communicating alternately with the superheated and saturated longitudinal steam passages situated at the front and rear of the header. The compartments in the header are isolated from one another by passages or slots, and thus unequal expansion of the metal of the alternating saturated and superheated steam compartments can take place without danger of the metal fracturing because of the varying temperatures. These passages or slots are used for housing the bolts which secure the elements to the face of the header, the tee-heads of the bolts

lying in a horizontal plane above the header and the nuts below, or vice versa.

Fig. 162 shows a general arrangement of the "MeLeSco" Multiple Valve Regulator. It consists of three chambers in the forward part of the superheater header, each extending transversely across the front and arranged one above the other. The upper chamber is part of the superheated steam compartment of the header, and has a flanged connection at one end for supplying superheated steam to the auxiliaries. The middle chamber is in direct connection with the main cylinder steam pipes, and the third or lowest chamber is used for balancing purposes and has no outside connection other than that for draining the chamber.

The valves, which are of comparatively small diameter, are operated by a camshaft in a similar manner to those on a motor

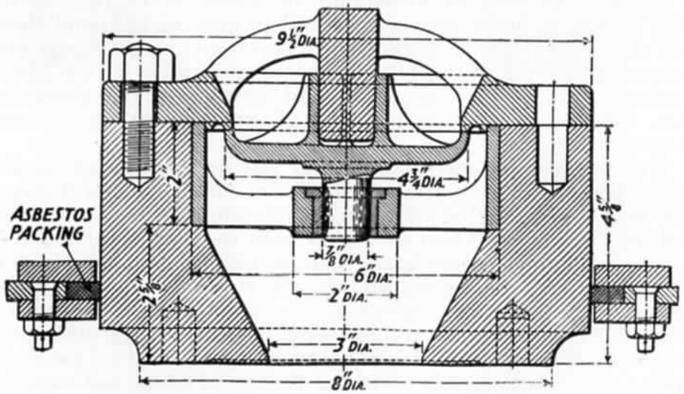


FIG. 163.—ANTI-VACUUM VALVE, L.N.E.R.

car, but in this design springs have been eliminated and closing is effected by positive mechanical action of the cams. The valves are balanced so nearly that only a minimum effort is needed to move them. This balancing is accomplished by providing a small pilot valve, which, on moving the regulator handle, lifts first, admitting steam to the balancing chamber preliminary to lifting the main valves. The main valves follow in succession; the first to lift is that adjacent to the pilot valve, the end valve on the right-hand side is next, followed by the centre valve, so that the passage of steam through the superheater and regulator is uniform, providing a perfect graduation in the supply of steam to the locomotive cylinders.

The anti-vacuum valve, seen in Fig. 163, is placed on the saturated steam side of the superheater header. Its object is to allow air to be drawn through the superheater elements and steam pipe into the cylinder when the engine is running with a closed regulator. The effect of the introduction of this air is twofold. In the first place, it has a cooling effect on the elements and prevents them burning at the firebox end, and in the second place, it prevents such vacuum being formed within the cylinder as would draw down the blastpipe ashes from the smokebox at the instant when the exhaust valve is opening. With the regulator open the pressure of steam within the element acts on the under side of the valve and keeps it closed. The valve, valve seating, and guides are of bronze. The valve body is of cast iron.

The superheater element of the standard " A " type (Fig. 164) consists of a continuous pipe formed of four lengths of solid, cold-drawn, weldless steel tubing connected by three return bends. The inlet and outlet ends of each element are bent upward, to allow them to be clamped to the bottom face of the header in such a manner that the inlet end communicates with a saturated steam compartment and the outlet end with a superheated steam compartment. The element, illustrated by Fig. 165, is the usual type provided with ball joints.

Another method of attaching the elements to the header (Fig. 166) is to finish them off with plain ends and expand these into the header direct. Front cover plates secured by studs and nuts are provided on these header castings to allow of the introduction of tools for expanding and extracting the elements. Figs. 167 and 168 show the method of expanding and extracting the superheater tubes.

The ends of the elements nearest the firebox, known as the return bends, are the parts which require the most careful attention in manufacture, as they must withstand high temperatures, and they are exposed also to erosion from the matter carried over by the high temperature gases in their passage through the flue tubes ; deposits are formed and the return bends are liable to be burned. The method of manufacture adopted for the " MeLeSco " integral machine-forged return bend, shown in Fig. 169, is a patented mechanical die-forging process, in which two pieces of tubing are bonded together without the use of additional material or flux, and a true hammer weld is performed under ideal conditions. In addition, the thickness of the metal is increased at the bend so that it is in fact stronger than the straight tube. The method of securing the element ends to the header is shown in Fig. 170.

To hold the component lengths of each element together tightly, prevent leaky joints due to vibration, and keep the element in its proper position in the flue tube, simple bands and supports are secured to the elements, usually two for each, near the extremities of the flues.

The " Swindon " superheater (Fig. 171) has been fitted to a number of engines on the G.W.R. system, and has given every satisfaction. This superheater is simple in construction, thereby rendering the different parts readily accessible. It consists of a number of superheating tubes C, which are about 1 in. dia. and arranged in groups of six. These tubes are expanded into the junction headers B, which are attached to the main header A extending across the inside of the smokebox. The two rows of larger diameter fire tubes containing the superheater elements are $4\frac{3}{4}$ in. inside dia. at the smokebox end and reduced to $3\frac{1}{8}$ in. inside dia. at the firebox end.

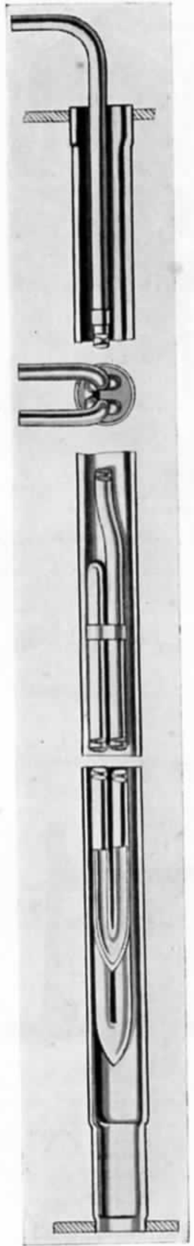


Fig. 164.—Standard " A " Type Superheater Element.

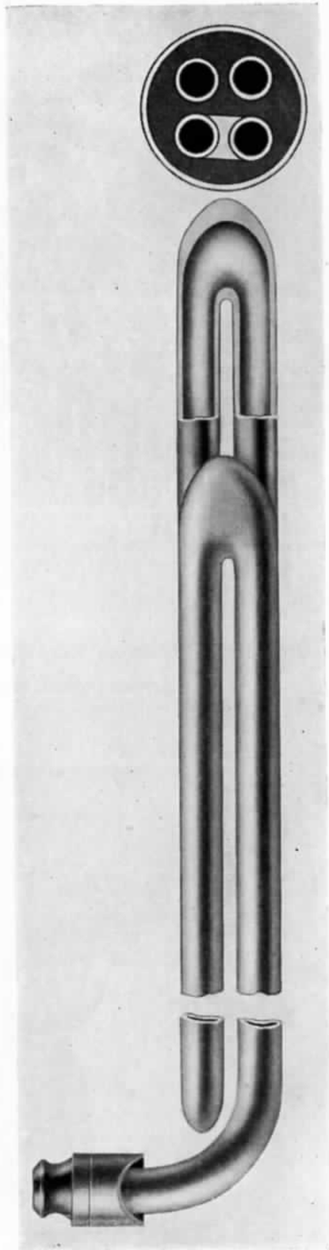


Fig. 165.—Element with " MeLeSco " Solid Machine-Forged Return Bend.

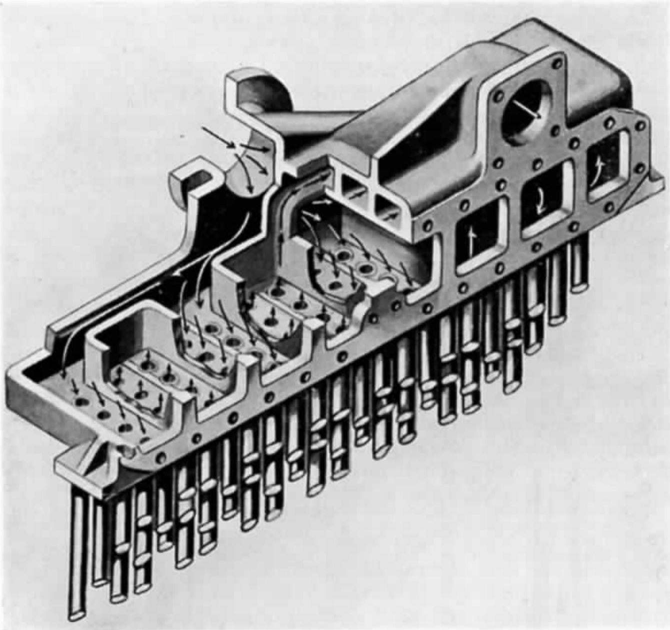


FIG. 166.—ELEMENTS EXPANDED DIRECT INTO HEADER.
(*Arrows indicate course of steam.*)

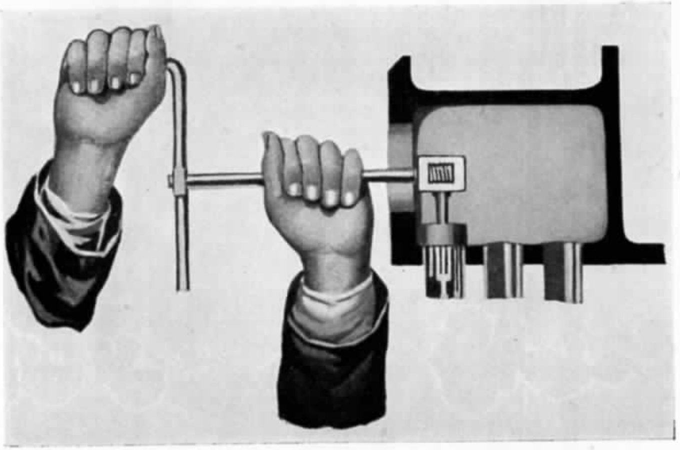


FIG. 167.—METHOD OF EXPANDING SUPERHEATER TUBES.

The ends of the superheater tubes and the header are covered by a spark plate which is hinged and worked by a suitable handle to give access to the tubes. Fig. 171 also gives a front view of the apparatus. The method of securing the elements to the header permits the header to be made of cast iron.

The saturated steam from the boiler passes through the

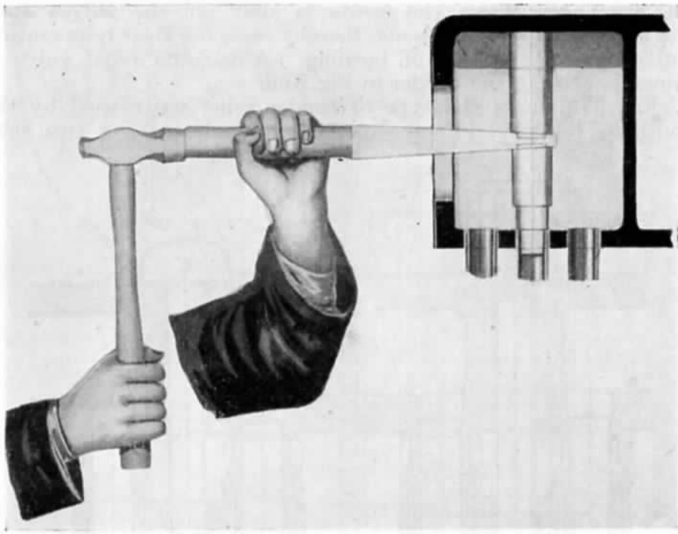


FIG. 168.—METHOD OF EXTRACTING SUPERHEATER TUBES.

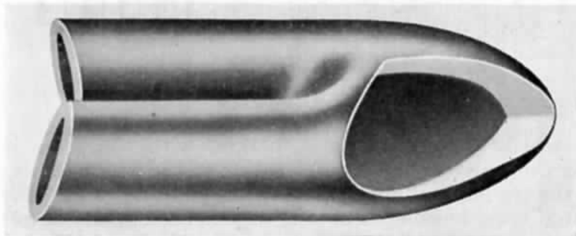


FIG. 169.—ENLARGED VIEW OF MACHINE-FORGED SUPERHEATER TUBE RETURN BEND.

regulator K and steam pipe L to the upper division of the main header, and thence through the junction headers of the superheating tubes back again to the lower division of the main header, before being finally delivered to the steamchests on the engine cylinders.

The return bends on the superheater tubes are made of plain bent tube electrically butt-welded to the straight tubes, as shown in Fig. 172.

To overcome the difficulty experienced in keeping superheater elements cool when steam is shut off while running, vacuum relief valves, or snifting valves, are mounted sometimes on the smokebox behind the chimney. They are carried in small chambers communicating with the superheater header, and are arranged so as to be kept closed by the pressure of the steam while the regulator is open and steam is circulating through the elements. When the steam is shut off, the valves open and admit air to the elements, thereby reducing their temperature and obviating the risk of burning. A vacuum relief valve is shown applied to the header in Fig. 160.

Fig. 173 shows the type of header relief valve used by the Southern Railway. Each superheater header carries two such

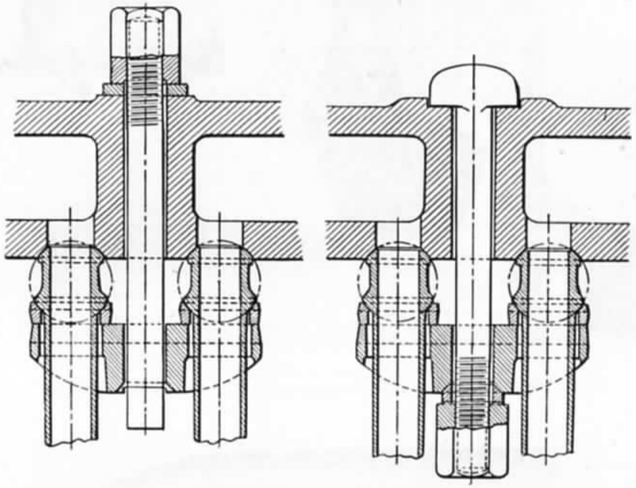


Fig. 170.—"MeLeSco" Joint Attachment.

valves which are automatic in action, with the seats inverted so that the valve falls off its face when the regulator is closed. When the regulator is opened the steam pressure reseats the valve.

Often, considerable trouble is experienced with engines using superheated steam, because of the development of "knock" in the connecting rod brasses, and so on. This "knock" has been shown to be caused by the high compression and suction in the cylinders when running with the regulator closed.

There is a steadily growing tendency in many countries at the present time towards the adoption of the smokebox location for the regulator, which is placed in a position between the superheater header and the steamchest, usually on the front of the header itself. By this arrangement steam is kept constantly circulating through the superheater, thereby entirely avoiding the risk of burning the element ends through their becoming dry. Among the advantages claimed for this arrangement are that the engine

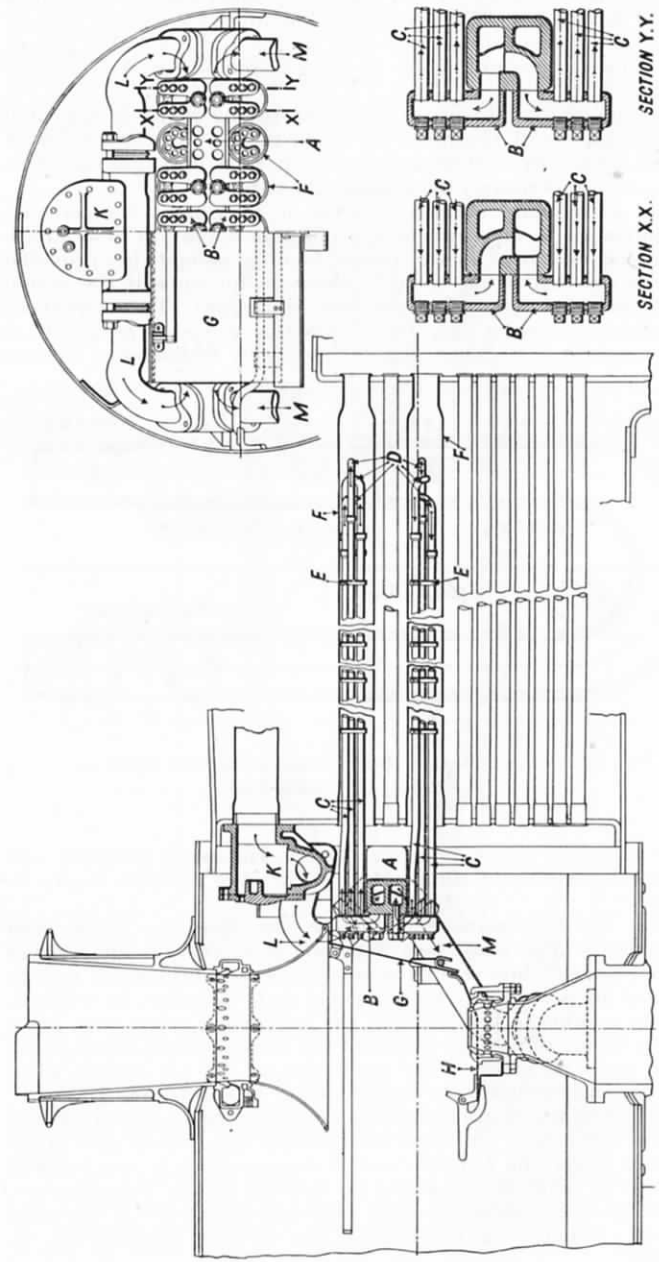


Fig. 171.—Details of "Swindon" Superheater, G.W.R.

responds more readily to the regulator, superheated steam may be used for working the auxiliaries, including feed water and air pumps, and the regulator, generally of the multiple valve poppet type, remains steamtight for prolonged periods, and is readily accessible.

The amount of superheat imparted to the steam is indicated by a pyrometer or thermometer fitted in the superheater outlet and connected by a flexible connection to a dial (graduated in degrees of temperature) fixed inside the cab.

The continuous maintenance of a maximum temperature of combustion is essential to the efficient operation of a superheater locomotive; hence every facility should be provided whereby the driver may readily ascertain for himself the actual conditions of combustion on the firegrate. The superheat thermometer is extremely useful for this purpose, as a fall in the temperature readings almost invariably indicates a decline

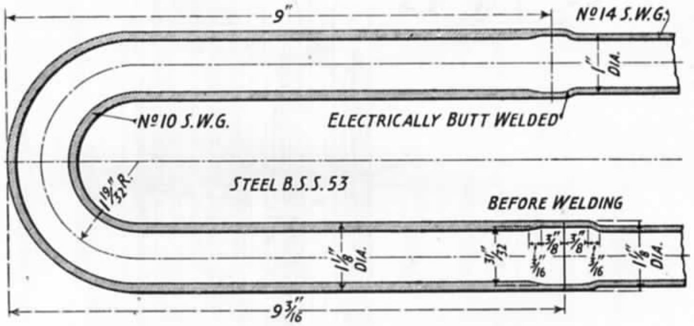


Fig. 172.—Electrically Butt-Welded Return Bend of "Swindon" Superheater.

in the efficiency of combustion. The thermometer generally will indicate a lowering of temperature before the pressure begins to decline.

Some firemen persistently carry the fires too thick, and consequently large quantities of carbon monoxide are given off at a comparatively low temperature. These conditions are readily indicated by a suitable thermometer, and, therefore, in addition to being a guide to the fireman, the instrument often may bring about a saving of coal by reason of the more efficient depth of the firebed and the more skilful regulation of the air supply when endeavouring to obtain the proper degree of superheat.

The foregoing is applicable also to fires which are carried too thin, as the excess air admitted through the firebed will dilute and thus lower the temperature of the products of combustion. This loss of temperature would be denoted by the thermometer, and the fireman necessarily must maintain his firebed at the most efficient thickness in order that the desired results may be obtained.

It is of importance, especially in the case of a new locomotive or when a new design of superheater is fitted, that the actual temperature of superheat should be measured, and for this purpose the electrical method of measurement is the most flexible and the most easily applied to a locomotive. A heat-sensitive stem is inserted, for instance, in the superheater header, and connected

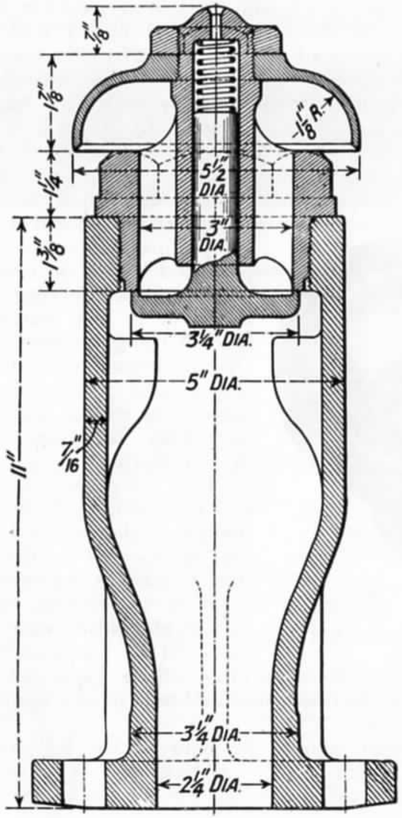


Fig. 173.—Superheater Header Relief Valve, Southern Railway.

therefrom to a direct reading indicator in the cab. An example of this is shown in Fig. 174, wherein will be seen a small circular box below for easy connection and disconnection of the connecting cable.

Every locomotive engineer is aware of the short sharp vibrations experienced on the road, and will appreciate, therefore, the necessity for special resilient mounting of the moving parts in the electrical indicator. The type of instrument shown incorporates the system known as "Resilia." In addition to the black pointer moving in accordance with the actual temperature, there is a red adjustable index which can be set by hand to any point on the scale, so that the engineman need not be troubled to read a temperature figure on the scale but can see at a glance whether the temperature is below, at, or above the desired figure. The instrument referred to is designed and manufactured by the Foster Instrument Co. Ltd.

Another type of thermo-electric pyrometer for locomotives fitted with superheaters is that designed and made by the Cambridge Instrument Co. Ltd. The illustration (Fig. 175) shows the indicator adapted for panel mounting, but for locomotive work it is supplied usually with two lugs on each side for wall-mounting. It has a scale 10 in. long, and incorporates two special features, namely, the provision of automatic cold junction temperature compens tion, by which variations in the atmospheric temperature are compensated automatically, so that they do not affect the accuracy of the reading. The other is the makers' patented magnetic cushioning device, whereby the moving system of the indicator is held magnetically in the field of the galvanometer magnet, and thereby is cushioned effectively against any shocks or vibration. This latter feature, as will be realised, is of special advantage in connection with locomotive work.

Fig. 174.
The Foster "Resilia" Pyrometer.

Fig. 176 shows the arrangement of the thermo-couple, which is enclosed for protection within a steel sheath and is inserted in the steam pipe as illustrated. A screwed union at the head of the thermo-couple makes a steamtight joint, and the connecting leads to the indicator are protected by a flexible metallic sheathing, which, for a short distance from the thermo-couple head, is protected further against the heat by asbestos insulation.

Due attention should be paid to the following when using superheated steam: (1) Lubrication; (2) Gland packings; (3) Unequal or excessive expansion of the metal in contact with the steam.

1. In the earlier days of the superheater, lubrication and gland-packing troubles undoubtedly were much more acute than at present. The animal or vegetable oils or fats, which were formerly the only lubricants used, were rendered totally unfit for superheated steam by the comparatively low temperature at which they vaporised. Considerable difficulty was experienced in lubricating efficiently the slide valves and pistons, with a resultant excessive wear, which almost proved fatal when the superheater first was introduced. The older forms of lubricant have now been superseded almost entirely by heavy-bodied high flashpoint mineral oils, which, when introduced into the steam chests and cylinders by a force pump, as commonly applied in

Fig. 175.—Indicator of Cambridge Thermo-Electric Pyrometer for Superheated Locomotives.

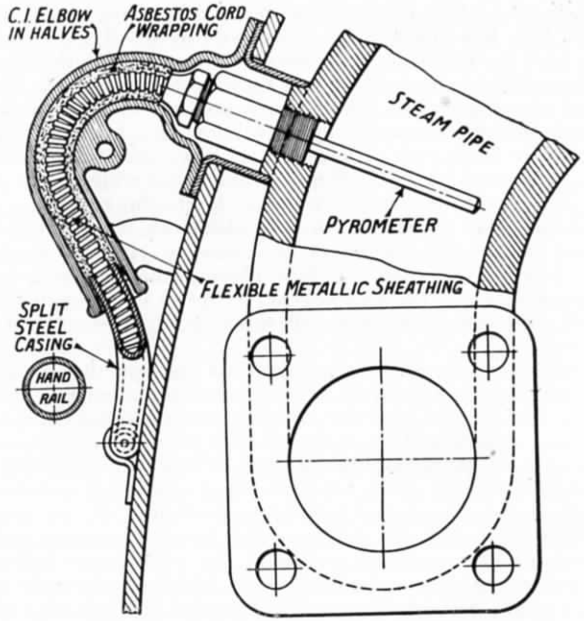


Fig. 176.—Arrangement of Thermo-Couple for Cambridge Pyrometer.

stationary or marine engineering practice, considerably reduce the difficulties of lubrication.

2. The deterioration of the older types of fibrous gland packing also was very rapid when subjected to the temperature of superheated steam. Today, however, there are many types of metallic packing which may be made of a special mixture for withstanding the high superheat temperatures.

3. The high superheated temperatures undoubtedly tend to distort the metals with which the steam is brought into contact. For the higher degrees of superheat the cylinders, valves, and so on, therefore are designed with a view to the elimination of excessive or unequal expansion.

Steam temperatures up to 500° F. have been adopted successfully with the ordinary slide valve. Piston or poppet-type valves, however, have proved most satisfactory for the highest degrees of superheat when used in conjunction with specially designed cylinders, suitable gland packings, and proper methods of lubrication for locomotive purposes.

The measure of success attending the use of locomotive superheaters is dependent greatly on the individuality of the driver, as it is only by the proper manipulation of the apparatus under the different and varying working conditions that the most efficient results can be obtained.

Some familiarity with the principle of superheating, with some knowledge of the economies from the use of superheated steam, is essential in the first instance. After this, by the application of this knowledge and attention to detail, the successful driver and fireman soon will become conversant with the actual working of the superheater, just as in past years with live and exhaust steam injectors, brake gears, and special lubricators.

That the efficiency of superheated steam increases with its temperature is now an accepted fact, hence the importance of a full appreciation of the different conditions, which may lead to a loss of temperature with consequent inefficient results.

To minimise these heat losses, therefore, the driver should see that his engine cylinders are warmed through thoroughly before leaving the shed, by first placing the reversing lever in full forward or full backward gear, with the cylinder drain cocks opened, and admitting a small amount of steam through the regulator.

In this manner the temperature of the cylinder metal may be raised to approximately that of the steam with which it is brought into contact, thereby greatly reducing initial condensation losses and allowing the full economical effect of the superheater to be brought more readily into use. The cylinder drain cocks also should remain open after starting until the pyrometer in the cab denotes a steam temperature of 400° F., or not more than 200° F. below the full working temperature, according to the amount of superheat required. In addition to raising the temperature of the cylinder metal, blowing through in this manner when first starting up will ensure the removal of dirty deposits in the steamchests or the carbonised remains of lubricant adhering to the wearing surfaces of the slide or piston valve faces and cylinder walls.

As the lubricating quality of the steam decreases with the amount of superheat attained, it will be obvious that proper attention to the arrangements provided for lubrication before beginning a journey is of vital importance.

When the engine is working heavily, the temperature of the cylinder and valve face metals, by contact with highly superheated steam, may be well over 600° F. ; hence the necessity for efficient lubrication, otherwise the wearing surfaces may become seriously scored or damaged, in addition to the possibility of excessive frictional losses. Special high flashpoint, heavily bodied, mineral oil therefore is used for lubricating the steamchests and cylinders, and some form of mechanically operated lubricator is adopted now almost invariably whereby the lubricant may be delivered positively to the parts to be lubricated. The various types of force-feed lubricators which have been found necessary and effective for use with superheated locomotives are dealt with in some detail in Chapter 14.

The amount of superheat obtainable dependent directly on the temperature of the flue gases, so that any defect or leakage whereby an excessive amount of air is permitted to enter the smokebox or firebox will be detrimental to the ultimate efficiency of the engine. It is essential that the fireman, after cleaning out the smokebox, should grease the rim of the door and see that it is home, securely tightened to give an airtight joint. For similar reasons the firehole door should not be opened unless absolutely necessary, otherwise the rush of cold air through the tubes will result in a sudden and considerable reduction in the amount of superheat obtained. This also applies to the firegrate, as a fire that is too thin will allow too much air to be admitted, more especially if the bars are bare in places. It is a well-known fact that bare places are formed when coal is fired in large lumps, as the smaller pieces surrounding the lumps are burned away rapidly, thus admitting an excessive amount of cold air. Hence there is the necessity for breaking the coal into pieces not larger than half bricks, and thereby maintaining an even thickness of incandescent fuel, particularly at the corners of the firebox and against the firebox plates.

This even form of fire, however, cannot be maintained if the coal is fired in large quantities, as with heavy firing there are periods at which the maximum incandescence and temperature is attained between the thickest and thinnest condition of the fire. The necessity for firing often and in small quantities is intensified also by reason of the amount of heat absorbed when a heavy charge of coal is newly fired, with a consequent heavy discharge of smoke. This, with the total amount of heat required for the evaporation of the moisture in the coal, will result in a considerable fall of the firebox temperature, in addition to reducing further the efficiency of the engine by the soot or unconsumed particles of carbon fouling the superheater tubes. With proper firebox conditions and a modern design of superheater, a steam temperature of 700° F. should be maintained easily, thus giving an available superheat of about 312° F. above that of saturated steam at 215 lb. absolute pressure per sq. in.

The superheat will be affected detrimentally if the water be carried too high in the boiler, thus causing wasteful priming and consequent partial flooding of the superheater. When this occurs a sudden drop of temperature will be denoted by the pyrometer, necessitating the immediate closing of the regulator, which then should be opened again gradually to prevent the water lifting with the steam.

Past experience, both experimental and in practice, has proved beyond doubt that the steam as delivered from a locomotive boiler under heavy working conditions almost invariably contains an excessive amount of moisture, hence the occasional application of different forms of steam driers between the regulator and cylinders.

If, however, this excessive wetness of the steam be reduced to a minimum by carrying the water level in the boiler at the most suitable height, the consequent smaller amount of moisture delivered is evaporated completely in the superheater, with a corresponding saving in the total amount of coal and water consumed for any given duty. Experiments have shown that every 1 per cent. of water passing into a superheater reduces the final temperature of the superheated steam by approximately 10° F., a decrease in temperature which results in lower engine efficiency and increase in fuel costs. A drier used in conjunction with a superheater performs the double duty of eliminating water from the saturated steam entering the superheater and cleaning the steam by ejecting scale-forming impurities and other foreign matter, thus keeping the superheater elements internally clean.

The illustration appearing on p. 256 shows interior of a superheater boiler, which has fitted in the steam dome what is known as the "MeLeSco" Tangential Drier, often used in conjunction with the superheating apparatus of the same design and manufacture. This type of drier provides a practical means of separating water and sediment from the steam entering the superheater and returning it back into the boiler against pressure by kinetic energy. The necessary space for a drier of ample capacity is provided in the dome by the placing of the regulator valve in the smokebox. Tests recently made show that its fitting resulted in a 60° F. increase in superheat.

From the foregoing, the importance of opening the regulator gradually when starting up will be evident, otherwise there will be a possibility of the water in the boiler lifting with the first rush of steam to the cylinders, with resultant priming and superheater losses.

Although the driver must be guided by the gradients and load on his engine, it will be found usually that the most economical results will be obtained with the regulator fully opened and the reversing lever notched up to about 25 per cent. cut-off. If, however, pounding in the rods, boxes, or journals should occur with this percentage of cut-off, a longer period of cut-off may be used, with the regulator partially closed.

With heavy loads, or up a stiff bank, the best results would be obtained with the regulator full open and the reversing lever notched up to as near mid-gear as is consistent with running the train to time. When it is necessary to stop at signals or stations the reversing lever should be put slowly over to full

forward gear immediately after closing the regulator, thereby giving the slide or piston valves a maximum amount of travel and thus ensuring that the highly heated metals of the valves and faces will not seize up, and preventing ashes from being sucked down the blast pipe from the smokebox.

The increased haulage capacity of a superheated steam locomotive is obtained by the use of large diameter cylinders, so that, with the corresponding heavier pistons and motion-work, pounding may be set up when running or drifting down a falling gradient. In this case the reversing lever should be put over to within one notch of the extreme end, thus forming a suitable air cushion in the cylinders and valve chests. Should the pounding continue, however, it will be necessary to open the regulator slightly, thus forming a cushion of steam for arresting the momentum of the piston and motion-work at the end of each stroke.

The temperature of the steam should be maintained as steady as possible, and under no circumstances should the amount of superheat allowable be exceeded. The efficiency of the engine increases with the degree of superheat, but should the temperature become excessive there will be the possibility of melting the gland packings, as these are subjected also to the frictional contact of the piston rods, and the lubricant used may lose its lubricating qualities. If, therefore, the superheater or cylinder metals are allowed to become overheated, it will be seen that gland packing troubles are likely to occur, or the pistons or valves will become seized or jammed because of the absence of suitable lubrication.

Should any undue vibration, groaning, or jerking in the valve gears or motion-work be observed, the reversing lever must be placed immediately in mid-gear until the irregularity is overcome. To prevent seizure between the highly heated valve and face metals or cylinder walls the lubrication should be increased by means of the handle on the oil pumps.

These irregularities, however, may be avoided when drifting down a falling gradient by slightly opening the regulator at such intervals as may be considered necessary, according to the particular conditions under which the engine is working.

After the return to the shed the fireman, when cleaning out the smokebox, should see that the superheater headers are properly brushed down, and the shed staff should see also that the flues containing the superheater elements are blown through frequently with the tube-cleaning apparatus provided.

The driver, in making his inspection, should examine the blast pipe top and base of chimney for traces of carbonised oil deposits, which would indicate an excessive supply of lubricant to the cylinders, and the stroke of the force pump or oil press should be adjusted accordingly. Spring safety or pressure relief valves often are fitted to the front and back cylinder covers for relieving excessive and dangerous compression in cases of priming or condensation troubles, and so on.

These relief valves are held in position by a spring and are adjusted by a screw, set to exert a pressure against the valve seat of several pounds above that of the initial working pressure in the cylinders. The inspection should include an examination of the adjusting screws and springs, to see that they are intact and in proper position.

If the cylinders are fitted with a by-pass arrangement, the levers connecting the cylinder cocks with the footplate gear should be overhauled to see that the rods and pins are in proper working order. As the efficiency of the snifting valves is dependent greatly on a free admission of air, it will be necessary to see also that the lift of the valves is adjusted properly, in addition to cleaning away any grit or foreign substance which may have been drawn in with the air when the valves have been in use.

In shedding the engine, it is important that the test cocks on the oil pipes should be closed, otherwise the condensation which usually occurs when the engine is cooling may fill the pipes with water, thereby interfering with the proper working of the oil pumps when starting out again.

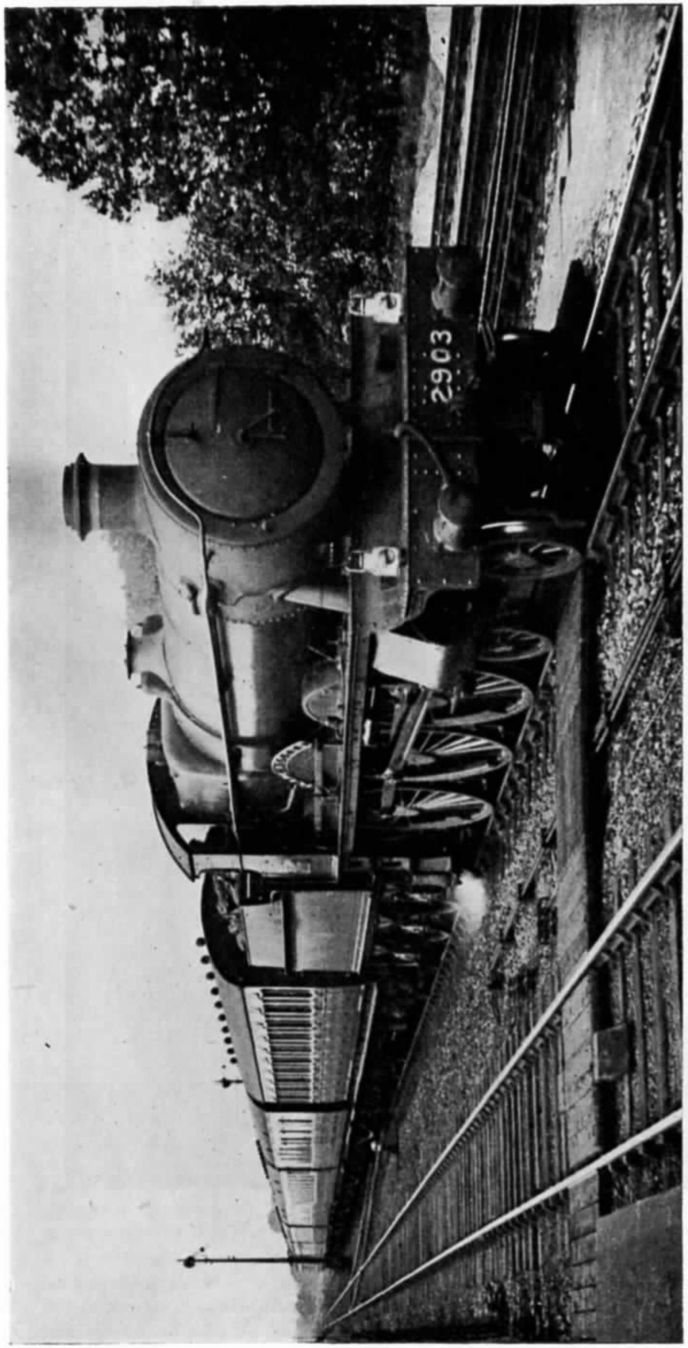


Fig. 176a.—Up West of England Express passing Taplow, G.W.R., hauled by 4-6-0 Locomotive No. 2903, *Lady of Lyons.*

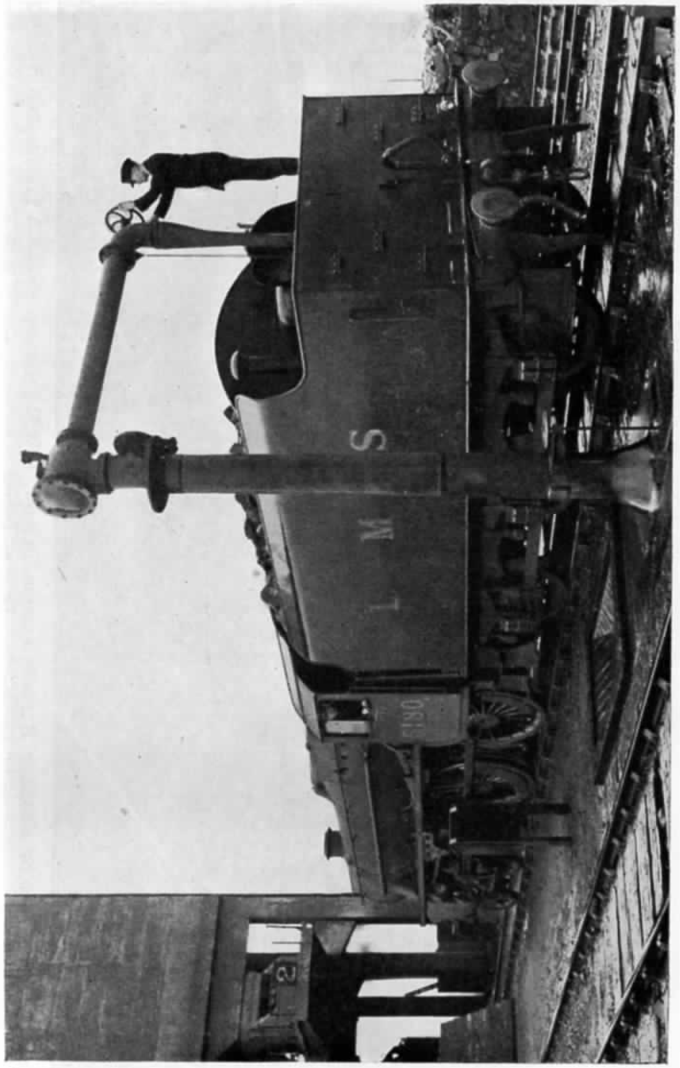


FIG. 177.—COALING AND WATERING A LOCOMOTIVE TENDER UNDER MODERN CONDITIONS.

CHAPTER 12

THE TENDER

THE tender is erected on its own framing, and is therefore a separate vehicle attached to the engine by the drawbar. It is designed with a water tank for the boiler-feed supply, and bunkers to carry the required amount of coal ; proper receptacles are provided also for the necessary tools, and lamps, and so on. The drawbar, which couples the engine to the tender, is made in the form of a long eyebolt ; the end containing the eye is connected to the engine by means of a strong pin 3 in. in dia. The straight end of the bar is usually about 4 in. in dia., and passes through the tender drag box ; it is secured by a 4-in. nut well tightened home, and kept in position by a split cotter.

The framing is made from steel plates about $\frac{7}{8}$ in. thick, which are straightened, slotted, and drilled as described for the engine frame plates. Cast steel hornplates, usually in the form of single angle plates, are riveted to the horns with $\frac{7}{8}$ in. dia. cold steel rivets, care being taken that they are fixed parallel, in order that the axleboxes, which are fitted afterwards, may work smoothly without any sign of jar or knock.

The spring brackets, which eventually support the whole weight of the tender when attached to the bearing springs, also are riveted to the main frame plates. Angle irons about 6 in.$\times$3 in.$\times\frac{3}{4}$ in. section are riveted to the top edge of the framing, and extend the full length of the tender to form a base for the water tank. The frame plates, placed on edge, then are set square and parallel to each other to the required gauge, and are held in position at the front end by the box front plate, which is securely fastened to the frames by angle irons riveted to the framing ends.

The back or trailing buffer plate is secured in a similar manner ; the drawbar, which passes through the centre of the plate, is held by suitable springs or strong rubber pads about 6 in. in thickness. The middle parts of the frame plates are stayed by strong tee-irons, which are fitted from side to side midway between each of the leading, middle, and trailing wheels. An inside framing made from iron or mild steel plates about 12 in.$\times\frac{1}{2}$ in. sometimes is fitted the full length of the tender, about 9 or 10 in. from the outer framing. The inside frame plates are secured to the outer plates by box brackets and are finished at the top with angle irons which give additional support to the tank bottom. The back plate, which forms the drag box, is fixed about 3 ft. or 3 ft. 6 in. behind the front drag box plate, and is secured by angle irons to the outside framing. The automatic, or the steam brake cylinder, whichever is adopted, is attached to the underside of this plate, and the brake-shaft, which passes transversely across the framing, is held by brackets secured to the outer frames by $\frac{3}{4}$ in. dia. cold steel rivets.

The diameter of the wheels varies from 3 ft. to 4 ft. in the different designs of tender. They are made usually with cast steel centres and rolled steel tyres; the process of manufacture is invariably as described for the engine wheels. The axle boxes, generally in the form of an iron or steel casting, are so designed that the brass bearing fitted therein may be withdrawn for repairs or renewal, when relieved of the weight of the tender The axle journals are about 6 in. dia. by 10 in. long, and are lubricated in different ways, as by ordinary worsted trimmings, or from an oil well contained in the bottom of the axleboxes. The latter method is perhaps the most efficient; a pad of cotton waste or some such material is packed inside the oil wells, thus retaining the oil, which is thereby continually lubricating the journals. Special arrangements, such as leather or metal rings, are fitted to prevent the escape of oil from the back of the boxes, and for keeping out dirt or grit, when the engine is running.

The bearing springs are of the laminated type, consisting of about ten to fourteen plates, which are held together by a buckle. Slide flange friction is reduced as much as possible by fitting a loose sliding shoe on top of the middle axleboxes, and also by giving the boxes a small amount of side play.

The tank bottom, which also forms the tender footplate, is made from mild steel plate $\frac{3}{8}$ in. thick, and is secured to the framing and to the angle irons, which are fixed the full length of the tender. The tank sides, which are made from $\frac{1}{4}$ in. or $\frac{5}{16}$ in. plate, have a large flat area, and therefore are strengthened suitably with internal gusset or plate stays to withstand the heavy rush of water that takes place when running over rough portions of the road.

The tenders of what may be termed modern British locomotives are built with coal capacities of from 4 tons to as much as 10 tons, and water capacities of from 3,500 gal. to 5,000 gal. A cornice or coal guard is fitted along the top of the sides and back of the tender to prevent the coal falling on to the road.

A tool box with sliding doors is formed often on the front of the tank immediately over the coal bunker, and is fitted with locking arrangements enabling the tools to be left secure when the enginemen come off duty. When not provided in this manner separate tool boxes are placed in convenient positions on the top of the tank.

For filling the tank with water an aperture fitted with a lid is formed in the top of the tank about 4 ft. from the trailing end. The dead load attached to the engine is considerably increased by this large body of water. Seeing that 4 tons of average coal will approximately evaporate over 30 tons of water, it is obvious that a reduction in the weight of water carried is of the greatest importance.

By the adoption of the water pick-up apparatus the dead load may be lessened greatly by reducing the size of the tank, and long runs may be made without the loss of time that occurs when having to stop at a column for water. The apparatus consists of a hinged scoop, which may be lowered by the enginemen when passing over the water trough. These troughs are usually about 17 in. or 18 in. wide by 6 in. deep and are fixed

between the rails. A pipe casting in the form of a bend is fixed to face the leading end of the engine, and secured by a flange about 15 in. diameter to the underside of the tank bottom.

The scoop is fitted with a hinged joint to the lower end of this pipe, and is connected by rods to a screw actuated by a hand wheel which is fitted upon the front of the tank for lowering, and to a steam cylinder or other device to give assistance when raising the scoop from the water. A vertical pipe is fixed inside the tank having a flange similar to the pipe below, and is secured by eight $\frac{3}{4}$-in. bolts which pass through both flanges and the tank bottom. The internal pipe is made in different forms, and may be curved at the top to throw the water downward, or may be a plain vertical pipe tapering to a larger diameter at the top than the bottom, with the discharge end about 7 in. above the water level when the tank is full. In the latter case a guard is fixed above the pipe to check the velocity of the water, which thus falls back into the tank; an overflow is provided also to prevent the tender top becoming flooded.

The scoop is about 10 in. wide, and dips from $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. into the water when in its lowest position, with sufficient clearance thus provided between the scoop and trough bottom to allow for wear of tyres and springs. The normal water level in the trough is maintained automatically by suitable valves or pumps, and the length of the trough is determined by the amount of water required or the available water supply—500 yds. is about the average, although troughs up to 600 yds. in length are in use. The troughs are fixed at a level and straight length of the line, and are located as far as circumstances will permit to supply the most suitable water for boiler-feed purposes at economical rates.

The above may be regarded as a general description of the mechanism and methods of use, but the details vary in design and operation on different locomotives and railways. Reference to the drawing on p. 282 shows the arrangement of the water pick-up apparatus on the latest streamlined engines of the L.M.S.R., and these tenders are fitted also with the device known as a "coal pusher." This is steam-operated, and its action ensures that a sufficiency of coal will be at hand always in the front end of the tender and available immediately for the fireman to shovel. In some cases locomotive tenders are fitted with roller-bearing axleboxes and in others with axleboxes designed for improved methods of lubrication, such, for instance, as the Isothermos, and the foregoing description of the tender as a whole refers more specifically to the design and construction of what may be termed "ordinary" standards without reference to the latest developments.

The speed of the train imparts the force necessary for lifting the water into the tank, and it will be found that from 15 to 20 m.p.h. must be attained before the water can be raised to the required height. At a speed of from 22 to 25 m.p.h., with a dip of 2 in., considerably over 2,000 gal. may be lifted into the tank when passing over a trough of average length, the quantity of water raised, however, remaining practically the same for any higher speed. Considerable resistance is exerted against the scoop as it moves through the inert body of water, and for

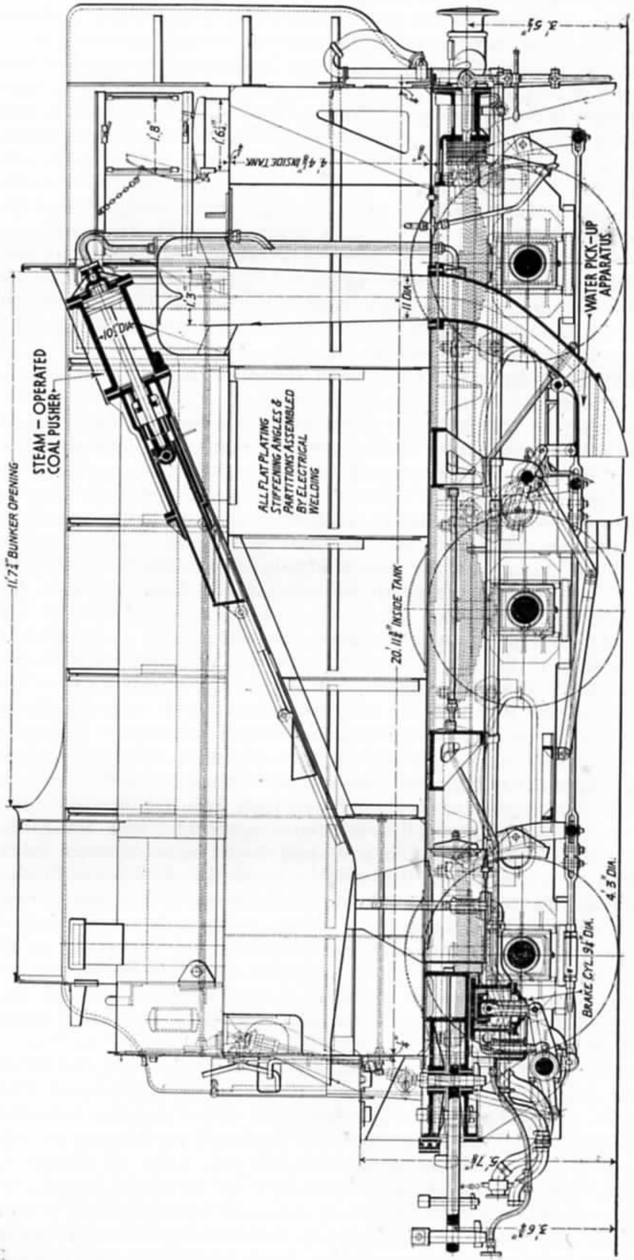


Fig. 178.—Tender of L.M.S.R. 4-6-2 Type Streamlined Express Locomotive fitted with Water Pick-Up Apparatus and Steam-Operated Coal Pusher.

this reason additional power is required to raise it; hence the necessity for steam or vacuum cylinders to assist when lifting the scoop into its normal running position. Drawbar pull diagrams show that the resistance of the water under certain conditions may be sufficient to absorb all the pulling power of the engine while it passes over the troughs with the scoop down.

The importance of accurately knowing the amount of water in the tender tank for boiler-feed purposes already has been mentioned, and various types of water-level indicators are in use on locomotives, these incorporating a gauge from which the fluctuations of the water in the tender readily can be seen.

The feed water is taken from the tender tank to the engine through these flexible hose feed pipes, which allow of disconnection when the tender is uncoupled from the engine for repair or other purposes. W. H. Willcox & Co. Ltd. is the maker of the "Jones-Willcox" patent wire-bound hose which, by reason of containing no rubber in its composition, will not perish, and is suitable for service in countries having hot climates.

In many countries where oil is more abundant than coal, or the latter is of very inferior quality, oil is used as fuel in place of coal. It has among its advantages that of making the fireman's work much less arduous, and more rapid combustion is possible. The apparatus used for feeding the fuel to the firebox varies in point of detail, but burners and atomisers are used in all cases. British experience with oil-fired locomotives dates from 1893 when James Holden, Locomotive Superintendent of the former Great Eastern Railway, designed the first British oil-burning locomotive. In the coal strikes of 1912, 1921, and 1926 the British railways introduced some oil-fired locomotives, mainly on the Holden and Scarab systems. The acute coal shortage in this country after the 1939-45 war, however, brought about the conversion to oil-burning of more than a thousand British main-line steam locomotives of all classes.

Admixtures of liquid and solid fuel also are used, and are known in some cases as colloidal fuel, experiments with which were made some years ago on the then Great Central Railway. "Briquettes" made up of fine powdered coal and liquid residues are used freely in many countries. Large numbers of locomotives are fitted with oil-fuel burning apparatus in the United States and elsewhere.

When trains are scheduled to run long distances without a stop, thereby making it impossible to change the engine *en route*, the difficulty has to be met of providing reliefs for the enginemen. This has been overcome on the L.N.E.R. by adopting what are known as "corridor" tenders, the tender having a corridor similar to that in a passenger coach, through which the relief enginemen can pass to and from the footplate. This was introduced when the L.N.E.R. adopted non-stop running between London (Kings Cross) and Edinburgh (Waverley), and has overcome what otherwise would have been an insuperable difficulty. It is illustrated in Fig. 179.

The locomotive water crane is a traditional item of railway equipment and is available in a range of standard designs to suit a variety of circumstances. The crane, as a rule, has a cast-iron pillar carrying a swivel arm and hose at a suitable height above

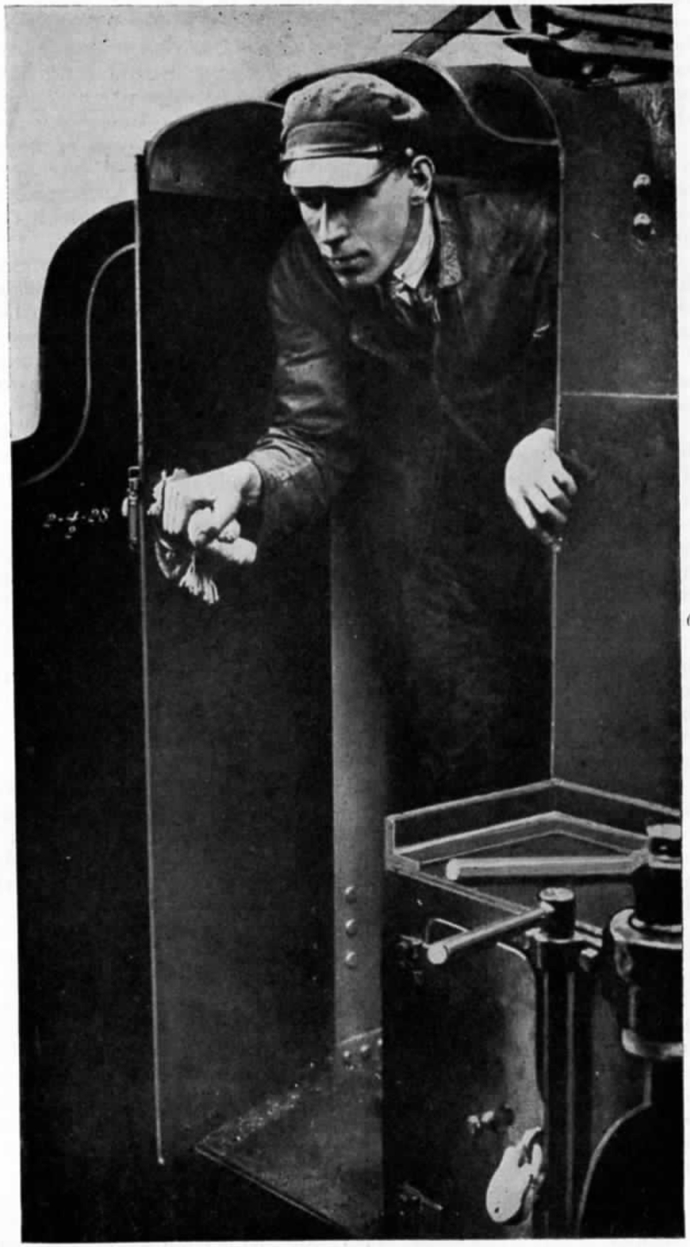


FIG. 179.—CORRIDOR TENDER, L.N.E.R. INTRODUCED TO ALLOW OF CHANGING ENGINEMEN DURING NON-STOP RUN, LONDON TO EDINBURGH.

the track. The swivel bend is provided with a roller which runs on an inclined circular track formed at the top of the pillar and so arranged that the arm will return automatically to a position parallel with the track after each locomotive filling operation.

The water supply is controlled by a sluice valve or by a balanced type hand-operated flow-regulating valve in the supply pipe leading to the pillar. In the example illustrated both valves are used; the sluice valve acts as a guard valve. The supply pipe usually is laid with sufficient cover to avoid risk of freezing in frosty weather. To supplement this precaution when frost hazards exist, it is desirable that water cranes should be fitted with an anti-freezing device which will drain the pillar down to the level of the control valve. This device takes the form of a drain cock or valve either operated by hand or working automatically. Several automatic types are available. The simplest is a small drain cock fitted in the body casting of the main valve and arranged to open as the valve approaches its seat, and to close whenever the main valve opens. An alternative automatic anti-freezing arrangement is to instal the pillar drain cock or valve with suitable actuating mechanism so that it remains closed whilst the swivel arm is over the track, but opens whenever the arm swings back parallel with the track.

When effective automatic anti-freezing devices are fitted for draining the pillars of water cranes, the necessity for open fires during frosty weather is avoided. Water cranes of the type illustrated are suitable wherever water can be supplied at the filling rates. Where a limited rate of flow only is available, a storage tank can be carried on the pillar, arranged to be replenished between locomotive filling operations. Units arranged on these lines are known as parachute water tanks.

Chemical injection pumps are a recent development, and are widely used where hard-water supplies require softening. A type of chemical proportioning apparatus used in softening plant is the hydrostat chemical pump. This is operated hydraulically and, injects into the water one or more chemical solutions exactly in proportion to the rate of flow.

FIG. 180.—GLENFIELD & KENNEDY WATER CRANE, WITH ANTI-FREEZING DEVICE.

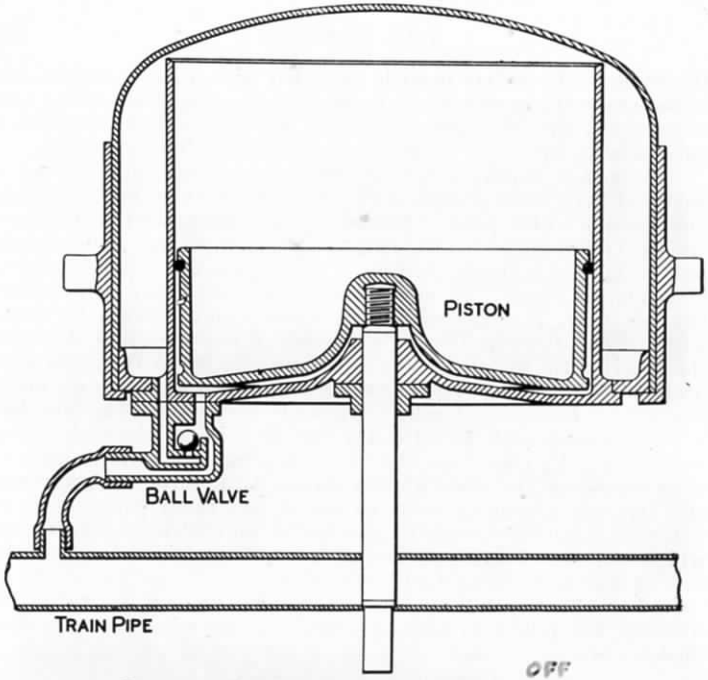


Fig. 181.—Automatic Vacuum Brake, "~~On.~~" OFF

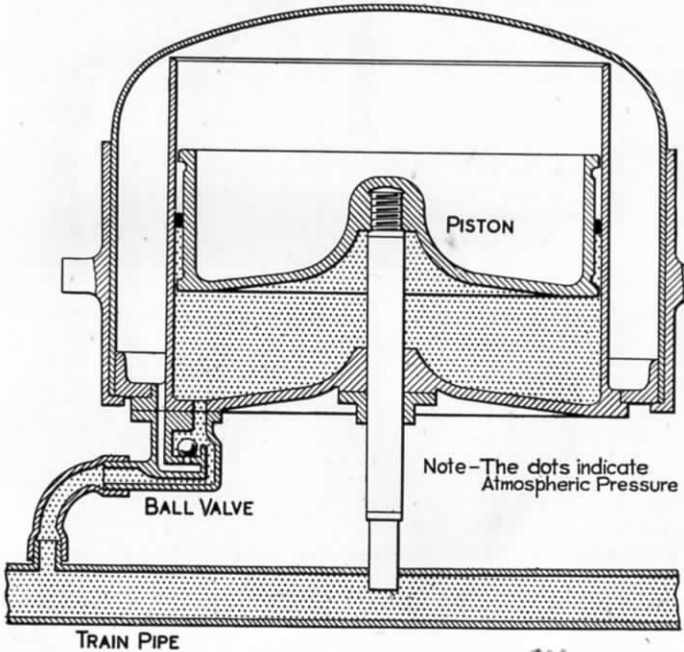


Fig. 182.—Automatic Vacuum Brake, "~~Off.~~" ON

Chapter 13

BRAKES

The safe working of a passenger train admittedly is dependent greatly on the reliability and efficiency of the brake power placed at the disposal of the driver. The momentum of a moving body increases with the weight and speed of that body, so that as these factors grow greater improvements in the brakes become imperative. The earliest forms of brake were generally of the hand-lever type, and therefore soon became obsolete. They were displaced gradually by more improved methods, until the increasing speed and length of trains brought about the introduction of brakes fitted to each of the separate vehicles. This innovation vastly augmented the brake power as compared with that limited to the engine and one or more vans.

Elaborate scientific experiments carried out by Sir Douglas Galton, George Westinghouse, and others definitely established the fact that the retarding power of a brake is greatly diminished when the wheels begin to skid on the rails. The adhesion of the wheels and the speed of the train therefore are the principal factors determining the total retarding power which may be exerted efficiently by the brakes. As the total retarding power that could be applied with the early brakes was proportional to the weight of the engine and brake vans only, it was considerably less than that obtained by utilising the friction of each vehicle, as with the continuous brake. Sanding the rails improves the adhesive capabilities of the wheels, thus increasing the retarding effect of the brake by diminishing the tendency to skid. At the higher speeds this liability to skid decreases, so that the effective brake power applied may be greater than at the lower speeds. When stopping a train quickly the maximum brake power first therefore should be applied carefully, and then gradually reduced as the speed diminishes. Various types of non-automatic brakes were at one time in used and different methods were adopted for obtaining the necessary brake power, such as by chains actuated with friction pulleys on the axles, steam pressure, air pressure, and vacuum, all of which in the earlier stages were non-automatic, so that when a breakaway occurred, or the parts became disconnected, the brake was rendered practically useless.

The air-pressure and vacuum brakes, as the most successful, were gradually improved, so that, when certain conditions appertaining to the public safety were demanded by Act of Parliament in 1889, the brakes as patented by the Westinghouse Brake Co. Ltd. and the automatic vacuum brake of Gresham & Craven Ltd. already were so far perfected as to comply with all the required conditions. These conditions were: (1) To provide continuous brakes for use on all trains carrying passengers. (2) The brake to be instantaneous in action and capable of being applied by engine driver and guard. (3) The brake must be self-applying in the event of any failure in the continuity of its action. (4) The brake must be capable of being applied to every vehicle of the train, whether carrying passengers or not. (5) The brake must be in regular use in the daily working. (6) The materials of the brake must be of a durable character and easily maintained and kept in order.

It will be seen that after these enactments became law non-automatic brakes for passenger traffic were a thing of the past, and also it will be understood readily that a large amount of ingenuity and persevering research must have been expended on the part of our leading engineers before a brake could be developed to comply with the stringent regulations as set down by the Board of Trade. The automatic vacuum and the Westinghouse brakes are practical illustrations of the survival of the fittest.

AUTOMATIC VACUUM BRAKE

In the automatic vacuum brake the power exerted by the brake blocks upon the wheels is obtained from the atmospheric pressure on a piston, working with the least possible friction in a cylinder, and transmitted by levers and brake rigging. The manner in which the pressure of the atmosphere is utilised and made to exercise the necessary force for retarding and arresting the momentum acquired by the train is best explained by a reference to the diagrams (Figs. 181 and 182) showing the pneumatic action of the vacuum brake in principle, whatever type of cylinder is employed. The illustration is actually of the "C" type, having an external combined ball and release valve.

The piston is an easy fit in the bore of the cylinder, and is kept airtight by means of a round flexible rubber ring known as the "rolling ring," which rolls between the piston and the cylinder walls without friction when the piston moves, lying undistorted in the "relieving groove" provided in the piston when in the "brake off" position. The piston rod attached to the piston is made of brass-coated steel, stainless steel, or other suitable material, and is maintained airtight by passing through a packing housed in the cover, known as the gland packing ring. This has the characteristic of being held firmly to the rod by atmospheric pressure outside when there is a state of vacuum inside the cylinder; this pressure is relieved when air is admitted to the cylinder, thus reducing the friction when movement is required. Air is extracted from the whole of the vacuum brake cylinder assembly through the train pipe *via* the hose pipe connection and valve, when both the top and bottom sides of the piston are in a state of partial vacuum. When air is admitted to the train pipe it flows through the connecting hose to the underside of the piston but is prevented, by means to be explained later, according to the type of cylinder, from reaching the top or chamber side of the cylinder.

The dark shading shown in the diagram indicates the air in the train pipe and cylinder, while the "top side" or chamber is still in a state of vacuum, so that the resulting difference in pressure forces the piston up. The actual power exerted is ·4913 lb. per sq. in., available on the under side of the piston. As the piston in all size cylinders is $\frac{3}{4}$ in. smaller in diameter than the bore of the cylinder, the actual area available is approximately that bounded by the cross-sectional centre line of the rolling ring; thus on a 21 in. cylinder the area available is approximately 334 sq. in. In calculating the ultimate force obtained from the cylinder the weight of the piston must be deducted; this varies from 50 to 100 lb. in different size cylinders.

Similarly with a carriage cylinder, where the top side is not connected to the ejector, as will be explained, the power of an application to 10 in. destruction in the train pipe, allowing that the vacuum in the chamber drops to 19 in. because of the piston stroke, will be $19-10=9$ in. effective vacuum, or $9 \times \cdot 4913$, which on the area of 334 sq. in. gives a pressure of 1,570 lb. approximately.

Hand release of the brakes on carriages is effected by means of the external ball or release valve which, when pulled manually, has the effect of connecting the top and bottom sides of the cylinder, so causing equalisation of pressure by the air flowing from the train pipe to the top side until the pressure is equal. It will be noted particularly that the air comes from the train pipe and not from the atmosphere outside, so that any failure of a ball or release valve does not mean a leak into the general system from the outer air, but only the particular cylinder concerned out of action.

Rolling ring cylinders are made in standard sizes ranging from 10 to 30 in.; the normal broad gauge sizes are 15, 18, 21, and 24 in. In any type of cylinder the top side of the piston must have sufficient volume above it to ensure that the stroke of the piston does not reduce unduly the effective vacuum above the piston. It will be realised that a state of vacuum for brake conditions means a state of rarefaction of the air, and that starting with a defined volume at 21 in. above the piston and then reducing this volume or "compressing" this rarefied air, will result in reducing the "vacuum."

It is necessary, therefore, to use additional chamber volume to give sufficient "top side" volume to compensate for the stroke losses, and this is arranged either by a chamber casing embodied with and all round the cylinder, known as the "combined type," as shown in Figs. 181 and 182, or by a separate chamber connected by a hose pipe to the top side of the piston. In separate type cylinders the valve requires an additional branch to effect this connection, and in the case of engine or tender cylinders which have connection to the auxiliary pipe from the ejector, no manual release valve is necessary. The connections to train pipe and auxiliary pipe, therefore, are double branch hose, although ball or release valves still may be used, and the driver's release valve on the ejector is available for independent release of the cylinders.

Fig. 183 shows the general arrangement of connections on

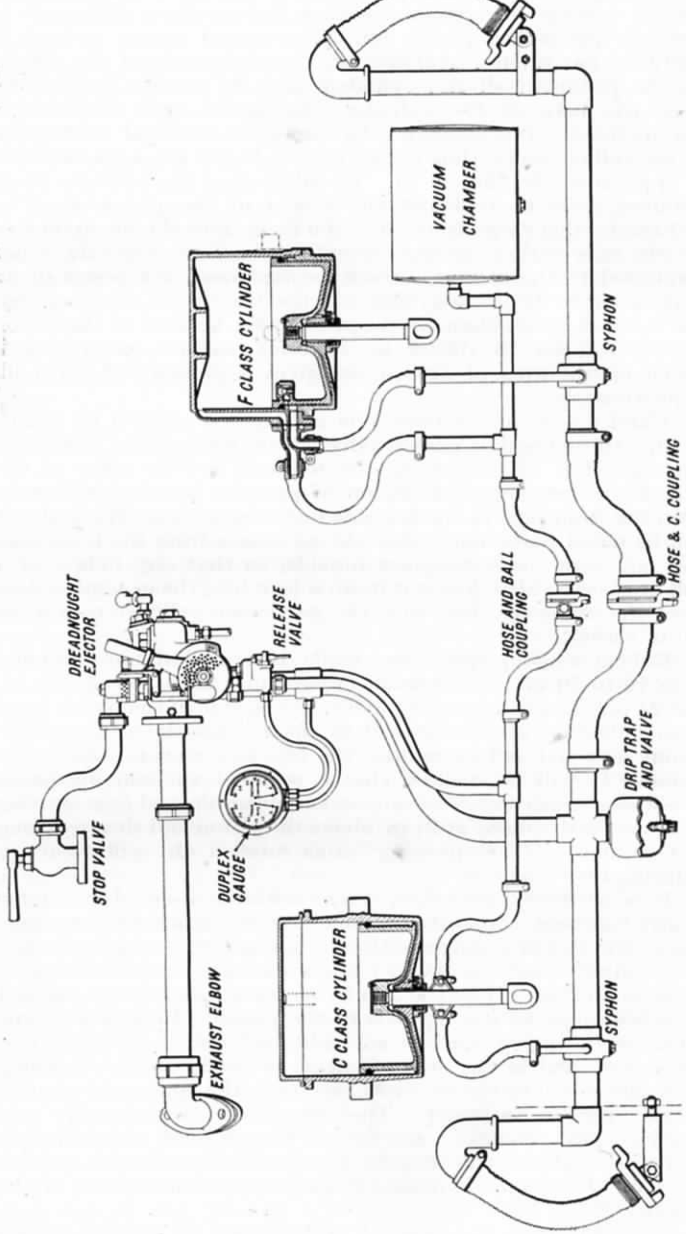


Fig. 183.—General Arrangement of Automatic Vacuum Brake applied to Engine and Tender.

an engine and tender. The driver's duplex vacuum gauge connects to the train pipe and the auxiliary pipe to the chambers respectively; the amount of destruction recorded in the train pipe by the admission of air through the driver's valve is a direct indication of the degree of power applied. In the "Full Brake On" position, the porting of the driver's valve gives a direct connection from the small ejector to the auxiliary pipe

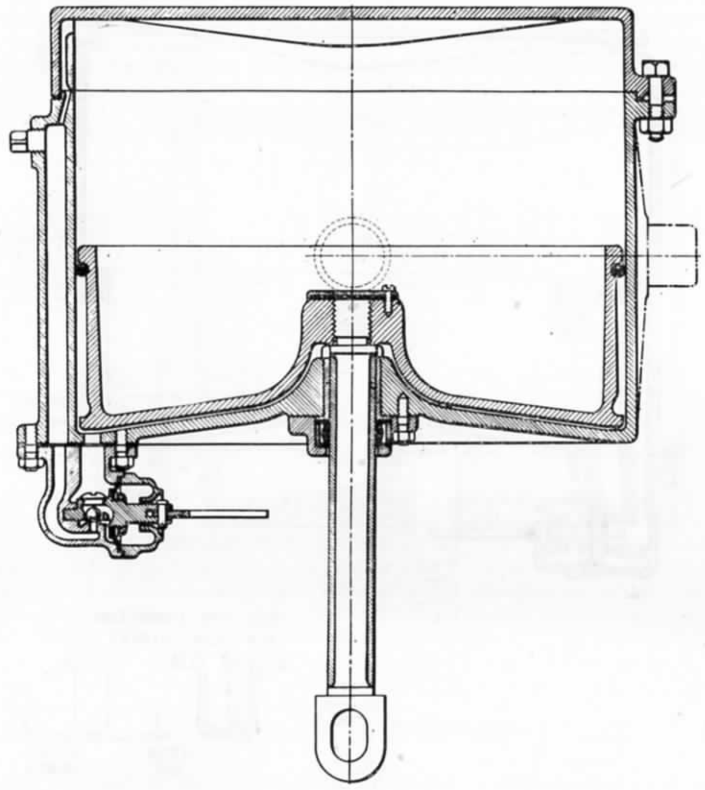


Fig. 184.—"C" Type Cylinder (Separate Pattern).

and the chambers, so that the full working vacuum is created and maintained on these cylinders, and any loss from piston movement is eliminated.

Fig. 184 shows a "C" type cylinder, the original rolling ring vacuum cylinder used throughout the world. The function of this type of cylinder is performed with an external ball valve, through which the chamber or top side is exhausted. On admission of air to the train pipe the ball seats and seals all connection to the chamber side, so isolating it. Hand release, as already described, displaces the ball from its seat, effecting equalisation and allowing the cylinder to fall off. The ball valve is fitted with a diaphragm, and re-creation of vacuum in the train pipe automatically draws in the spindle, allowing the ball to return to its seat and function in the ordinary manner.

The " E " type cylinder (Fig. 185) differs from and improves on the " C " type cylinder in the following respects :—

Air is extracted from the " top side " or chamber *via* three holes (*a*) drilled in the piston head below the rolling ring when in

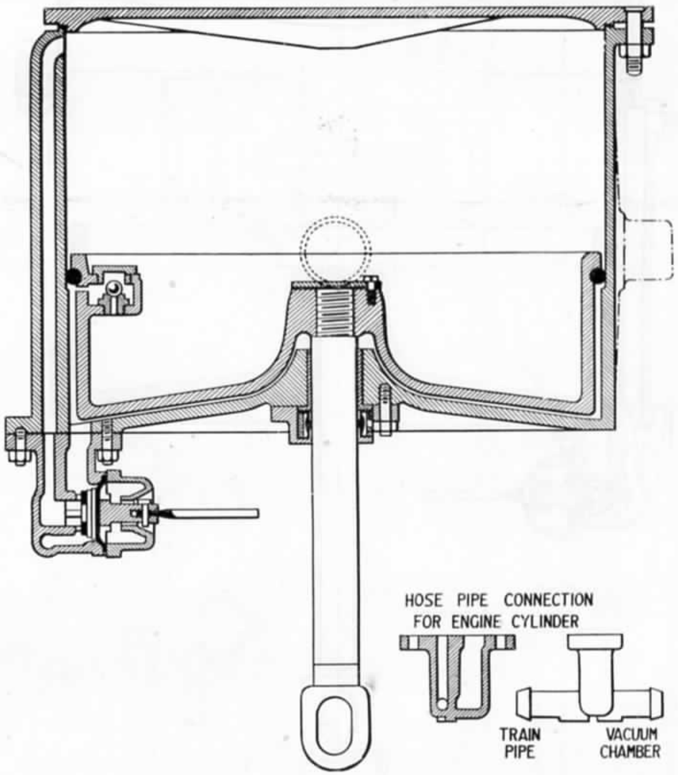


Fig. 185.—" E " Type Cylinder (Separate Pattern).

its relieving groove and thence past the internal ball valve located inside the piston head. The ball valve in the piston head only serves the purpose of isolating the chamber side momentarily until the piston has moved up sufficiently to get the rolling ring out of the groove, after which isolation of the chamber side is effected by the compressed rolling ring, which is a highly efficient seal. The power and endurance of the brake cylinder, accordingly, is not dependent on the seal of a ball on its seat. Hand release is effected by an external release valve, replacing the ball valve of the " C " type cylinder, which isolates the chamber side,

under normal conditions, by a rubber-seated valve loaded by the power of the diaphragm under atmospheric pressure.

" C " and " E " type cylinders are interchangeable as complete units and a " C " type cylinder can be converted readily to an " E " type cylinder by drilling the piston head and fitting a special small separate internal ball valve and substituting the standard external ball valve with a standard release valve. By this means cylinders and valves on any railway system can be standardised throughout at a minimum cost, and the advantages of the " E " type cylinder are obtained. The " F " type cylinder, shown in Fig. 186, has been designed to facilitate the examination

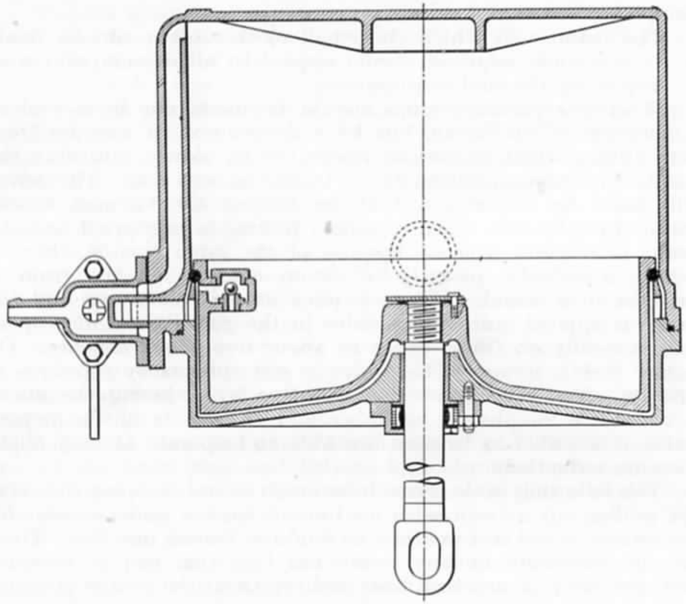


Fig. 186.—" F " Type Cylinder.

and renewal of the roller ring and is fitted with a new type of release valve or hose connector which is reversible. Its pneumatic action and function is exactly the same as that of the " E " type cylinder, but instead of a top cover there is a bottom pan enabling the piston to be removed from the cylinder without taking the body of the cylinder down. In the case of engines or tenders this is a great convenience, more particularly in all cases where heavy large-diameter cylinders are used.

Both cylinders and brake shafts move in their bearings, a fact which is frequently ignored. A great deal of trouble and brake defects can be avoided if these moving parts are given a chance and oiled or greased occasionally.

The Board of Trade requirements are complied with in a simple but effective manner by the vacuum automatic brake, It is instantaneous and capable of being applied by either driver or guard. The brake is also self-applying, because the severance of the train pipe, as by a vehicle becoming detached, will admit air and thus apply the brakes.

The brake train pipe is now the most approved means of providing passenger communication, and by the alarm cord in the carriages any passenger can admit sufficient air into the train pipes to attract the attention of the driver or guard. When communication is made in this manner the brake is not applied fully, so that if the alarm is given in a tunnel or some such inconvenient place, the driver, by opening the large ejector, is able to bring the train to the end of the tunnel or other convenient stopping place.

The manner in which the small ejector often can be made to do the work required should appeal to all drivers who wish to keep down the coal consumption.

Whenever possible, stops should be made not by a violent application of the brake, but by a destruction of vacuum from 5 to 10 in., which should be re-created by slowly returning the handle to running position as the train comes to rest. The driver will learn by experience that by having the vacuum nearly restored at the end, when stopping, jerking is prevented and the brake is released without the use of the large ejector, thereby saving a definite quantity of steam every time the train is brought to a stand. When a quick stop is necessary and the brake is applied quickly the valve in the guard's van also opens automatically on trains of up to about five or six coaches. On longer trains, however, the valve is not sufficiently sensitive to operate, or if it is made too sensitive by reducing the choke between the diaphragm chamber and the inside of the poppet valve it is liable to become unstable and operate at very slight vacuum reductions.

The following table gives the average actual stopping distances for pulling up a train with continuous brakes under reasonable conditions of rail and weather, as found in British practice. These do not constitute by any means the best that can be effected, but are based on practical tests and represent the results obtained with limited braking on the locomotive and with the losses in time incurred with normal equipment in the propagation of the brake power. Improvement in brake design, higher locomotive braking, and improved rapidity of application can be arranged in practice to give stopping distances of nearly half those shown in the average figures given.

Speed at Time of Brake Application	Distance to Stop
30 m.p.h.	175 yd.
40 ,,	310 ,,
50 ,,	485 ,,
60 ,,	700 ,,
80 ,,	1,250 ,,
90 ,,	1,575 ,,

It must be realised that the better stops visualised represent an approach to the maximum attainable, as any greater braking forces would tend only to skid the wheels and decrease the retarding force.

An example of the practical possibility of distance to pull up from 60 m.p.h. (with correct braking and rapid pneumatic generation of power) would be 350 yd.

As already mentioned with regard to stopping distances, it will be appreciated that at very high speeds especially, some measureable time elapses between the application of the brake and the full generation of continuous brake power, particularly on long trains.

Various types of " rapid acting valves " have been produced and used from time to time, but these, although effecting very rapid application of the brake, had the disadvantage of being uncontrollable, that is to say, they were self-acting, and if the first valve acted the other valves also opened and took the option to limit the application out of the driver's hands. Gresham & Craven Ltd. has developed an advanced design of direct admission valve for the Vacuum Brake Co., permitting great rapidity of action in a full service or emergency application, but leaving the degree of application and all full control still in the driver's hands.

It will be realised that the application of continuous brakes entails a change in pressure in the train pipe, which is dependent on the flow of air (whether the system is vacuum or compressed air) in and out of the pipe, so that operation at remote points is dependent entirely on the rapidity with which the working fluid can flow through the pipes. In the ordinary way, with a vacuum system, all the air for application has to be supplied from the driver's admission valve, plus additional air in emergency applications from the guard's van valve, and all such air has to fill the train pipe and fittings and also the cylinders under the pistons. It is this filling of the cylinders that sets the limit to the rapidity of application of air supplied through a 2-in. pipe from one point. On short or low speed trains this time is negligible, but on long trains or on trains travelling at very high speeds (100 m.p.h. or over) the time to admit the necessary air has an influence on the best stop that can be effected, when the use of direct admission valves ensures all the rapidity that can be safely given while retaining complete controllability.

The direct admission valve is arranged to operate by the action of the admission air passing from the driver's brake valve, which opens the direct admission valve independently to admit air to the vacuum cylinder direct from the atmosphere to a degree directly proportional to the condition of the train pipe. By this means the filling of the cylinders is effected by air taken all from the atmosphere and none from the train pipe, so that the air for brake application has only to fill the train pipe and is not required for cylinder application. The train pipe is of very small volume and is rapidly filled with air; in addition, therefore, to rapidity of operation the application of the cylinders is rendered more simultaneous instead of being progressive.

Fig. 187 shows the Gresham direct admission valve, the working of which is generally as follows. Air is extracted from the brake cylinder through the usual hose connector pipe *via* the non-return valve A direct from the train pipe. The lower extension spindle of the valve B is a clearance fit, so air is extracted also at the same time from the enclosed cavity above the diaphragm D. The whole valve is then balanced and in a state of working vacuum. On admission of air into the train pipe from the driver's brake handle the cavity below the diaphragm D is filled with air to a degree of vacuum equal to that of the train pipe, but air cannot get to the vacuum cylinder as the valve A seats with the air pressure above it.

A state of vacuum exists above the diaphragm D so that the

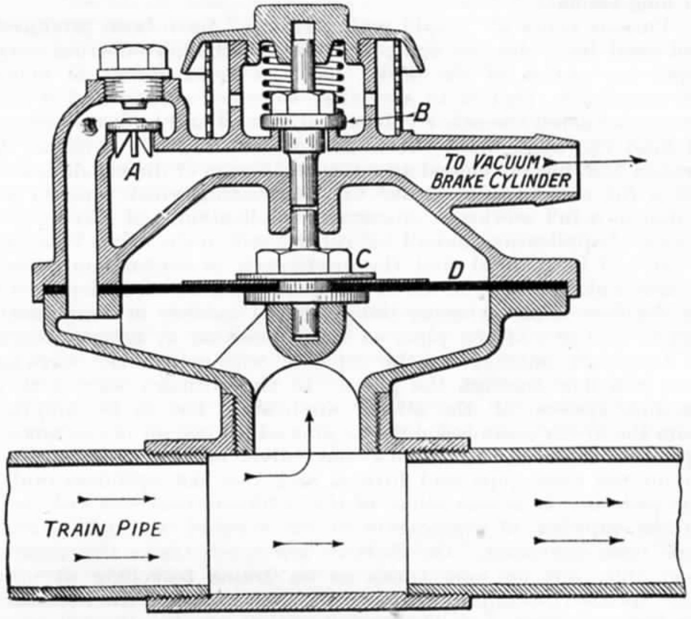


Fig. 187.—Gresham Direct Admission Valve.

pressure of the air admitted under it causes it to rise and the extension spindle on the diaphragm D marked C comes in contact with and lifts the valve B. This allows air to flow direct from the atmosphere (through an air filter surrounding the valve chamber) to the cylinder. Meanwhile, the air also finds its way slowly to the cavity above D *via* the clearance round the spindles of B and C until the pressure above and below the diaphragm is the same when the diaphragm depresses and allows valve B to close again. It will be seen from this action that the cylinder will have air admitted to it directly up to a point where the pressure in it is balanced by the pressure under the diaphragm, *i.e.*, train pipe pressure. Meanwhile the air for the cylinder operation has been provided from the outer air and not from the train pipe, so that the speed of operation, although graduated and controllable,

is materially increased as only the train pipe and the small cavities below the diaphragm have to be filled.

For very long trains such as fitted freight trains, a further type giving a double function is available. This is shown in Fig. 188, and has the additional feature that extra air also is fed to the train pipe itself by the action of the valves filling a long train pipe with additional air "inshots," ensuring that the train pipe is filled in the minimum time and giving great uniformity of cylinder operation with the same benefits of speed and controllability. The action of this valve as far as the

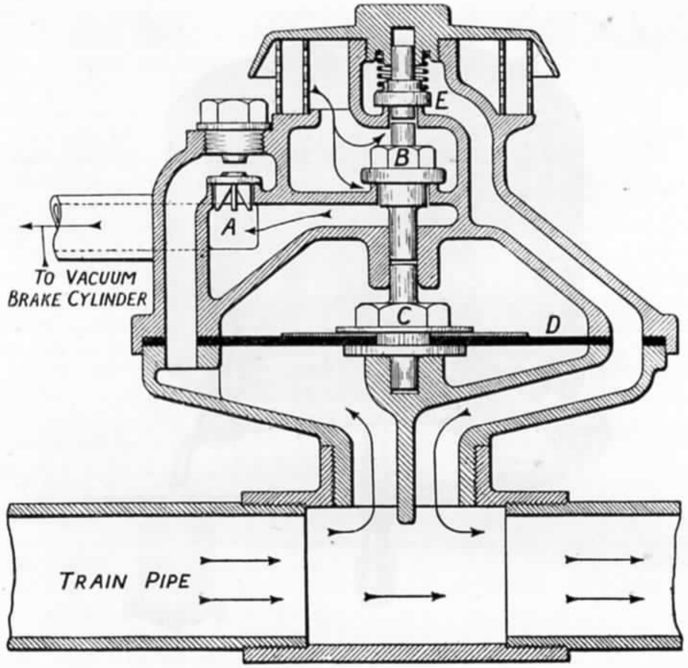


Fig. 188.—Gresham Combined Direct Admission Valve.

cylinder is concerned is as described in the ordinary direct admission valve, but, furthermore, the lifting of the direct admission valve, after admitting air to the cylinder, continues to rise and lifts valve E, giving a restricted admission of extra air direct to the train pipe.

The Westinghouse Brake Co. has developed a quick-service brake application valve, the operation of which depends on the difference in pressure between the brake pipe and the lower chamber of the cylinder. The valve is shown on a cylinder in Fig. 189, and in section in Fig. 190, with explanatory lettering, from which, together with the text, the construction and operation can be followed. When making a brake application, a reduction of the vacuum in the brake pipe made in the usual way causes the quick-service valve on each vehicle to effect a further local reduction in the brake pipe, thus increasing the speed of propagation throughout the brake pipe to an extent not otherwise possible. As each quick-service valve opens and lets air locally into the brake pipe, a separate stream of air is admitted at the same time to the brake cylinder. This stream of air bears a definite proportion to the volume admitted to the brake pipe through the ejector or driver's brake valve, and to the volume let into the brake pipe by the quick-service valve. Therefore, at all times the amount of air admitted into the brake

Fig. 189.—External View of Westinghouse Quick-Service Valve.

pipe and the cylinder is under the direct control of the driver, and does not depend on the uncertain factor of volume reservoirs with leakage chokes, as embodied on the various forms of vacuum rapid acting valves, heretofore used.

The port connections of the valve are shown in Fig. 190. During a brake application air enters the valve from the brake pipe through the valve nozzle B, and passes through port H into chamber G beneath the diaphragm L, causing the diaphragm to rise and unseat the ball K. Atmospheric air from the strainer and connection E then enters chamber Y, where it is divided into two streams, one stream of air passing direct to the brake pipe through port M and past valve V, and the other passing

to the brake cylinder through port Z, chamber A and port C. The chamber Y, from which this air is distributed to the brake pipe and the lower chamber of the cylinder, falls to atmospheric pressure immediately the atmospheric valve K opens, so that air at atmospheric pressure is delivered into both brake pipe and lower chamber of cylinder, irrespective of whether the valve is at the head or rear of the train.

To guard against the possibility of loss of brake force because of the strainer at atmospheric port E being choked by mud or dust, a special device is introduced into the valve whereby a by-pass valve D is unseated and air can flow from the brake pipe through B, past valve D, port N, chamber A, and port C, direct to the lower chamber of the brake cylinder, should the brake pipe vacuum drop more than a predetermined amount without atmospheric air entering chamber Y through ball valve K. The diameter of valve D is a little larger than the outside diameter of its seat, thus leaving an annular area subject to the degrees of vacuum in the brake pipe B.

When a reduction in brake pipe vacuum is made by the driver, the pressure on the annular area of valve D tends to lift valve D against the lower chamber vacuum in port M, but the stability of diaphragm L is arranged so that it lifts ball valve K and lets atmospheric air into M before the vacuum in B is sufficiently reduced to lift valve D. If, however, the strainer is choked, port M remains at lower chamber vacuum, and the decrease in vacuum in B acting on the annular area of valve D causes valve D to lift and brake pipe air flows through port N into the brake cylinder. Valve D lifts during each brake release and permits air to flow from the lower chamber to the brake pipe. This valve is arranged to provide a certain leak between the brake pipe and port M, and so to the brake cylinder.

The positive action of the valve permits of its operating satisfactorily should some vehicles be fitted with the existing type of ball or release valve, and some fitted with the quick-service brake valve. The quick-service propagation is effective if vehicles fitted with the quick-service valves are separated by vehicles fitted with " through pipe " only.

With the Westinghouse quick-service valve, a service brake application is obtainable at the rear of the train in about one-third of the time required with the standard vacuum brake.

The use of a brake application valve that lets air into the brake system underneath the coach makes it necessary to provide a suitable air strainer, and for this purpose a special design has been developed by the Westinghouse Company, as shown in Fig. 189. The strainer is coupled to the valve by a standard hose connection and clips, and for installation purposes a special fixing device is provided whereby the strainer can be suspended by a clip to the adjacent branch pipe connecting the cylinder with the brake pipe. This provision obviates the need for drilling holes for fixing bolts. The complete installation of the quick-service valve and the strainer requires only the use of a spanner.

It should be noted that the valve provides adequate safeguards against any conditions which may arise in service.

The valve, as already stated, is operated by the difference in vacuum between the brake pipe and the lower chamber of the brake cylinder; it has no operative connection to the upper chamber of the brake cylinder, and consequently does not endanger normal automatic action in the event of a breakaway.

Should the strainer become choked and atmospheric air thus be prevented from entering the cylinder through passage E, valve D (Fig. 190) will permit brake-pipe air to flow direct into the cylinder and apply the brake as with standard vacuum brake.

Valve D operates during application should the strainer become choked. As it operates also during each release of the brake, it is safeguarded thus against becoming inoperative.

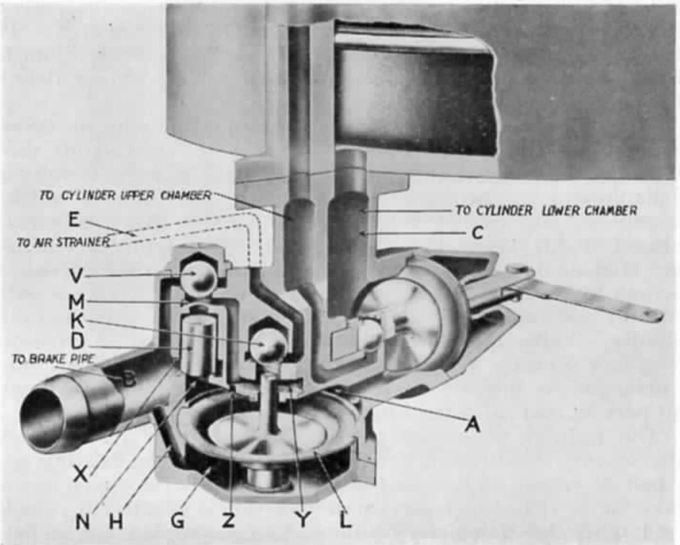


FIG. 190.—WESTINGHOUSE QUICK-SERVICE BRAKE APPLICATION VALVE SHOWN IN SECTION.

In the event of diaphragm L becoming punctured, this will allow free communication between the brake pipe and the lower chamber of the brake cylinder. Under this condition, when a brake application is made, it would be as with the standard vacuum brake; furthermore, in such a case, the defective valve will operate in application and release with other cylinders on the same train fitted with quick-service valves.

Although the valve is protected by an efficient strainer, should balls V and K in any particular valve not be tight, because of the pressure of dirt, the worst conditions which would arise would be that in the cylinder concerned the brake would be applied as with standard vacuum brake.

With the brake-van valve the operation of the valve depends on a difference in pressure between the brake pipe and a small capacity chamber on the top of the brake-van valve; this chamber is evacuated through a port way which runs through the spindle of the poppet valve in the van valve.

During a brake application this capacity chamber gradually becomes equalised with the brake pipe, and, as will readily be understood, if the brake pipe is gradually reduced, the chamber above the brake-van valve reduces at the same rate and the valve does not open. If the brake pipe is rapidly reduced, however, the reduction of the chamber above the valve, as it is at a slower rate, enables the poppet valve of this valve to open momentarily and allow a certain volume of air into the brake pipe.

The efficiency of braking apparatus on both locomotive and train is dependent largely on limiting the stroke of the piston to a minimum travel sufficient to give the required brake block clearance when the brake cylinder piston is in the release position. If, because of brake block wear, travel of the piston becomes excessive, it results in a considerable drop in the top chamber vacuum so that the brake force available to stop the train is reduced considerably. This is specially the case with the combined type cylinder, where a full stroke of the piston will reduce the top chamber vacuum from 20 to about 14 in., equal to a reduction of 30 per cent. in the theoretic brake force available. With separate type cylinders where a larger reservoir capacity is usually provided for the top chamber of the cylinder, the reduction is not so great. However, even in this case it is of the greatest importance to keep the piston stroke to a minimum, as in addition to the loss of brake force the brake release time is greatly increased when the piston stroke is too long. Further details concerning slack adjusters will be found on p. 335.

Continuity of the brake throughout a train is obtained by fitting one or more suitable brake cylinders on each separate vehicle and connecting up a continuous train pipe interconnected between vehicles with flexible hose pipes and quick couplings. The couplings are arranged to pull apart without tearing or break should the vehicles part from each other inadvertently. The vacuum in the train pipe operates every cylinder and is under direct control of the driver. A steam ejector connected to the train pipe is fitted on the engine and by means of the driver's application handle the air can be drawn out or admitted throughout the whole train.

The ejector, either a combination instrument with the jet cones and operating valves and mechanism all embodied in the one fitting, or alternatively, with the application valve as one fitting under the driver's control with the jets located at another place, is arranged to be supplied with dry steam from the boiler, preferably from the dome. It is provided with a steam stop valve controlling the steam supply so that the ejector cones or fittings are accessible for examination or renewal while the boiler is in steam.

Pumps of the double-acting plunger type are used also on steam locomotives as maintaining exhausters, enabling the small ejectors to be shut off when sufficient speed has been attained for the pump to operate as a maintaining ejector. These pumps require power to drive them, but it is considered that the steam used in the locomotive engine from which this extra power is obtained is used more economically than when used in an ejector for the same purpose, though the pump requires more attention and maintenance.

The first combination ejectors, products of Gresham & Craven Ltd. for the Vacuum Brake Co., have evolved successively through a range of types, of which the latest types, known as the "Dreadnought" and "Super-Dreadnought," are in extensive use and have largely replaced the former "B" and "C" class ejectors, although many of the latter are still giving useful service.

The drawing (Fig. 191) illustrates a "Dreadnought" combination ejector. The principle on which air ejectors work is by a jet of steam being discharged through nozzles to give a very high velocity, which, combined with the reduction of pressure of the steam by expansion to a pressure below atmospheric pressure, induces air in contact with the jet from the surrounding chamber, which is connected in turn with the train pipe, so extracting the air from the brake system.

The "Dreadnought" type of jet is an annular jet or "ring" jet, as distinct from a solid jet, and is formed by leading the steam between two concentric cones fitting one inside the other. Such an "annular" jet presents a large superficial area to the surrounding air to effect entrainment, as not only its outer surface but also its inner surface are open to cavities connected to the train pipe.

The outer cone or steam guide of the small ejector is 14, and 15 the inner cone, the steam passing through the narrow space between these two cones. The same action occurs in the large ejector, where the relative outer and inner cones are 13 and 17.

The small, or maintaining, ejector is continuously in operation and serves the purpose of maintaining against natural leakage into the train system. It uses from 4 to 6 lb. of steam per min. according to circumstances, which is so small a proportion of the steam used by the engine when working as to be negligible. Steam for the small ejector is regulated by the steam-valve handle 43 and should be open or closed to get the "best setting." The working of a steam jet is such that its best efficiency is at one steam pressure, and in effect is the act of regulating the steam valve throttling the steam supply to a constant pressure. If the pressure is very high and the valve were opened wide, too much steam would pass and the efficiency be impaired, because of choking.

The large, or creative, ejector gives additional extractive power for rapid initial creation of vacuum in the system or re-creation after an admission of air. Placing the driver's brake handle in the "brake off" position automatically opens the main large ejector steam valve 47 to supply steam to the large cones. Placing it in the "running" position closes the main steam valve and cuts off the large ejector. The small ejector is capable of effecting release but takes longer.

The disc valve is arranged so that in both the "brake off" and "running" positions direct communication is effected between the ejector jets and the train pipe while the ports to atmosphere are closed. In the "brake on" position the cavities leading to

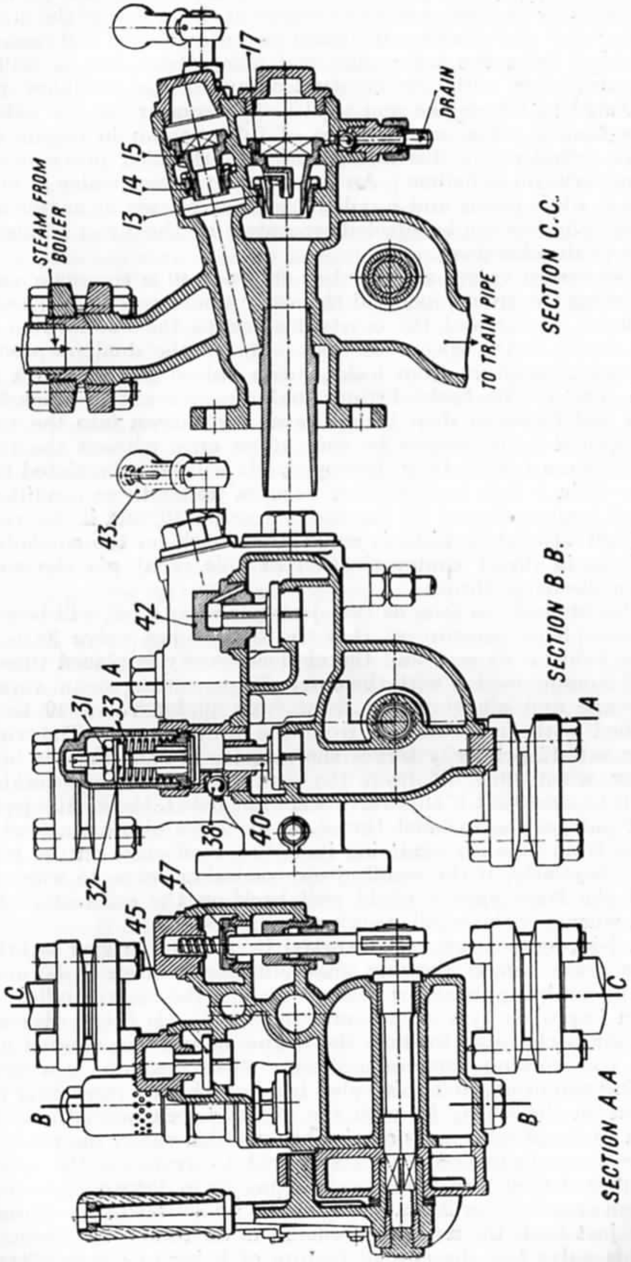


FIG. 191.—DETAILS OF "DREADNOUGHT" COMBINATION EJECTOR.

the train pipe are opened direct to atmosphere, so air flows to the train pipe in greater or lesser degree at the option of the driver. In the full " on " position the small ejector, which is still running, is cut off from the train pipe and atmosphere, but is still in communication with the cavity leading to the auxiliary pipe connected to the engine and tender chambers or the top side of the cylinders. The maintenance of full vacuum in engine and tender cylinders by this means has been detailed previously in the remarks on cylinders. An independent release valve is fitted between the ejector and auxiliary so that release of engine and tender cylinders can be effected separately by the direct admission of air to the chambers.

Non-return valves are fitted as shown; 40 is the main valve protecting the train pipe, and the valve under cap 42 is between the large ejector and the cavity leading to the main valve 40. This cavity is the special air lock, serving the dual purpose of preventing moisture from leaky steam valves getting down the train pipe to the brake fittings and also preventing smokebox gases and fumes or dust being drawn back down into the train pipe should both ejectors be shut off at once without the train pipe vacuum having been destroyed. It will be appreciated that if the train is left in a state of vacuum under these conditions, air will tend to flow to fill the vacuum under 40, and if this valve were not absolutely tight it could draw back on the smokebox, which is in direct communication at this point *via* the small ejector discharge throat.

This air lock, as soon as the ejectors are both off, will become at atmospheric pressure so that the ball or pea valve 38 is no longer held on its seat and the air lock cavity is placed thus in direct communication with the outer air, permitting steam vapour to escape and allowing any draw from under valve 40 to be supplied with free cold air from the atmosphere. The valve under cap 42 primarily serves the purpose of isolating the large ejector when shut off from the small ejector when working. It will be seen that if this valve were not fitted, the small ejector could pull on the exhaust throat of the large ejector instead of on the train pipe, so rendering its action ineffective on the train pipe. Similarly, if the small ejector isolating valve 45 were not fitted the large ejector could pull back on the exhaust of the small whenever the small ejector were not on.

A ¾-in. application valve worked by a finger trigger is fitted to the brake handle allowing small admissions of air to be made for light brake applications without moving the main handle.

An improved type of vacuum relief valve is fitted over the main air back valve to limit the degree of vacuum created and make the working vacuum uniform; 21-in. vacuum is a usual working condition, and this valve is adjustable by increasing the tension on the spring 33 with the nut and lock nut 32 and 31. When 21 in. of vacuum is attained under this valve, the pressure of the atmosphere above it is sufficient to overcome the spring and allow the valve to open, so admitting air to destroy any excess vacuum created over 21 in. There is set up a state of equilibrium which just feeds the necessary amount of air to effect balance.

This valve has the special feature of being of the pop type,

allowing full valve open and admission capacity immediately 21 in. is created. This is achieved by having two areas on the seating, the first opening to admit air pressure to the second, thus rapidly subjecting an increased area to pressure and fully overcoming the power of the spring.

The " Super-Dreadnought " ejector is identical in all essentials with the " Dreadnought "; the large ejectors are in every respect the same. Whereas the " Dreadnought " has one small ejector, the " Super-Dreadnought " is provided with two which can be used optionally with one or both on for maintaining purposes. By this means, while using only one ejector, a saving of steam can be effected with a short or well-maintained train, and when a longer or more leaky train is being worked, the additional maintaining ejector can be used, giving increased extractive capacity at the expense of slightly more steam.

The steam admission to these small ejectors is by the usual handle, the initial movement opening steam to one ejector and further movement opening both. Another feature is that instead of being opened to atmosphere by the ball valve falling from its seat, the air-lock arrangement is opened positively and mechanically by a cam extension on the small ejector handle which engages a seating valve. In shutting-off the small ejector on the " Super-Dreadnought " ejector it is important to confirm that the handle is right over to ensure that the air-lock valve has been opened by the cam, otherwise there will be a possibility of moisture getting into the brake fittings.

A new ejector of the solid jet type, termed the " S.J.," has been patented and produced by Gresham & Craven Ltd. for the Vacuum Brake Co., for those having a preference for this type of instrument, which is specially suitable also for very high pressure locomotives. This ejector is illustrated diagrammatically in Fig. 192.

In operation and function from the driver's point of view, it is identical with previous Gresham ejectors; it includes a small ejector handle which supplies steam from valve N at best setting to the small or maintaining ejector P. This draws air *via* back valve A and main valve C from the train pipe. The large or creative ejector Q is supplied with steam from the main valve F when the driver's handle is put in the " brake off " position by the cam G lifting the spindle of the valve F. Air is drawn by the large ejector *via* valve B and main valve C from the train pipe. The valves A and B isolate the large and small ejectors from each other respectively in the manner explained in the " Dreadnought " types.

The disc air admission valve, however, has been replaced by a lift type of valve. This valve, marked E, gives more than a full 2-in. bore admission, and is provided with an additional auxiliary admission valve D embodied in the main valve, all worked from the driver's main brake handle. Movement of the handle to the " brake on " position operates finger lift H and raises the spindle of the air valve, first opening the auxiliary valve D to give small admissions of air. This has the further effect of admitting some air under the main admission valve E, so partially putting it in balance. When, therefore, this also begins to lift, by the wings of the spindle projections contacting with E, very little effort is required to open the main valve, which has not to be opened against full vacuum, enabling small openings of the main valve to be made with the minimum of effort and the maximum of controllability. It will be realised that cams G and H are on the one common spindle operated by the driver's handle, but are separated in the diagrammatic projection.

In the absence of the porting arrangement on the disc type of valves, the isolation of the small ejector from the train pipe in the full " brake on " position is effected by the bell crank K

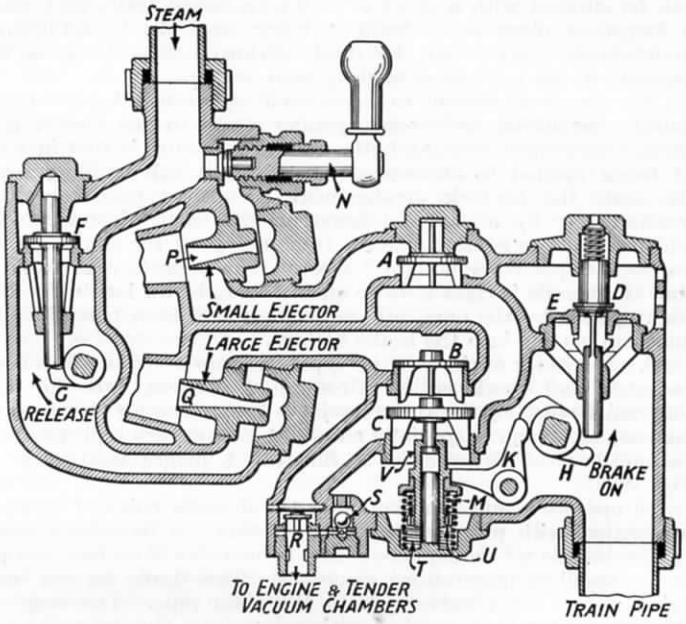


Fig. 192.—Diagrammatic View of " S.J." Ejector.

engaging with the back of the cam H. This pulls down the sleeve V against the spring M and shuts the main air valve C, thus effectively and positively cutting off the train pipe from the small ejector which remains on and pulls direct *via* valve A on the auxiliary pipe through the back valve R. The usual standard engine brake release valve, not shown on the diagram, is fitted below the valve R.

No relief valve is fitted on the ejector itself, but a standard relief valve is fitted at a suitable point on the train pipe at a slight distance from the ejector, so that the powerful local influence of the jets will not open the valve prematurely. To provide, however, for the limitation of the vacuum created on the top side of the engine and tender cylinders by the small ejector when the driver's

handle is in the full " brake on " position, the spring-loaded back valve C constitutes an internal relief valve.

The underside of the valve C is necessarily at atmospheric pressure when the valve is closed, as in this position the main air valve E must be open. When the small ejector has created 21-in. vacuum (or whatever the working vacuum may be) above the valve C, the atmospheric pressure under it is sufficient to overcome the spring M and allow the valve to lift and admit air to destroy the excess creation. The tension on this spring is adjustable readily by the tension nut U which is adjusted for the correct working vacuum. The usual ejector drain ball valves are provided, and a ball air-lock relief valve similar to the " Dreadnought " also is fitted on the side of the instrument.

The working positions are exactly the same as with previous ejectors, namely, " brake off," " running," and " brake on," the first and last coming to positive stops and the running position readily felt by the arm of crank K falling into the depression of the cam H. The particular features of interest in this ejector are that all seatings except valves A are readily renewable, and that the seatings and spindle guides for valves F and E also are removable as complete units, and renewed readily without any wear on the main body.

The operation of the air valve and the main steam valve is also unique, as these are worked by " lifters " and not mere cams, with the result that they are practically frictionless, have no side thrust on the spindles and no wear on the guides. The ejectors can be arranged for combined steam brake valves in the ordinary way and all parts are readily accessible.

The Metcalfe vacuum brake ejector (Figs. 193 and 194) is a new design of improved efficiency incorporating a compound arrangement of ejector nozzles which enables the instrument to create the necessary working vacuum in less time than any type of locomotive ejector hitherto available, without any corresponding increase in the steam consumption. The nozzles, which are of the solid jet type, and therefore free from excessive wear and furring up which takes place with the annular type nozzles, are arranged in the form of two separate ejectors (large and small) each delivering through an independent exhaust tube into the common exhaust pipe.

The small ejector is used continuously and maintains the vacuum in the brake pipe system, and the large ejector is used for obtaining a quick release after brake applications. Each ejector consists of a combination of steam nozzle, vacuum tube, and discharge tube, and these are so arranged that air is entrained at two points, the primary supply between the steam nozzle and the vacuum tube and the secondary supply at the opening between the vacuum tube and the discharge tube. This arrangement is found greatly to increase the efficiency of the ejector.

As this type of ejector is designed to work over a very wide range (a vacuum of 21 in. can be maintained with steam pressures of 50 lb. upwards), a steam-pressure regulator is fitted so that at the higher steam pressures the large ejector can be regulated. This ensures that the minimum quantity of steam necessary to create the desired vacuum at any given steam pressure is used, resulting in a greatly reduced steam consumption. The driver's control handle has the usual three principal positions, " brake off,"

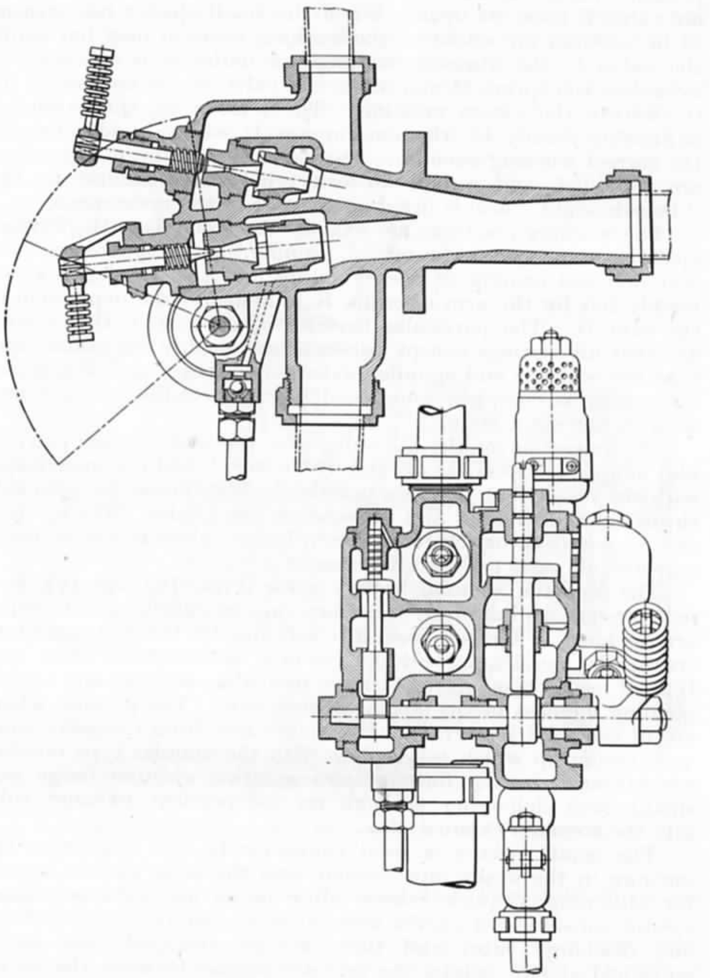


FIG. 193.—*Top:* SECTION THROUGH NOZZLES, STEAM, EXHAUST, AND TRAIN PIPES. *Bottom:* SECTION THROUGH STEAM AND AIR ADMISSION VALVES.

" running," and " brake on." When the driver's control handle is moved to the " brake off " position, a cam acts on the lower stem of the steam valve, opens it, and allows steam to pass from the upper into the lower valve chamber and so directly into the large ejector nozzle.

When the control handle is in the " running " and " brake on " positions the steam valve remains closed. When in the latter position, a cam acting on the lower stem of the air admission valve lifts this valve, so allowing air to pass freely from the atmosphere directly into the train pipe to apply the brake. This air valve is of the ordinary drop type and has been adopted in place of the usual rotating or disc valve in other ejectors with which air leakage is experienced frequently, and the cost of upkeep of which is heavy. With the drop type of valve, air leakage

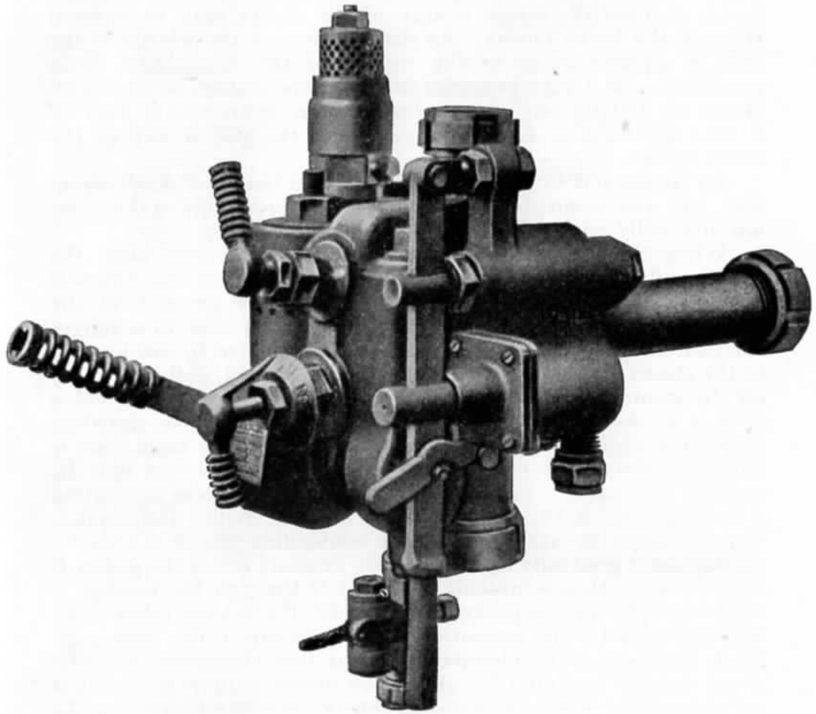


FIG. 194.—METCALFE VACUUM BRAKE EJECTOR FITTED WITH STEAM BRAKE VALVE.

is practically eliminated and under normal conditions no upkeep will be required.

As a steady and constant degree of vacuum must be maintained in the brake system, a relief valve is fitted to avoid any variation. This valve is so set that with any increase of the standard train vacuum, air is admitted to the train pipe system to prevent the vacuum rising above the predetermined figure. Driver's release valve and steam brake valves also are fitted to the ejector when required. The Metcalfe vacuum brake ejector is interchangeable with the existing standards.

STEAM BRAKE

Many engines and tenders are fitted with steam brakes, which can be worked in conjunction with the automatic brake upon the train, or used separately when the engine is running light or working goods trains. This type of brake is very simple; the power is obtained by admitting steam at boiler pressure behind a piston contained in a cylinder about 10 in. dia. placed below the footplate. The piston rod is connected to the brake levers so that the whole energy of the steam may be exerted through the brake blocks. As the adhesion of the wheels to the rails is proportionate to the weight of the locomotive, it is possible to use a very powerful brake on the engine, so that with steam at 180 lb. per sq. in. pressure an approximate load of 6 tons is available for transmission by the piston rod to the brake levers.

By Gresham & Craven's automatic steam brake valve, shown in Fig. 195, the steam brake is applied on the engine and tender automatically with the vacuum brake as follows:—

When the ejector creates a vacuum in the train pipe, the chamber *A* on the inner side of the vacuum or controlling piston *B* also is exhausted through the port *C*, and the pressure of the atmosphere which is exerted against the outer side thus moves the piston inwards. This movement is transmitted by the lever *D* to the steam piston *E*, which is fixed upon its seat, and thus shuts off the steam supply to the brake cylinder at *F*, when the valve is then in the off or running position, as shown in the drawing. When the vacuum brake is applied, the air in the train pipe is admitted also to the chamber *A* through the small feed hole *H*, and the ball valve *G* is closed by the rush of air, thus preventing a sudden application of the brakes on the engine and tender. The pressures on either side of the controlling piston *B* thereby are equalised gradually until the steam pressure forces the piston *E* from its seat, thus admitting steam at *O* through the passage *J* to the cylinder and applying the brakes. The release takes place automatically by the recreation of the vacuum in the train pipe again exhausting the chamber *A* as at first described, and the steam supply is shut off. After the steam supply is closed a certain amount will be retained in the cylinder and connection *J*; this is passed through the exhaust port *K* and on through the port L, which is in communication with the exhaust barrel of the combination ejector through the hole *M*, when the valve is again in its running position.

The piston *E* is so formed that when open for steam at *O* the exhaust port at *K* is closed and the steam in passing to the brake cylinder is in contact with the top side of the piston at N, the effective area of which is equal to that of the end *O*, thus putting the piston in equilibrium so that its movement is easily controlled by the varying amount of vacuum in the train pipe and chamber *A*. The application of the steam is thereby proportionate to that made by the vacuum brake. The diagonal passage *P* prevents the accumulation of pressure on the side of the piston *Q* because of leakage, which would disturb the

equilibrium. When the ejector is closed the steam valve is maintained shut by the trigger *R* being hooked over the pin. It is so arranged that it is impossible for the trigger to hold the lever *D* when a vacuum is created in the chamber *A*.

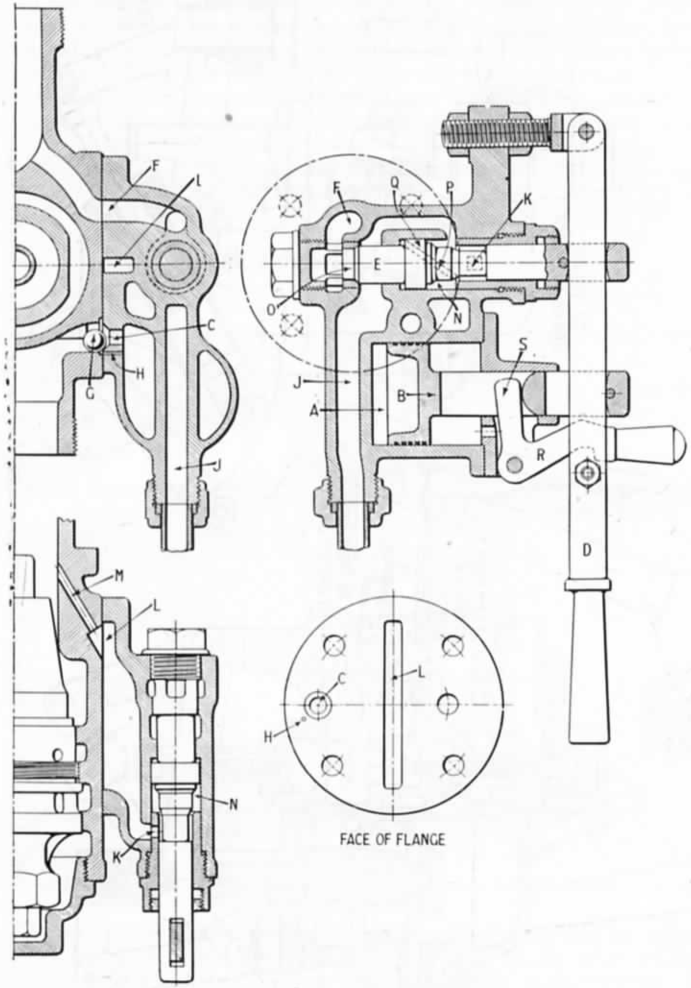


Fig. 195.—Gresham & Craven Automatic Steam Brake Valve.

It will be observed that the action of hooking the lever pulls out the piston *B* by means of the catch *S*; when the vacuum is created the piston is forced back and, pressing on the catch, unhooks the trigger, and the lever is then free.

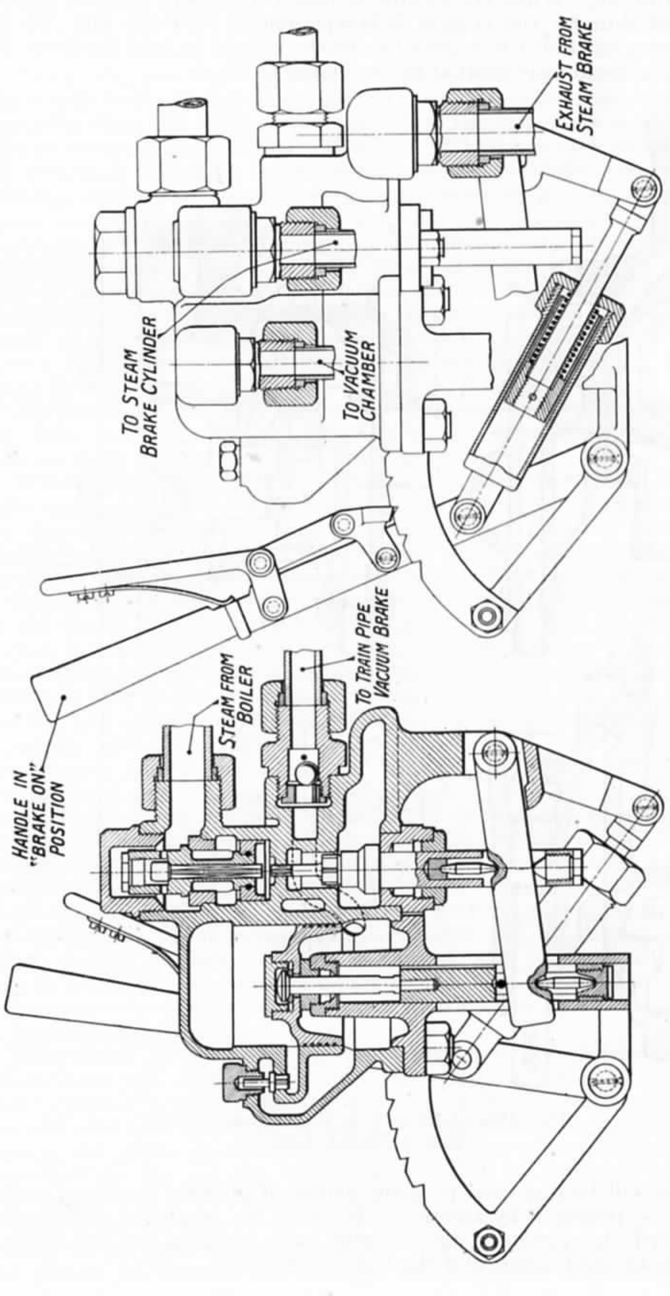


Fig. 196.—Gresham & Craven Graduable and Automatic Steam Brake Valve.

From the foregoing will be evident the important duty of the vacuum piston, sometimes called the air piston, in controlling the admission or exhaustion of steam to and from the brake cylinder, and every care therefore should be taken to maintain it in the best possible working condition. Seeing that the piston is easy of access, it should be taken out for examination from time to time, and cleaned with a cloth and lubricated before replacing. It is also important that the steam piston and seat in the brake valve should be maintained steamtight, otherwise a constant blow, because of steam leakage, will take place through

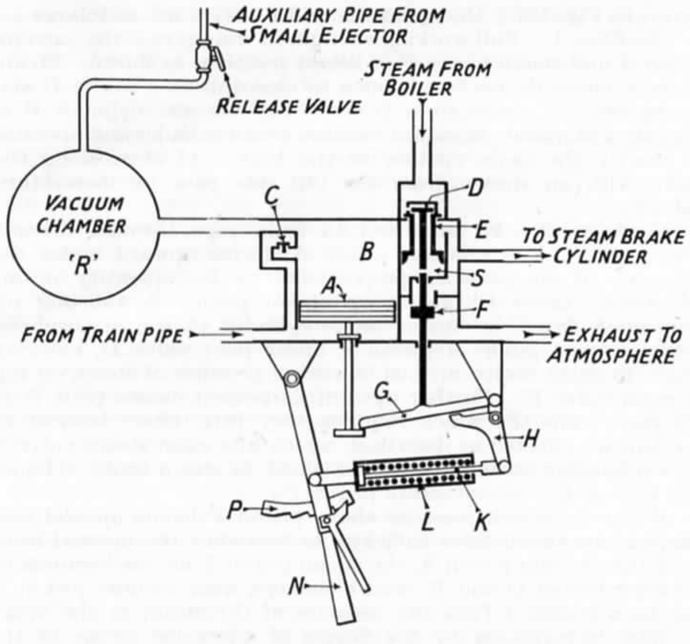


Fig. 197.—Diagram of Graduable and Automatic Steam Brake Valve Mechanism.

the exhaust port, which is open always when the piston is on its seat.

When a new piston or seating is fitted, care should be taken to ensure that the piston is a proper length, to give a full opening at the exhaust passage with the piston upon its seat. If the exhaust passage is allowed to become throttled some resistance may be offered to the release of steam, thus causing the brake blocks to rub on the wheels. The ball G placed between the two ejector faces should be examined occasionally, as any obstruction would affect the creating or the destroying of the vacuum.

The automatic steam-brake valve illustrated and described, although still largely used, has the limitation that absolutely synchronous graduation of the pressure of the steam brake with the pressure of the vacuum brake is not effected under all conditions, particularly after wear and usage have occurred.

Gresham & Craven's graduable automatic steam brake valve, manufactured for and supplied by the Vacuum Brake Co. Ltd., now has been patented and is in extensive use. It has the exclusive feature of ensuring synchronous action of the two brakes (steam and vacuum), whether in application or release.

It can be arranged for direct attachment to the ejector or as a separate piped fitting, and Fig. 196 shows the graduable steam brake valve in section. For clarity of description this arrangement has been reproduced in diagrammatic form, as shown in Fig. 197 ; the operation and function are as follows :—

Condition 1.—Full working vacuum in train pipe : the vacuum piston A and steam piston F in lowest position, as shown. Steam brake cylinder connection is open to atmosphere. Valves D and E are shut to steam from boiler. The vacuum cylinder B is actually a miniature standard vacuum brake cylinder and operates in exactly the same manner as the brake cylinders along the train, with air drawn from the top side past the non-return valve C.

Condition 2.—Air admitted to train pipe through driver's brake valve. The vacuum piston A moves upward under the influence of air pressure proportional to the quantity of air admitted. Lever G pushes up steam piston F, shutting off connection from the steam brake cylinder to the atmosphere. Top extension guide of piston F opens pilot valve D, allowing steam to enter cavity S, thus balancing pressure of steam on top of main valve E. Further upward movement causes pilot D to lift main valve E, which requires very little effort because of the balance effected as described, which lifts main steam valve E thus admitting steam from boiler direct to steam brake cylinder and also on top side of steam piston F.

When the steam pressure above piston F builds up and produces a downward force sufficient to overcome the upward force from the vacuum piston A, the steam piston F moves downwards, shutting valves D and E until a balance with vacuum piston A has been struck. Thus the pressure of the steam in the brake cylinder is regulated by the degree of admission of air to the train pipe, so the steam brake goes on and comes off with a force truly proportional to the train pipe vacuum at any moment. It will be seen particularly that the action begins as soon as any air is admitted and not after a certain degree of vacuum has been destroyed in the train pipe.

The initial admission of air to piston A of the miniature vacuum cylinder B is damped out by the provision of a separate ball in the connection to the train pipe, which allows air to be drawn out full bore, but the ball seats on the admission of air and the air has to reach the piston through a small restricting hole. This is effected so that the local admission of air may have time to put on the vehicle cylinders synchronously with the movement of the piston F.

Hand Operation.—The movement of handle N to first notch of sector plate P compresses spring L, and by means of spindle K and bell crank H acts on lever G as before. Steam piston F is now balanced against spring L instead of against vacuum piston A. Further movement to second or other notches increases the load in the spring L and consequently alters the pressure in the steam brake cylinder in direct proportion.

The hand lever accordingly can be put in a notch and left there, when the steam brakes will be held on with a corresponding force. For instance, in the first notch, if going down a long bank, the brakes will remain on with one quarter of the maximum available power and so on *pro rata*.

THE WESTINGHOUSE AUTOMATIC BRAKE

The Westinghouse automatic brake is continuous throughout the train and is operated by compressed air from a pump and stored in the main reservoir on the engine. This compressed air is fed by a driver's brake valve into the train pipe and past triple valves to an auxiliary reservoir on each vehicle.

The brake is applied by reducing the pressure in the train pipe, which causes the pistons of the triple valve to move and permit some of the compressed air stored in the auxiliary reservoirs to pass to the brake cylinders, the pistons of which are forced outwards, applying the brake blocks to the wheels.

The brake is released by restoring the pressure in the train pipe, which causes the triple valves to close the communication between auxiliary reservoirs and brake cylinders and open a port from the brake cylinder to the atmosphere, through which the compressed air escapes from the cylinder. The spring in the cylinder then can push back the piston and withdraw the blocks from the wheels.

The brakes usually are applied by the driver, or in cases of emergency by the guard, but a breakaway, rupture of a hose coupling, or other accident causing an escape of air from the train pipe, also immediately apply the brakes, hence the term "automatic."

As shown in Figs. 198 and 199 the complete apparatus consists primarily of a steam cock which supplies steam through the pump governor, which is adjusted automatically to cut off the supply of steam when the desired pressure of air has been forced by the pump into the main reservoir. This reservoir is connected directly through an isolating cock to the driver's brake valve. The compressed air passes from the driver's brake valve through a feed valve which is adjusted to maintain the desired pressure in the train pipe automatically. The compressed air flows from the train pipe through the feed grooves of the triple valve into the auxiliary reservoir, whence it passes to the brake cylinders, to apply the brakes as already described. Hose couplings connect the train pipe throughout the train, and the communication between vehicles is controlled by coupling cocks.

The pump for supplying the compressed air (Fig. 200) is arranged vertically, and consists of a steam cylinder 61 and air cylinder 63, joined by the centre-piece 62. The main steam piston 77 and air piston 78 are fastened both to the same rod, and move together as one piece. The pump is driven by steam,

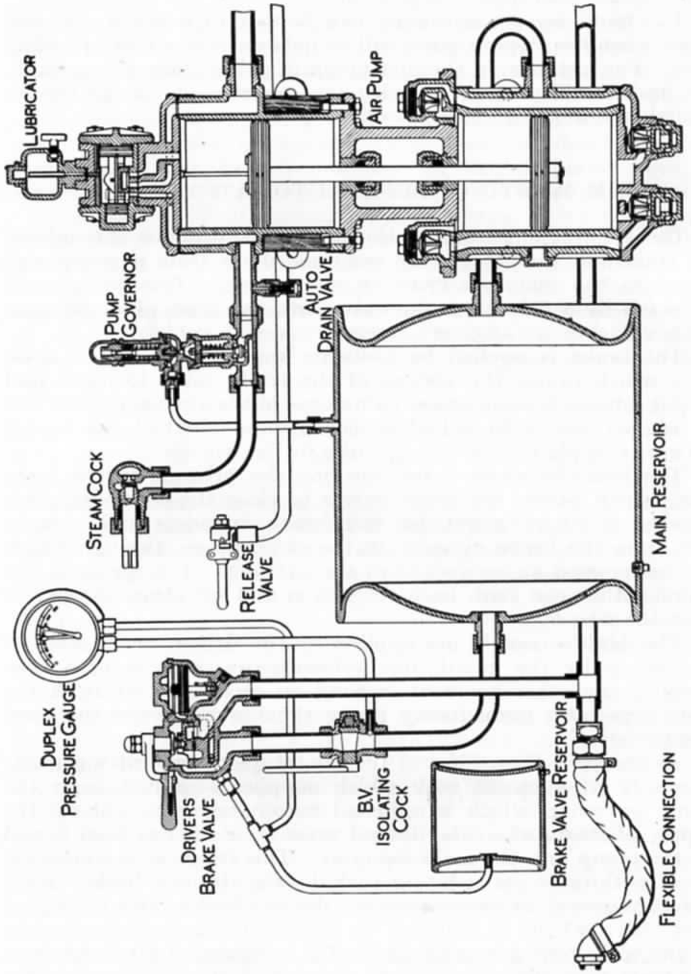


Fig. 198.—General Arrangement of Westinghouse Air Brake Equipment on Locomotives.

which is admitted to the upper cylinder 61. The supply and exhaust steam to and from this cylinder is controlled by a distribution slide valve in conjunction with the main valve, by which it is operated. The movements of the main valve are governed by the reversing valve 65, which is actuated by the main piston 77.

The air piston 78 moves in exactly the same manner as the steam piston 77. At each upward stroke the former draws air from the outside atmosphere through the strainer 92 and the lower receiving valve 91 into the bottom part of the cylinder 63, and delivers at the same time the air from the top part of this cylinder through the upper discharge valve 91 into the main reservoir. At each downward stroke of the piston 78 this action simply is reversed, and air is drawn in through the upper receiving valve 91, and simultaneously discharged from the opposite end

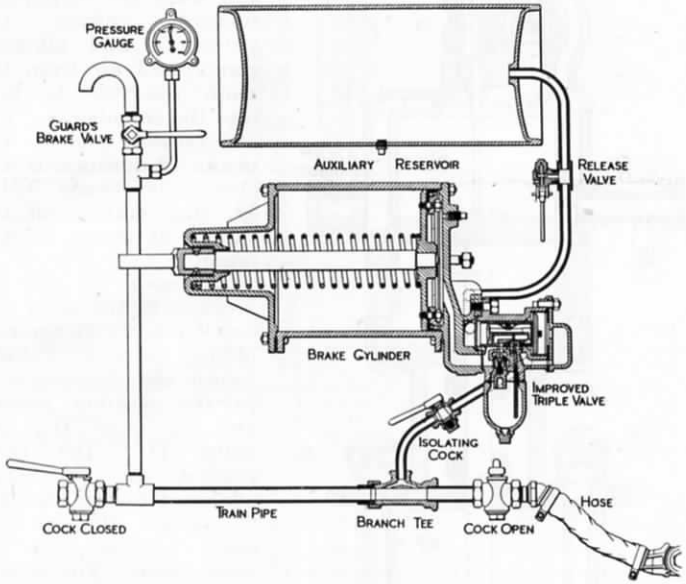


Fig. 199.—General Arrangement of Westinghouse Air Brake Equipment on Train.

of the cylinder through the lower discharge valve 91 into the main reservoir.

The air valves are of the ordinary description, and all of the same size. They are arranged so that they can be removed easily and examined. A small oil cup, with tap, is placed on the top of the air cylinder, and should be used exclusively for the purpose of lubricating this cylinder. For lubricating the steam cylinder and valve motion, a lubricator 110 is supplied with each pump. The condensation water, which may collect in the lower part of the steam cylinder when the pump is not working, should be drained off by opening the cock provided for the purpose.

A considerable saving in steam is effected by the use of the air pump governor (Fig. 201) as the air pressure automatically is kept within certain limits and the pump, therefore, never works unnecessarily. The governor is attached to the steam pipe leading from the locomotive boiler to the air pump. Steam from the boiler enters the governor at F, flows through the valve 14, and passes by D to the pump, which thus is put into operation, and will continue to work until the air pressure in the main reservoir, acting upon the underside of the diaphragm 9, exceeds the tension to which the regulating spring 7 is set. Any excess of pressure will force the diaphragm upwards, lifting the valve 11 and allowing compressed air from the main reservoir to flow into the chamber G. The air pressure forces the piston 12 downwards and closes the steam valve 14, thus cutting off the supply of steam to the pump.

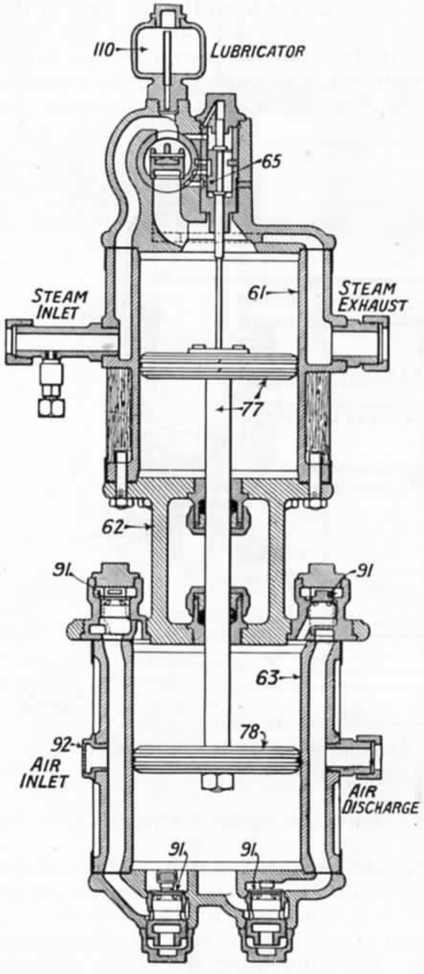


Fig. 200.—Compressed Air Pump of Westinghouse System.

As soon as the air pressure in the main reservoir is reduced, the regulating spring 7 will return the diaphragm 9 to the position shown, and so close the pin valve 11. The compressed air previously admitted to the chamber G escapes through the small port *a* into the atmosphere. The steam, acting upon the lower side of the valve 14, lifts this valve with the piston 12 to the position shown, and again flows from the boiler to the air pump, keeping the latter working until the required air pressure is obtained again in the main reservoir. The regulating spring 7 may be adjusted by means of the screw 6 to suit the pressure of air intended to be carried in the main reservoir.

As previously mentioned, the compressed air is fed by the driver's brake valve into the train pipe and past the triple valves into the auxiliary reservoir on each vehicle. The principle of this brake valve (see Fig. 202) is not to allow the driver in ordinary applications of the brakes to discharge air directly from

the main pipe, but from a small reservoir connected with chamber T of the valve. Then the reduction of air pressure thus effected in the reservoir is repeated automatically and properly at once in the train pipe by means of a small equalising piston 11 placed

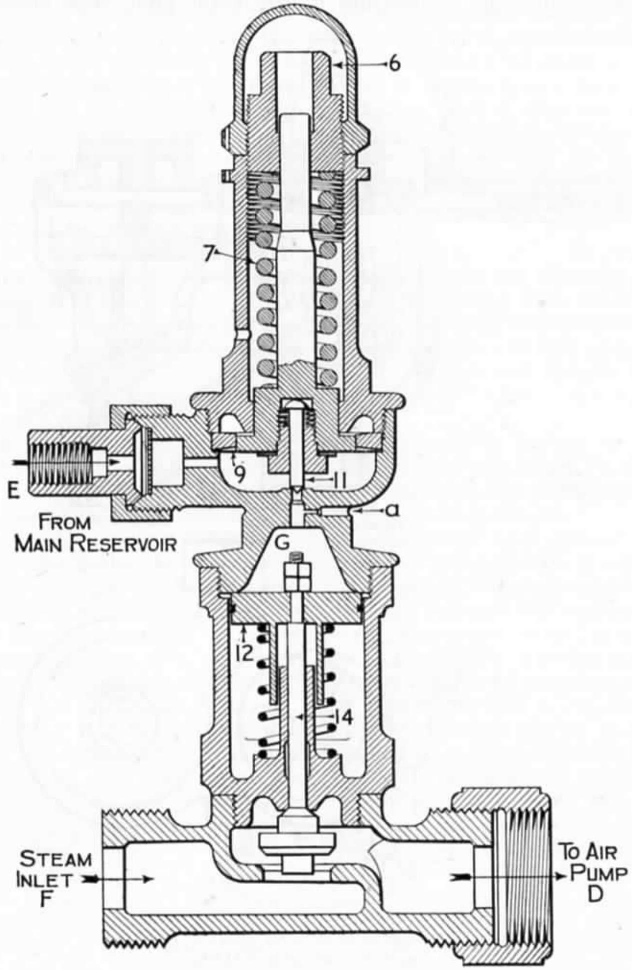


Fig. 201.—Westinghouse Air Pump Governor.

between the air in the chamber T and that in the train pipe E. The piston moves in accordance with the variations in pressure above and below it, and governs an exhaust valve U in such a manner that the air pressure in the train pipe always must equalise with that in the small reservoir connected with the valve chamber T. Even if the exhaust of air from the brake valve reservoir is stopped abruptly by the driver, the discharge valve U always is closed gradually by the piston when equilibrium of pressure is established throughout the train. The equalising device, therefore, will provide under all circumstances for a uniform reduction of pressure in the train pipe, thus ensuring

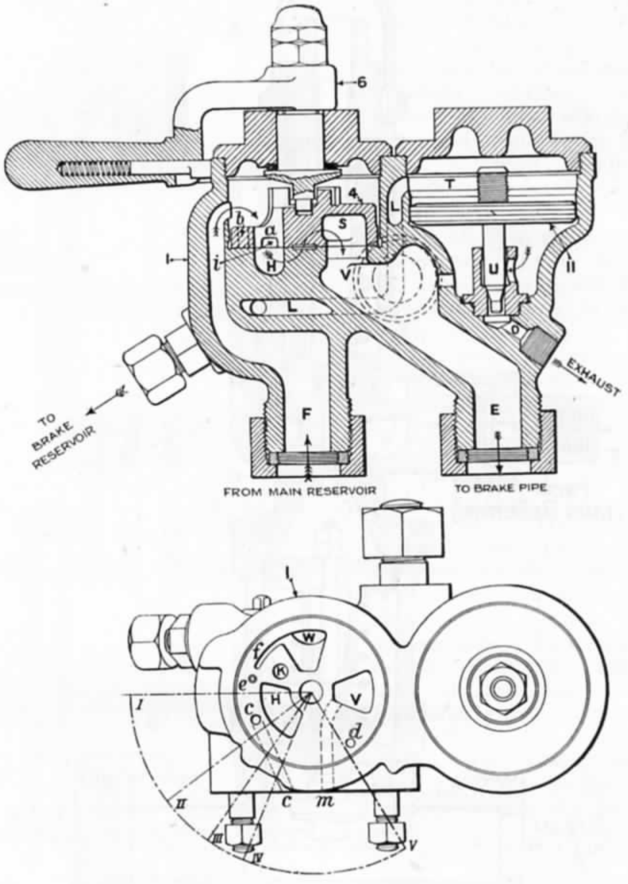


Fig. 202.—Sectional and Plan Views of Driver's Brake Valve.

a uniform application of the brakes to all the vehicles in the train.

There are five principal positions of the brake valve handle, and the operation of the valve for working the brake is as follows :—

1. Position for Charging the Train and Releasing the Brakes.—When the valve handle 6 is placed in the position as shown in

Fig. 202 (top view), compressed air from the main reservoir, entering the brake valve at F, flows through the ports *a* and *b* and cavity *i* (in the rotary valve 4), through the ports *e* and K (in the valve body I) to the passage L, whence it passes to the chamber T, seating the equalising piston 11 and also feeds into the small reservoir attached to the brake valve.

At the same time compressed air from the main reservoir also flows through the port *a* of the rotary main valve 4 into the blank cavity H in the body I. This, in the present position of the valve, communicates with the cavity S in the valve face, and allows the air to pass through S into the port V and the train pipe E. Thus a direct and free communication is established from the main reservoir to the train pipe, as well as to the chamber T and the small reservoir attached to it. The exhaust valve U closes the port O, and equal pressure exists on both sides of the piston 11.

2. Position Whilst Running.—When the valve handle is turned into the second position the air flowing through the passage *a* of the rotary valve feeds into the cavity H in the valve seat, but no longer can pass to the train pipe E, as the communication between the cavities H and S now is cut off. In this position, however, the port *b* in the rotary main valve 4 corresponds with port *c* in the body I, leading to the attached feed valve (see Fig. 202 (lower view)).

3. Lap Position.—When the valve handle is placed in this position, all ports in the rotary valve 4, as well as in its seat, are closed, and all communication to and from the train pipe E, the chamber T, and the brake valve reservoir is cut off.

4. Position for Moderate Applications of the Brake.—To apply the brakes with moderate force the valve handle is turned to the position 4, when air from the chamber T and its reservoir is allowed to escape into the atmosphere through the passage L and port *e* in the body I, the recess *f* in the rotary valve, and the exhaust opening W in the valve seat. This causes a reduction of pressure on the top of the piston 11, the excess of pressure, now acting on the underside of this piston, forces it upwards, unseating the discharge valve U, and allowing air to escape from the train pipe E through the exhaust pipe O, until the pressure in the pipe throughout the train is equal to that yet remaining in the chamber T. When equilibrium thus is established the piston is moved back and the valve U returned to its seat, closing the exhaust port O, and preventing further escape of air.

5. Position for Emergency Applications of the Brake.—When the valve handle is turned beyond the position 4 towards the right, a wide and direct communication between the train pipe and the atmosphere is established through the port V, the cavity S in the rotary valve 4, and the exhaust opening W in the seat of that valve ; the air therefore escapes from the train pipe E with great rapidity, causing instantaneous application of all the brakes with full power.

The feed valve (Fig. 203) is adjusted automatically to maintain the required pressure of air in the train pipe. When the driver's brake valve handle is in the "running position," air is allowed to pass from the main reservoir through port c in the brake valve to port C and chamber A in the feed valve. This forces the piston 4 toward the right into the position shown, and with it the slide valve 5, which uncovers port B through which the air flows to the train pipe E, thus charging the latter to the desired maximum pressure for which the regulator is set. Compressed air at the same time feeds through port D, check valve 10 and passage F into chamber G.

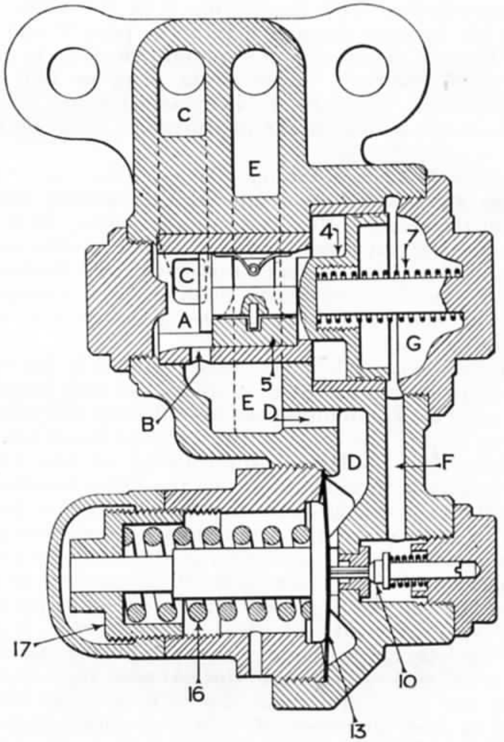


FIG. 203.—REGULATING FEED VALVE OF WESTINGHOUSE BRAKE SYSTEM.

The regulating device consists of a diaphragm 13 loaded with a spring 16, and in the operation of feeding the diaphragm gradually becomes depressed as the maximum pressure in the train pipe is reached. So long as the regulating valve 10 remains open, greater pressure exists on the left side of piston 4, keeping open the feed, but when valve 10 is closed, leakage past the piston from the main reservoir equalises the pressure on either side of piston 4. This allows spring 7 to force over the piston and slide valve to the left, thus closing the feed.

When the train-pipe pressure decreases, the spring 16, acting upon the diaphragm 13, opens the valve 10, thus allowing the air

in chamber G to communicate with the brake pipe E. The main reservoir pressure, overcoming the tension of the spring 7, again forces the piston 4 with slide valve 5 to uncover port B, charging the train pipe until the pressure therein again overcomes the tension of the regulating spring 16.

The spring 16 can be adjusted by means of nut 17 so that any pressure, within certain limits, can be carried in the train pipe. If there is any leakage from the train pipe, this valve will maintain automatically the working pressure. The capacity for

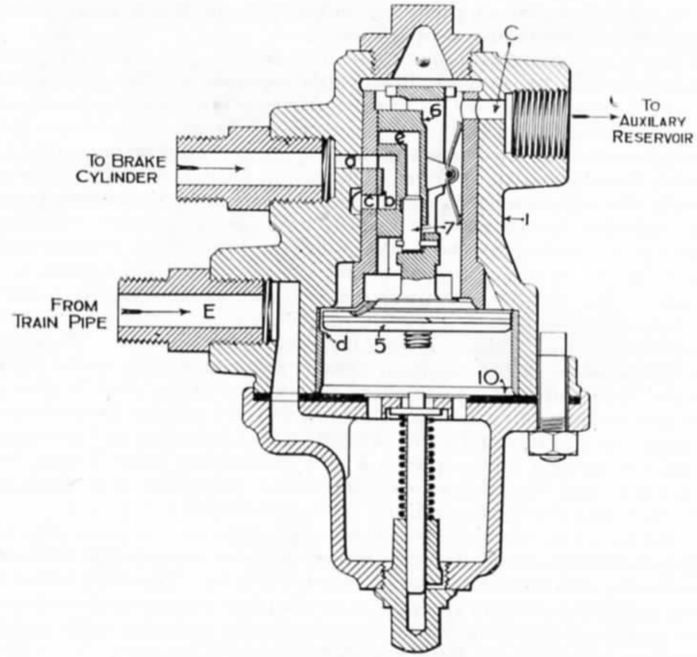


FIG. 204.—WESTINGHOUSE "ORDINARY" TRIPLE VALVE.

feeding is such that on ordinary trains the brakes may be released through this feed valve without placing the driver's brake valve handle in full release position, so that it is impossible to admit any higher pressure to the train pipe than that to which the regulating spring is set.

The Westinghouse "Ordinary" Triple Valve (Fig. 204) controls the admission and exhaustion of air to and from the brake cylinders. It is operated by the variations of pressure in the train pipe in such a manner that it automatically admits compressed air from the corresponding reservoir to the brake cylinder whenever the pressure in the train pipe is reduced, and discharges the compressed air from the brake cylinder when the original pressure in the train pipe is restored.

The construction and the method of operation of this valve are as follows :—

Enclosed in a case 1 is a piston 5, carrying with it a slide valve 6, which covers the port *a* to the brake cylinder, and in the position shown establishes a communication between port *a* and the atmosphere by the cavity *b* and exhaust passage *c*. Compressed air from the train pipe enters at E, and, forcing up the piston 5, feeds past it through the groove *d* and passage C into the auxiliary reservoir, which thus is charged with an air pressure equal to that in the train pipe. The reservoir, triple valve, and train pipe then contain equal air pressure, and so long as this is maintained the brake remains out of operation

On a reduction of pressure being made in the train pipe the piston 5 will be moved downwards because of the excess of pressure now acting on its upper surface. The piston—having a limited movement without affecting the slide valve 6—closes the feed groove *d*, at the same time unseating the graduating valve 7, which thus opens the port *e*. The piston then also moves downwards the slide valve 6, which cuts off the communication from the cylinder to the exhaust port *c*, and opens the port *e* to the passage *a*, leading to the brake cylinder, into which compressed air from the auxiliary reservoir immediately flows and applies the brake. The further downward movement of the piston 5 and slide valve 6 is arrested by the decrease of pressure above the piston caused by the air flowing into the brake cylinder. As soon as the pressure in the reservoir thus is reduced a little below that in the train pipe, the piston 5 is moved up so far that it closes the graduating valve 7, while the slide valve 6 retains its position. Simply by producing further reductions of pressure in the train pipe, the motion of the piston 5 and graduating valve 7 may be repeated, and the driver can introduce gradually any desired pressure into the brake cylinder from zero to the full power.

When a considerable reduction of pressure in the train pipe is made suddenly, the piston 5 is forced down at once to the limit of its stroke, and seated on the leather gasket 10. The slide valve 6 then entirely uncovers the port *a*, so that the compressed air from the auxiliary reservoir flows into the brake cylinder with great rapidity, applying the brakes with full force.

To release the brake, air again is admitted from the main reservoir to the train pipe. The air pressure, acting against the reduced pressure in the auxiliary reservoir, forces the piston 5 and slide valve 6 into the positions shown, thus permitting the air in the brake cylinder to exhaust through the port *c*, and at the same time the auxiliary reservoir is recharged through the feed groove *d*.

The Westinghouse Quick-acting Triple Valve (Fig. 205) forms the essential part of the quick-acting brake apparatus. Its operations are controlled by the variations of pressure in the train pipe as described for the "ordinary" triple valve. The device consists of two piston valves, one working horizontally and the other vertically. The horizontal main piston valve is in its construction and operation similar to that in the "ordinary" triple valve.

In ordinary applications of the brake only the horizontal

main piston valve operates, admitting air from the auxiliary reservoir into the brake cylinder, and the secondary piston 13 and the valve 18 remain at rest. When, however, on a sudden reduction of the pressure in the train pipe the piston 5 and its

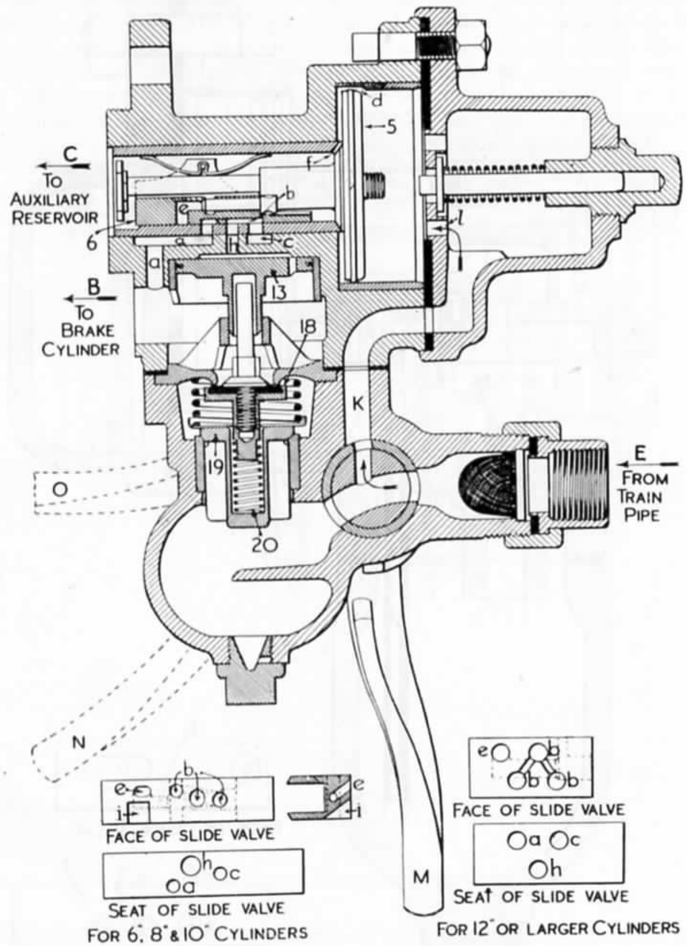


Fig. 205.—Westinghouse Quick-Acting Triple Valve.

slide valve 6 are brought to their extreme positions towards the right, compressed air is admitted to the upper side of the secondary piston 13. This, driven down, opens the valve 18, thus admitting compressed air from the train pipe through the check valve 19 to the brake cylinder, which at the same time is charged also with compressed air, admitted by the slide valve 6, from the auxiliary reservoir. The discharge of air from the train pipe into the brake cylinders has the effect of reducing the pressure in the train pipe rapidly which causes a practically simultaneous action of the brakes even on the longest goods trains.

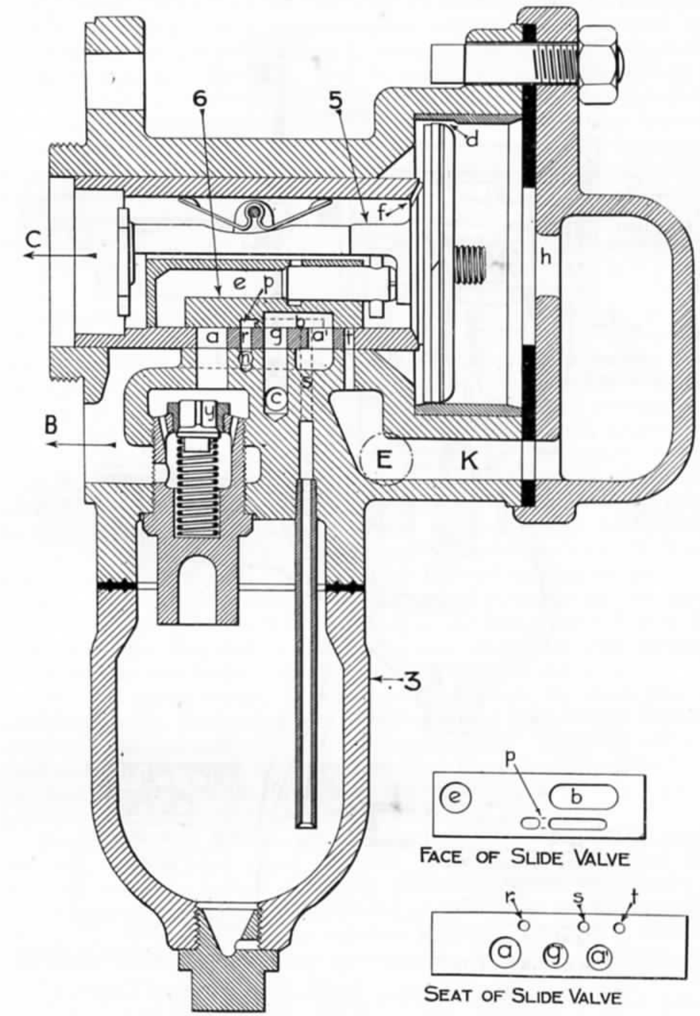


FIG. 206.—WESTINGHOUSE IMPROVED TRIPLE VALVE.

To release the brakes, compressed air from the main reservoir is admitted by means of the driver's valve into the train pipe, whence it enters the triple valve by the passages K and *l*, and forces piston 5 and slide valve 6 to their original position. In the course of this movement the exhaust cavity *b* of the slide

valve first connects the passage *h* to the exhaust port *c*, relieving the pressure from the top side of the piston 13, which is returned to the position shown by the air pressure in the brake cylinder, whilst the spring 20 closes the valve 18. As the slide valve 6 completes its leftward movement the cavity *b* also opens the passage *a* to the exhaust pipe *c*, which discharges the air from the brake cylinder and releases the brakes. The auxiliary reservoir is again charged, as already described, through the grooves *d* and *f*.

To secure the simultaneous release of the brakes a nipple, having an aperture corresponding to the size of the brake

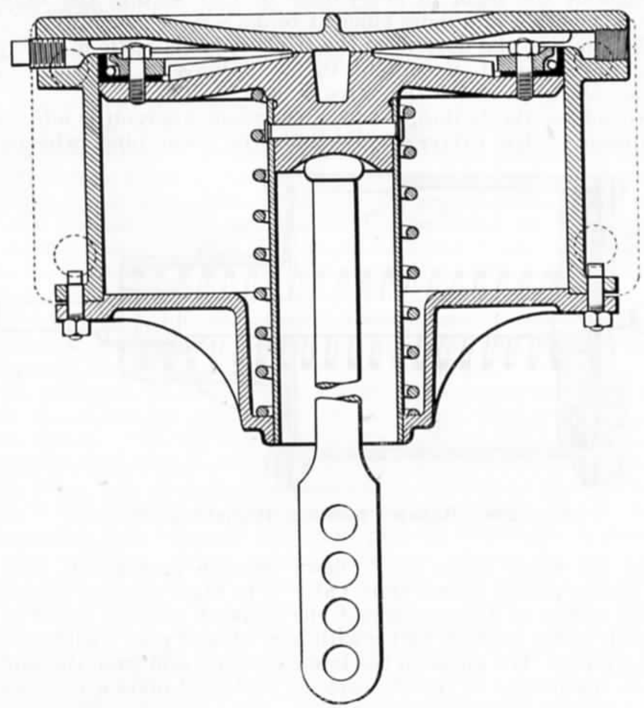


FIG. 207.—BRAKE CYLINDER, VERTICAL TYPE.

cylinder with which it is used, is inserted in the mouth of the exhaust port of the triple valve. By means of the cock in the lower part of the triple valve the whole brake apparatus on a vehicle, or simply the quick-acting feature thereof, may be put out of use without in any way affecting the action of the brakes on other vehicles of the same train. In the vertical position M of the cock handle the quick-action is in use; by turning it to N the brake is entirely put out of operation, and by turning still further to the position O the quick-action only is taken away, and the apparatus works in precisely the same manner as the "ordinary" triple valve.

The Improved Triple Valve (Fig. 206) has been designed to give a closer approach than heretofore to simultaneous action of all the triple valves in a train. As illustrated, the valve is in the release position, and the bulb is open to the atmosphere. When the slide valve 6 is moved by applying the brakes, the bulb 3 is closed to the atmosphere and opened to the train pipe by the cavity *p* and port *s* shown in dotted lines. The local reduction of train-pipe pressure thereby produced by the forward triples in a train causes an earlier action of the rearward triple valves, which results in a more nearly simultaneous braking effect throughout the train in every case of first setting the brakes, with a smoother and more efficient brake service generally.

The bulb at the bottom of the triple valve is made in different sizes, proportioned in content to the volume of the train pipe of the vehicle on which the valve is used.

To release the brakes, air from the main reservoir is admitted by means of the driver's valve into the train pipe, whence it

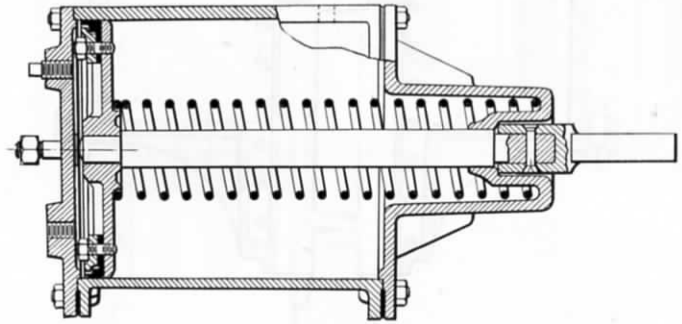


FIG. 208.—BRAKE CYLINDER, HORIZONTAL TYPE.

enters the triple valve at E, flows through passages K and *h*, and forces piston 5 and slide valve 6 to their original position. In the course of the movement the exhaust cavities *b* and *p* in the slide valve connect port *g* with port a^1, and port *s* with port *r*, respectively. The air from the brake cylinder and from the bulb 3 is then discharged to the atmosphere, and the brakes are released. The auxiliary reservoir is then recharged again through grooves *d* and *f*.

A brake cylinder (Figs. 207 and 208) is fitted to the locomotive, tender, and to each braked vehicle. Each brake cylinder contains a piston, having its rod attached to the brake gear in such a manner that the brake blocks are pressed against the wheels when the piston is forced out by air pressure.

As long as the brake is not applied the cylinder is free from air pressure. When, however, the brake is put into operation, compressed air is admitted to the cylinder by the corresponding triple valve, and the air pressure, acting upon the piston, forces the latter forward, thus applying the brake blocks to the wheels. When the air is allowed to escape from the cylinder, the spring (which has been compressed in applying the brake) extends and

returns the piston and brake gear to their original positions, thereby releasing the blocks from the wheels.

To prevent the application of the brake from slight leakage in the train pipe, each brake cylinder is provided with a small groove, which establishes a communication between both sides of the piston when the brake is not applied. If, because of such leakage, a slight flow of air to the brake cylinder should occur, the air would pass through the groove to the atmosphere without moving the piston. When, however, a considerable quantity of air is admitted to the cylinder, as in ordinary application of the brake, the piston is immediately forced past the groove and an escape of air from the cylinder is thus prevented.

To ensure that the pistons of all the brake cylinders in the train completely clear the corresponding leakages groove, the driver always should reduce the pressure in the train pipe by not less than 5 lb. whenever he puts the brake into operation, and care must be taken also that on every vehicle the brake gear is so adjusted that it allows the piston to travel sufficiently far.

The brake cylinder should be lubricated at least every three months, and it is recommended that "Paragon Grease" be used for this purpose. The grease should be warmed, so that it may be readily injected with a syringe, and the brake gear should then be detached from the crossheads and the pistons turned round a few times.

In the case of the Quick-Acting and Improved Brake Apparatus, the auxiliary reservoir, triple valve and brake cylinder frequently are bolted together to form one piece.

In addition to the foregoing parts, the engine is fitted also with the following adjuncts: (*a*) A gauge, having a red and black hand. The red hand indicates the pressure of the air in the main reservoir, and the black hand the pressure of air in the train pipe. (*b*) A drip cup, inserted in the train pipe on tank engines and tenders to intercept any oil or moisture which otherwise might pass through the train pipe to the brake apparatus on the vehicles. (*c*) A release valve, to enable the air to be discharged direct to the atmosphere from the brake cylinder or auxiliary reservoir, if occasion requires. (NOTE.—This release valve is included also in the carriage equipment.) (*d*) A release spring, to withdraw the brake blocks from the wheels when they have been applied by means of the hand brake only. (NOTE.—Carriages and wagons fitted with hand brakes also require this release spring.)

Guards' vans are fitted with a single hand-gauge to indicate the pressure of air in the train pipe, and a cock for applying the brakes in cases of emergency.

As the complete apparatus now has been described, some particulars of the operation of the brake will be of interest.

To apply the brake with moderate force, the handle of the brake valve must be removed beyond the "Lap Position" (III) towards that for "Ordinary Applications" (IV), and a reduction of pressure made of not less than 5 lb., after which the handle must be placed in the "Lap Position" (III). When the brakes have been put in operation, very small reductions of the pressure in the train pipe will serve gradually to increase the brake power, as circumstances may require. The brakes are applied fully when a reduction of 25 lb. has been effected in the train-pipe pressure, and it would be useless to discharge any further quantity of air, except as directed for emergency applications. The handle of the brake valve should never be placed in the "Release Position" (I) just before applying the brake.

For quick stops in emergency, the brake valve handle must be turned to the right as far as possible to the "Emergency Position" (V) and left there. If the brake should be applied from the train, either by the guard opening the cock in his van or automatically (because of a separation of the train, rupture of hose couplings, etc.), the driver at once must aid in stopping the train by turning the brake handle toward the right, as in ordinary applications, which also will prevent the escape of air from the main reservoir. It is to be remembered that less brake force is required for stopping from a low speed than from a high speed, and the brakes should not be applied so forcibly as to skid the wheels, which is less effective in stopping.

After the train has been brought under control and before it comes to rest, to prevent the jerk which often is experienced at this moment, the brake valve handle may be put in the "Release Position" (I) until the train comes to a stand, and then be brought back immediately to the "Running Position" (II).

In releasing the brakes, the brake valve handle should be put momentarily into the "Release Position" (I) to reverse the triple valves, but brought back at once to the "Running Position" (II), in which position the pressure in the train pipe and auxiliary reservoirs will be restored to the authorised maximum through the feed valve without any danger of creating a pressure higher than that authorised.

The air brake on any vehicle may be released by hand if necessary. For this purpose, the wire attached to the release valve handle and fixed to the carriage frame must be pulled, and the valve held open until the brake is released. When the release valve is connected with the auxiliary reservoir, the valve should be held open only until the triple valve piston is reversed and air begins to escape from its exhaust port.

When trains are worked by two engines, the brakes should be entirely under the control of the driver of the leading engine. On the second engine the isolating cock in the main reservoir pipe under the driver's brake valve must be closed, and the brake valve handle placed in the "Release Position" (I) as soon as the leading engine is coupled on to the train. The air pump of the second engine should be kept going and the maximum air pressure be maintained in the main reservoir, so that the driver of the second engine may be ready at any time to take charge of the brakes in case of necessity or emergency, when he can apply all the brakes in the train by throwing open the brake valve in the usual way. After the leading engine has been uncoupled from the train, the driver of the second engine at once should open the cock under the brake valve. If he omits to do this, he will not be able to release the train brakes from the engine.

The following points apply more particularly to the working of the brake.

Before the pump is started, the drain cock must be opened so that any water which has collected in the steam cylinder is drained off. Preferably, this cock should be left open after the engine has finished work, to avoid any accumulation of water, which may freeze in winter and split the steam cylinder. The lubricator in the top head must be emptied of water by opening the plug valve, and then should be filled with the lubricant provided for the purpose. The small oil cup on the top of the air cylinder also must be filled once a day with good mineral oil. Tallow or other animal or vegetable oils must not be used in the air cylinder. The piston rod glands must be kept well packed to prevent condensed steam from the steam cylinder from running down into the air cylinder.

After the pump has been attended to in accordance with these directions, it should be started slowly, to allow the water of condensation to escape from the steam cylinder and to prevent knocking, which may occur when the air pressure in the main reservoir is low. If the pump is not fitted with an automatic governor, it should be kept working continually at moderate speed, and be so regulated that the prescribed pressure is maintained in the main reservoir.

The air pressure in the main reservoir should be 90 lb. per sq. in., and the pump governor should be set to maintain this pressure. It is important that the main reservoir and drip cup should be drained regularly. For this purpose the plug in the main reservoir, as well as the bottom cap of the drip cup, should be unscrewed at least once a week.

When the main reservoir has been charged to the prescribed pressure for working the brakes, the driver's brake valve must be tested to see that it works properly in all positions of the handle. When the train is running the handle of the brake valve must always be kept in "Running Position" (II).

The driving wheel brake should never be cut out.

The pressure in the train pipe should be 70 lb. per sq. in., and the feed valve by which the pressure of air is maintained automatically in the train pipe when the brake valve handle is in the "Running Position" should be set to that pressure.

The couplings between two vehicles are united by placing their heads face to face at right angles, and then turning the projecting rib of one into the corresponding groove of the other. When couplings are disconnected, they should be attached always to the dummy couplings to prevent dust and sand getting into them. Before the couplings are separated the corresponding coupling cocks must be closed.

Before coupling on to a train, the driver must see that his main reservoir is charged to the prescribed pressure. In attaching to a train, the brakes of which are not already charged, the brake valve handle should be placed in "Running Position" (II) before the coupling cocks are opened. When these are opened between the tender and the front vehicle, the pressure in the train pipe on the engine will be reduced and the brakes on the engine and tender will be applied automatically. After the cocks between the tender and train have been opened, the brake valve handle should be placed in the "Release Position" (I), and the train pipe and auxiliary reservoirs charged until the black hand of the gauge shows that the pressure which is authorised, and to which the feed valve is set, has been reached at the front of the train. As soon as this pressure is shown on the gauge, the brake valve handle should be placed in the "Running Position" (II), and when this has been done the black hand on the gauge will be seen to fall below the desired pressure. This is because the pressure in the train pipe is greater at the front than at the rear of the train, and the flow of air from the main reservoir, now restricted to the passage through the feed valve, allows a momentary equalisation of the pressure throughout the train. The fall in pressure thus indicated will, however, be restored quickly and automatically to the desired pressure through the feed valve.

The brake handle must never be left long enough in the "Release Position" (I) to charge the train pipe and auxiliary reservoirs beyond the authorised pressure, as this may retard the release of the brakes after an application has been made.

When several attachments are being made, the driver should have full pressure in his main reservoir, and while the vehicles are being coupled up should have his brake valve handle in the "Lap Position" (II) until the train is made up completely, when he must place the handle in "Release Position" (I). It must remain there until the black hand of the gauge shows that the pressure which is authorised, and to which the feed valve is set, has been reached at the front of the train. As soon as this pressure is shown on the gauge the brake valve handle must be placed in the "Running Position" (II), in which position the whole train pipe will be charged automatically to the authorised pressure through the feed valve.

Before closing the train pipe cock and uncoupling the hose in order to detach the engine or any vehicle from a train, the brakes on the whole train, if possible, should have been released fully to facilitate the shunting. If vehicles carrying different air pressures be coupled together the brakes will apply themselves automatically on those which have the highest pressure.

When the train has been made up and the driver believes that all the brakes are charged with air to the authorised pressure, he should place his brake valve handle in the "Lap Position" (III) and signal for the brakes to be applied from the rear vehicle of the train. To do this the rear cock should be opened on the last vehicle, and the person making the test then should walk up the train and ensure that brakes on every vehicle, including the engine and tender, are all applied. He must inform the driver if any of the brakes are not in operation and how many vehicles in the train are unbraked. When the driver has received this information, he should put the handle of the brake valve to the "Release Position" (I) to reverse the triples, and then bring it back to the "Running Position" (II). In this position the pressure in the train pipe and auxiliary reservoirs will be restored through the feed valve to the authorised pressure to which that valve is set.

The object of this test is to show that the brake is in working order throughout the train. If there should be air in the train pipe and a cock closed, or the brake pipe uncoupled in any part of the train, the brakes would be applied on the vehicles in rear of the obstruction by the opening of the cock on the last vehicle, but the driver would not be able from the engine to release the brakes which have been applied in rear of such obstruction. On the other hand, if there is no air in the rear part of the train pipe behind the obstruction, although the driver may believe he has charged the whole train from the engine, the opening of the cock in the rear of an obstruction would not apply any of the brakes, and the driver must be told by the person making the test that the brakes are not in working order.

Whenever the locomotive is changed or temporarily detached from the train, and in all cases where the hose couplings between any of the vehicles have been separated and recoupled, the brakes on the entire train invariably must be tested in the manner described.

On locomotives fitted with air brakes, and vacuum ejectors and piping in addition, for handling vacuum-braked trains, it is necessary to provide means for synchronising the air-brake application with that of the vacuum brake. The proportional valve described and illustrated in Fig. 209 has been designed by the Westinghouse Company for this purpose. It is operated by the degree of vacuum obtaining in the vacuum brake system. The air brake application, it will be noted, is a "straight air application," that is, compressed air is admitted direct from the main air reservoir to the brake cylinder. If the locomotive is fitted with automatic air brakes, the compressed air is admitted to the brake cylinder through the exhaust port of the triple valve, or through a double check valve.

The proportional valve consists essentially of two elements, a diaphragm operated on by the vacuum obtaining in the vacuum brake pipe, and a mechanism for admitting air to, or exhausting air from, the air brake cylinder. The chamber A on one side of the diaphragm 2 is piped to a small volume reservoir to increase the effective capacity of the chamber, and communication with the chamber B on the other side of the diaphragm 2, which is itself in communication with the vacuum brake pipe, is maintained through a small ball check valve 8, which retains the normal degree of vacuum obtaining in the brake pipe.

One arm of a bell crank 10 is connected to the diaphragm 2, the other engaging with a hollow stem 13 joining two balancing pistons 14 and 15. The upper piston 14 carries a poppet valve 25, which controls the exhaust of air from the air brake cylinder, with which the chamber C above this piston is in communication. The upper part of this chamber is closed by a valve 26 attached by a loose pin joint to the exhaust valve 25, the valve 26 controlling the admission of air from the air reservoir (which is in communication with chamber D) to the brake cylinder.

When a vacuum brake application is made, the vacuum is destroyed partially or wholly in the brake pipe and in the chamber B. The diaphragm is then forced to one side by the differential of the pressures acting on it, moving the bell crank 10 and causing the balancing pistons 14 and 15 to move upwards, first seating the exhaust valve 25, and then, in a further movement, opening the inlet valve 26 and allowing compressed air to flow to the brake cylinder and build up a pressure in the chamber C. This pressure reacts downwards on the piston 14 and tends to balance the force exerted through the diaphragm. As soon as a pressure has been reached in the brake cylinder proportional to the degree to which the vacuum brake has been applied, the balancing piston 14 will be forced downwards and the inlet valve 26 will seat. This will take place recurrently as a graduated application is being made.

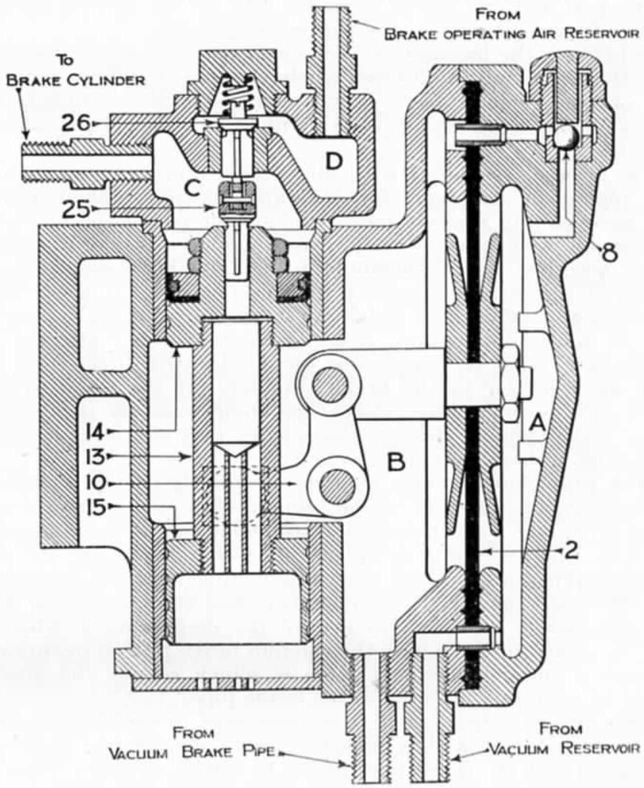


Fig. 209.—Westinghouse Straight Air Brake Application Valve (Proportional Valve).

If the vacuum brake is released wholly or partially, the load due to the vacuum differential acting on the diaphragm 2 will be reduced and the pressure of the air in the brake cylinder, acting on the piston 14, will move this downwards away from the exhaust valve 25, allowing air to escape to atmosphere from the brake cylinder until its pressure has been reduced to an amount proportional to the vacuum brake condition then obtaining. When this point has been reached, the piston 14 will move upwards and close the exhaust valve 25.

Irregularities in the working of the brakes may be dealt with as follows :—

If on any of the vehicles the air brake apparatus does not work properly, and there is no time to remedy the defect, the particular apparatus may be shut off without affecting the brakes on the rest of the train. For this purpose a stopcock is placed in the branch pipe leading from the train pipe to the triple valve. This cock is closed when the handle stands across the branch pipe and open when the handle lies along the pipe.

If the vehicle is fitted with a quick-acting triple valve, the handle of the cock in the bottom part may be placed first in the horizontal position O (see Fig. 205) and the brake again tested. If its action is still defective, the apparatus must be put out of action by turning the cock handle to the position N between the horizontal and vertical positions. The release valve must then be opened and all the air pressure discharged from the brake apparatus. The brake must never be put out of action on any vehicle unless the apparatus is defective. When it is necessary to put the brake out of action, the driver must be advised and the fact reported at the end of the journey, so that the defect may be remedied before the vehicle is again put into service.

In the event of the bursting of a coupling hose, the brakes on the entire train will be applied and the train brought to a standstill. The cock in the train pipe immediately in front of the burst hose must then be closed and the driver signalled to release. All the brakes in the rear of the burst hose must be released, which will be done by opening the release valves and discharging all the air pressure from this portion of the train, on the vehicles of which, consequently, the air brakes then will be inoperative. The driver should then be told how many brakes thus have been put out of action, and how many still remain in working order.

If the train should part, the brakes will be applied automatically to both portions of the train, which will thus be stopped. The cock in the train pipe at the rear end of the first section should be closed and the driver signalled to release. The two parts of the train then must be recoupled, the hose couplings united, and the brakes on the second section also released by the driver. When it has been ascertained by inspecting each vehicle that the brakes all are properly released, the train can proceed.

To provide a means of automatically taking up brake-block wear, the Westinghouse Brake Co. provides a special light-weight steel automatic slack adjuster, known as the "Weslak" slack adjuster. This is inserted usually in the main pull rod of the brake rigging ; the head end of the adjuster is attached by pivot to the brake shaft lever, and the opposite end to the pull rod. As this adjuster is constructed entirely of steel, and because of its special design, there is only a small increase in the total weight of the equipment after deducting the weight of that section of the pull rod which it replaces.

The construction and operation of the slack adjuster are as follows :—

The apparatus consists of a screwed shaft on which a ratchet

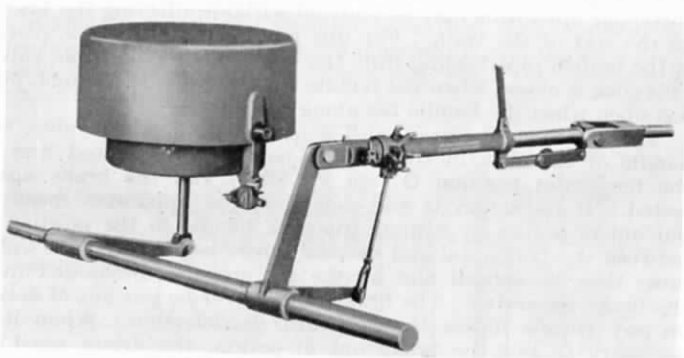


FIG. 210.—"WESLAK" SLACK ADJUSTER SHOWN AFTER RESETTING.

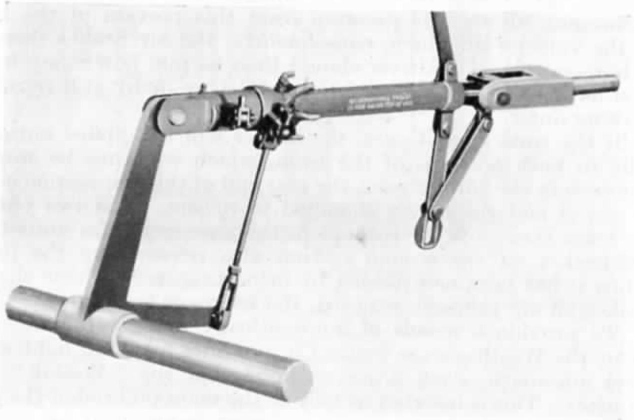


FIG. 211.—"WESLAK" SLACK ADJUSTER BEFORE RESETTING.

wheel is keyed; the shaft and ratchet, which rotate in bushes, are housed in the head of the adjuster. At the opposite end of the shaft there is a tubular trunnion nut, machined from solid steel, which is linked at its outer end to the brake rigging, and the head of the adjuster is linked to the pull rod lever of the brake shaft. The pull link is connected at its lower end to a lever on the brake shaft, and at its upper end to the operating pawl bracket of the slack adjuster.

During a brake application the pull link and pawl bracket move upwards, causing the pawl to slide over the tooth on the ratchet wheel, which is prevented from rotating in an anti-clockwise direction by a safety latch. If the brake clearance is within the limits maintained by the adjuster, the upward movement of the brake shaft lever will stop before the pawl passes over the top of the ratchet tooth into the next tooth, but if the clearance exceeds the limits the continued upward movement will permit the pawl to pass into the next tooth of the ratchet wheel.

During brake release, the downward movement of the pawl causes the ratchet wheel and shaft to rotate in a clockwise direction and reduce the break block clearance by drawing the tubular trunnion nut towards the head of the adjuster. As the ratchet wheel rotates, the safety latch slides over the safety ratchet wheel tooth and registers in the next tooth, thus preventing the shaft and ratchet wheel from rotating in an anti-clockwise direction during the next brake application.

When new brake blocks have been fitted, the slack adjuster is extended fully to its maximum length and the resetting indicator is then in a horizontal position. When, on the other hand, the brake blocks are worn and the adjuster has nearly completed its working range, the resetting indicator falls to a vertical position. Fig. 210 shows the "Weslak" slack adjuster after resetting, and Fig. 211 when resetting is required.

FIG. 211A.—DOWN BOURNEMOUTH EXPRESS PASSING WEST WEYBRIDGE, S.R., HAULED BY "SCHOOLS" CLASS LOCOMOTIVE NO. 928, *Stowe.*

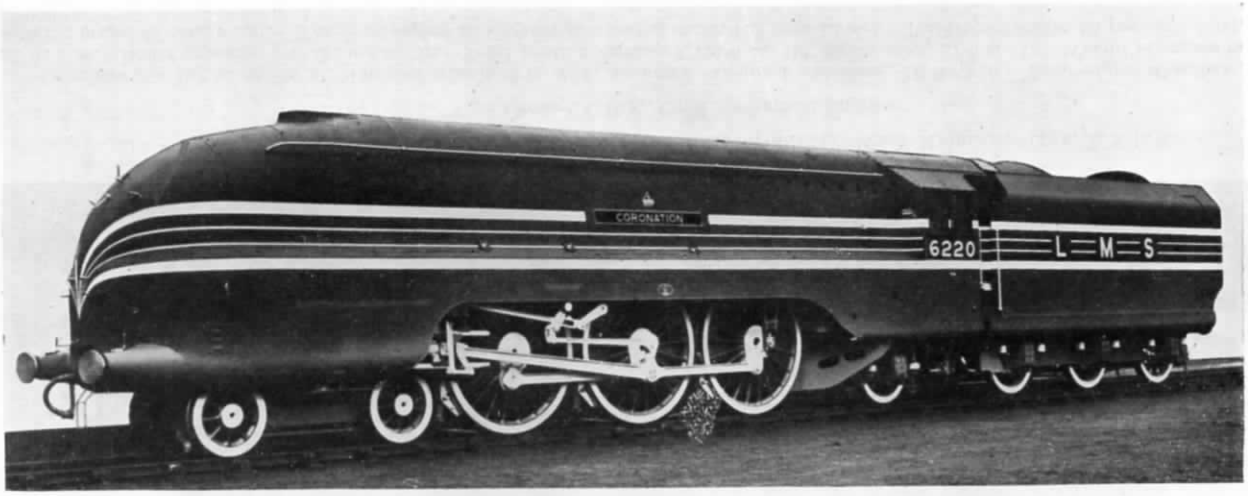


FIG. 212.—STREAMLINE 4-6-2 FOUR-CYLINDER EXPRESS LOCOMOTIVE, L.M.S.R.

Sir William Stanier, Chief Mechanical Engineer (*retired*).

Cylinders (4), 16½ in. by 28 in. Coupled wheels, 6 ft. 9 in. diameter. Coupled wheelbase, 14 ft. 6 in. Total engine wheelbase, 37 ft. Boiler pressure, 250 lb. per sq. in. Total heating surface, 3,663·5 sq. ft. Grate area, 50 sq. ft. Weight of engine in working order, 108 tons 2 cwt. Weight of engine and tender in working order, 164 tons 9 cwt. Tractive effort (85 per cent. b.p.), 40,000 lb.

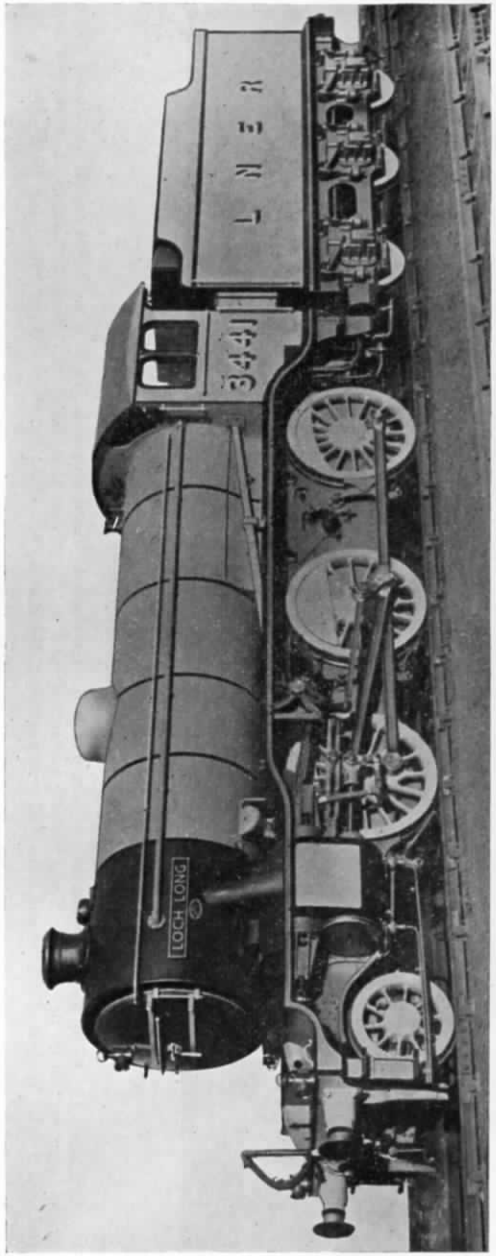


FIG. 213.—THREE-CYLINDER 2-6-0 TYPE ENGINE USED ON THE HEAVILY-GRADED WEST HIGHLAND LINE, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 18½ in. by 26 in. Coupled wheels, 5 ft. 2 in. diameter. Coupled wheelbase, 16 ft. 3 in. Total engine wheelbase, 25 ft. 2 in. Boiler pressure, 180 lb. per sq. in. Total heating surface, 1,731·6 sq. ft. Grate area, 27·5 sq. ft. Weight of engine in working order, 68 tons 8 cwt. Weight of engine and tender in working order, 112 tons 12 cwt. Tractive effort (at 85 per cent. b.p.), 32,939 lb.

CHAPTER 14

LUBRICATION

IN passing through the different grades from cleaning to driving, sufficient time will have elapsed for the driver to have picked up many useful hints on the proper application of the lubricants to the wearing surfaces. In this there is ample scope for the display of that discretion which should guide him in adapting his methods to suit the various circumstances and conditions under which he is expected to run his engine. The oil consumption in the working of a railway is so large and costly that the departmental heads insist on the strictest supervision; thus much credit is derived from the economical use of oil, just as of coal. That the wearing surfaces may be damaged by an insufficient supply of oil is incontrovertible, so the driver may feel sometimes that he is between the hammer and the anvil in attempting on the one hand to economise and on the other risk having to take the blame for failures from heated axles or bearings.

The matter, however, is not quite so arbitrary as would appear at first sight, for, by the proper attention to trimmings, the viscosity of the oil, the atmospheric conditions, and the removal of trimmings when standing for any length of time, many drops of oil may be saved which tell their own tale at the end of the month.

Again, by strict attention to the cleanliness of lubricators, syphons, trimmings, and oil pipes, and so on, a steady supply of oil can be ensured, thus keeping the wearing surfaces in far better condition by the steady application of a few drops of oil at the proper time and place than by flushing the surfaces with a larger quantity of the lubricant in an intermittent manner.

The movement, or lack of movement, in the part to be lubricated determines to a certain extent the method of lubrication. Connecting-rod ends, eccentric straps, and coupling rods, for instance, where the movement is sufficiently pronounced, are lubricated by the agitation of the oil in the cups when the engine is working; plug trimmings usually are fixed inside the central oil tube to regulate the flow to the bearings.

Those portions of the engine having no throw generally are lubricated by tail trimmings, which syphon the oil from boxes or wells, as in the case of the piston rods, valve spindles, and axleboxes, or from cup lubricators as usually fitted to the top slide bars.

By taking off the syphon tops, where plug trimmings are used, at the end of each journey to see exactly how much oil is in the cups, a driver soon can learn to regulate his trimmings to feed just the quantity of oil required.

Much depends upon the manner in which the trimmings are made, for by carefully adjusting the number of the worsted strands to suit climatic conditions or thickness of oil, and so on, a known quantity can be fed constantly to give a steady supply to the bearings.

In making a big-end trimming, for example, first measure with a piece of wire the distance from the top of the syphon pipe to the bearing, and ascertain at the same time the thickness of the brasses. Assuming that this distance is 6 in., the wire should be twisted for about 4 in. in the middle part, leaving the doubled end for the bottom, and the two ends sufficiently long for bending at the top. Wrap the worsted singly lengthwise over the twisted part of the wire to the required thickness, counting the number of strands to know exactly how many will be required when replacing, or for any alteration that may be made necessary by a change in the thickness of the oil supplied from the stores.

After wrapping the worsted, twist the ends left for the top to leave $\frac{1}{2}$ in. of bare twisted wire, which will make the trimmings about $5\frac{1}{8}$ in. from the top of the wire to the bottom of the worsted. Bend the ends for the top outward and upward so that the wire will rest on the top of the tube to prevent the trimming from slipping downwards, and the upright ends will come into contact with the syphon cover, thus preventing the trimming from being thrown upward by the throw of the crank.

Give two neat short turns to the wire below the worsted so that they will just enter the brasses, to conduct the oil to the bearing, and the $\frac{1}{2}$-in. piece of bare wire inside the tube at the top will act as a reservoir, allowing the oil steadily to feed its way downward through the worsted to the journal. A small hole is bored through the cap of the syphon and tapped. It is usually plugged with cork, cane, or other porous material, thus allowing the admission of a certain amount of air necessary to permit the feeding of the oil and at the same time preventing the oil being thrown out of the cups by the motion of the rods.

The stringing of these corks, although a simple matter, should be done as neatly as possible, thus giving evidence of careful attention on the part of the driver and fireman. The corks are dispensed with in some types of lubricators, in which the holes in the caps are closed with a button, held in position by a spiral spring. In this type of syphon the trimming also is replaced sometimes by a bent wire, which projects a short distance down the tube, so that the oil which it retains at every throw of the rod drops from its end down to the journal. This is known as a " needle " lubricator.

The foregoing lubricators are not really syphons, but have been so designated because generally they are referred to as such by drivers and firemen. Lubricators with tail trimmings, however, may be classed as syphons, seeing that the oil is syphoned from the oil-box or well, first upward and then downward from the higher to the lower level by the action of capillary attraction in the trimming. In supplying the oil to the part to be lubricated each worsted strand may be looked upon as a small capillary tube which has a continuous action as long as the oil supply lasts; hence the necessity for removal of trimmings where possible at times when the supply of oil is not required. The amount of oil that a trimming will convey is varied, therefore, by the thickness of the oil, the number of strands, or the cleanliness of the trimming.

The mops which are used in conjunction with tail trimmings for lubricating the valve spindles and piston rods are apt soon to look filthy, so that fairly frequent renewals should be made if only to denote that they are receiving the required attention.

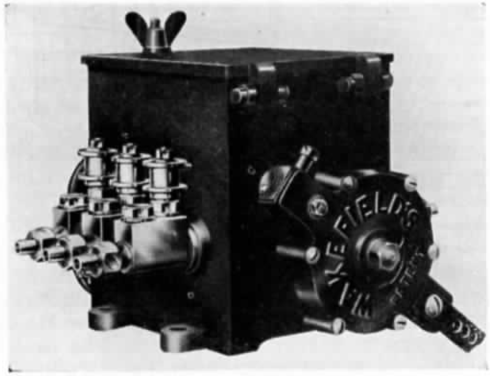


FIG. 214.—WAKEFIELD NO. 2 PATTERN MECHANICAL LUBRICATOR.

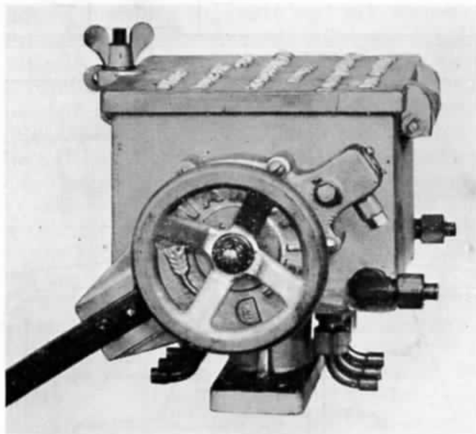


FIG. 215.—WAKEFIELD NO. 7 PATTERN MECHANICAL LUBRICATOR.

Tail trimmings also will be found on different parts of the motion-work. They are so simple that little need be said about their construction, beyond mentioning that for axleboxes, and so on, the twisted wire should be of sufficient length to allow the trimming just to enter the brasses.

Before leaving the shed the driver should examine the engine and tender axleboxes, to make sure that the oil is in contact with

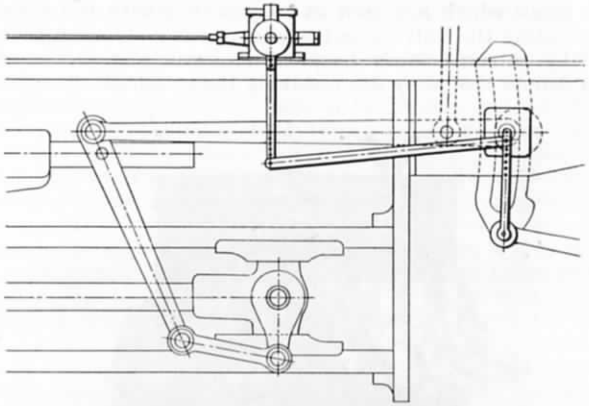


FIG. 216.—MECHANICAL LUBRICATOR DRIVEN FROM EXPANSION LINK OF WALSCHAERTS VALVE GEAR. (See also Fig. 231.)

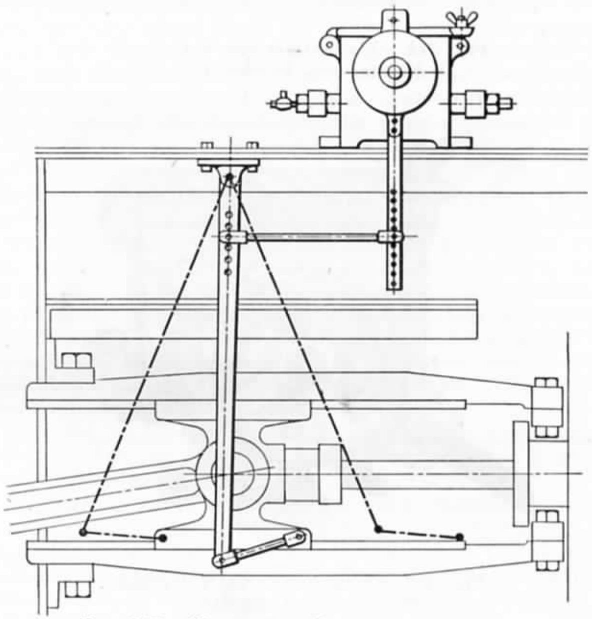


FIG. 217.—MECHANICAL LUBRICATOR DRIVEN FROM CROSSHEAD.

the journals. If water has found its way into the boxes during the washing-out, it should be syphoned out. Otherwise the oil will float, and only water will be in contact with the journal, which would be liable to heat up because of the oil supply being cut off. This also applies in a lesser degree to the other lubricators,

as by the displacement of a cork or a cover water might be retained and interfere with the proper lubrication of the parts affected.

For greater convenience in working, particularly in view of the prevalence of long non-stop runs, the oil-boxes for all the coupled axleboxes and horn blocks now are located frequently side by side on the footplate in a position above the fire-hole door, where the driver easily can adjust the trimmings and supply of oil while the engine is running, without having to leave the cab. Long pipes convey the lubricant down to the coupled axlebox bearings and horns.

The steady increase in the weights of locomotives and rolling stock generally and the modern practice of long-distance non-stop runs have rendered the question of axle lubrication of the greatest importance. These modern conditions of high-speed transit and heavier loads, therefore, have brought about the introduction of various devices, designed with a view to the prevention of delay caused by hot axleboxes and frictional losses in other wearing-parts.

The mechanical system of lubricating axleboxes has been used for several years past by most of the important railways in Great Britain and abroad, with results which demonstrate a perfection of lubrication that is quite unattainable with the ordinary method of oiling by worsted trimmings. The Wakefield system consists of a mechanical lubricator, usually one of the types shown in Figs. 214 and 215, which, when actuated by means of some convenient moving part of the engine giving constant stroke, as shown in Figs. 216 and 217, forces oil through copper feed pipes to the axleboxes in constant regulated quantities which automatically cease when the engine comes to rest. The oil feed pipes from the lubricator are taken first to a test valve, which is connected by flexible tubing, usually armoured rubber hose of a special oil-resisting quality, to a check valve fitted into the top of the axlebox, for locomotives with underhung springs, and at the side for locomotives with overhung springs (see Figs. 218 and 219). The check valve ensures that the oil pipe remains full, enabling the oil to be delivered to the journal directly the locomotive begins to move, and also prevents the oil pipes from emptying when the locomotive is at rest. The test valve—which should be inserted at the highest point of the oil feed pipe—is for the engineman to ascertain by sight whether any individual pump is working or the oil pipe is full, by unscrewing the test valve and allowing the oil to flow through the small hole, as shown in Figs. 218 and 219.

Fig. 220 shows a general arrangement of a locomotive fitted for lubrication on the Wakefield mechanical system for valves, cylinders, regulator, piston rods, steam brake cylinder, slide bars, and axleboxes.

This system of mechanical lubrication applied to slide bars on locomotives is an arrangement whereby the oil is fed through the feed pipes to a reversible cock, which distributes the oil to the check valves fitted in the top and bottom bars. The reversible cock is connected to the reversing lever of the locomotive by a rod which, when in the forward position, actuates the reversible cock in such a manner that the oil is allowed to pass to the top bar or, if the reversing lever is in the backward position, to the bottom bar. This ensures that the oil is fed, under pressure, from the lubricator to the slide bar that is taking the thrust. This arrangement, perhaps, is appreciated better on works locomotives and shunting engines, where the continuous forward and reverse running of the locomotive necessitates careful lubrication of the top and bottom bars.

For locomotives fitted with single slide bars, a simple check valve is fitted into the bar, and oil fed through from the lubricator. The following descriptions of the Furness & Roscoe lubricators

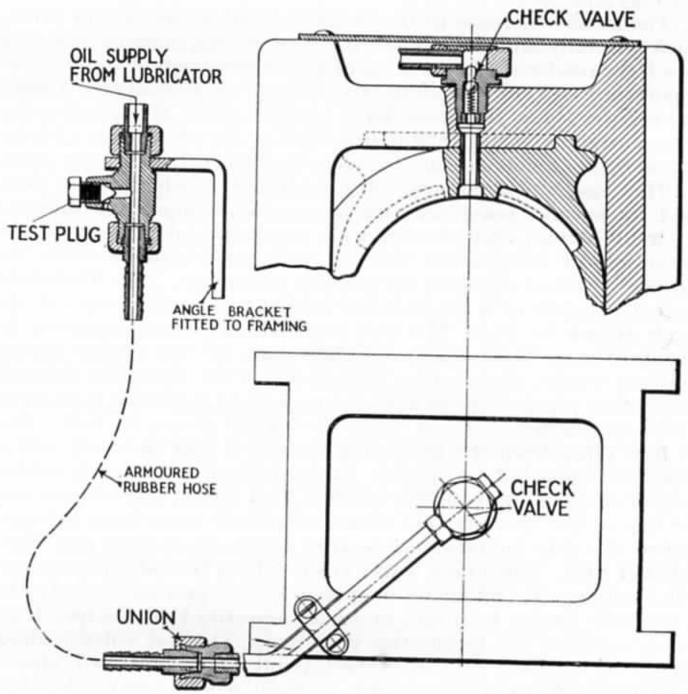


Fig. 218.—Method of Applying Forced Feed Lubrication to Locomotive Axleboxes with Underhung Springs.

have been retained in the present edition, as doubtless a large number of locomotives of the older types, fitted with them, are still in service. The more modern types, virtually in all cases, have superheater boilers, and are equipped with mechanical or sight-feed lubricators as standard fittings. Detailed references are made to both patterns on succeeding pages.

For the lubrication of the piston rings or the valve faces the presence of steam and the temperature of the parts to be lubricated must be taken into consideration, so that the methods adopted are very different from those already quoted for the motion-work. Ordinary oils which might be suitable under atmospheric conditions in most cases would be totally unsuited to the high moist

temperatures, and would vaporise or lose entirely their lubricating qualities immediately they were introduced into the steamchests or cylinders. The oil mostly adopted is a thick black mineral oil which has withstood satisfactorily severe tests under high steam pressures and temperatures. As the piston-ring friction always is present when running, the lubrication of the cylinders must be continuous either with the steam pressure in the cylinders or with steam shut off, as when drifting or running down a bank. The

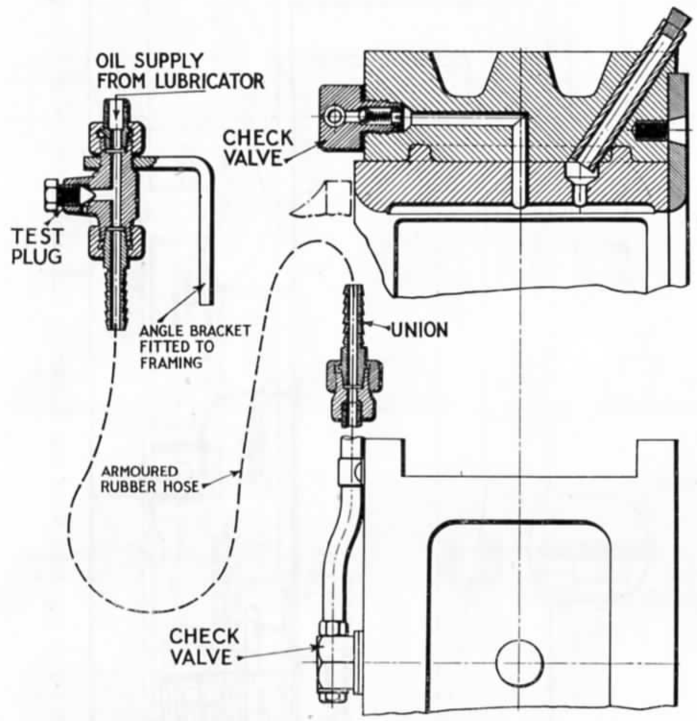


Fig. 219.—Method of Applying Forced Feed Lubrication to Locomotive Axleboxes with Overhung Springs.

Furness lubricator, which sometimes is fitted to either the back or front covers, and sometimes to the crown of the cylinders, is used extensively for supplying oil under the latter conditions. The presence of a vacuum when drifting has been mentioned already in describing the principle of the air valve, and this principle is applied to the Furness lubricator ; the suction caused by the pistons is made to lift a small valve which admits a few drops of oil from the body of the lubricator to the cylinders. The lift of this valve should be as little as possible so that it is returned quickly upon its seat, or the oil will be driven back by the returning piston before the valve has closed. It is maintained upon its seat by the pressure when steam is admitted to the

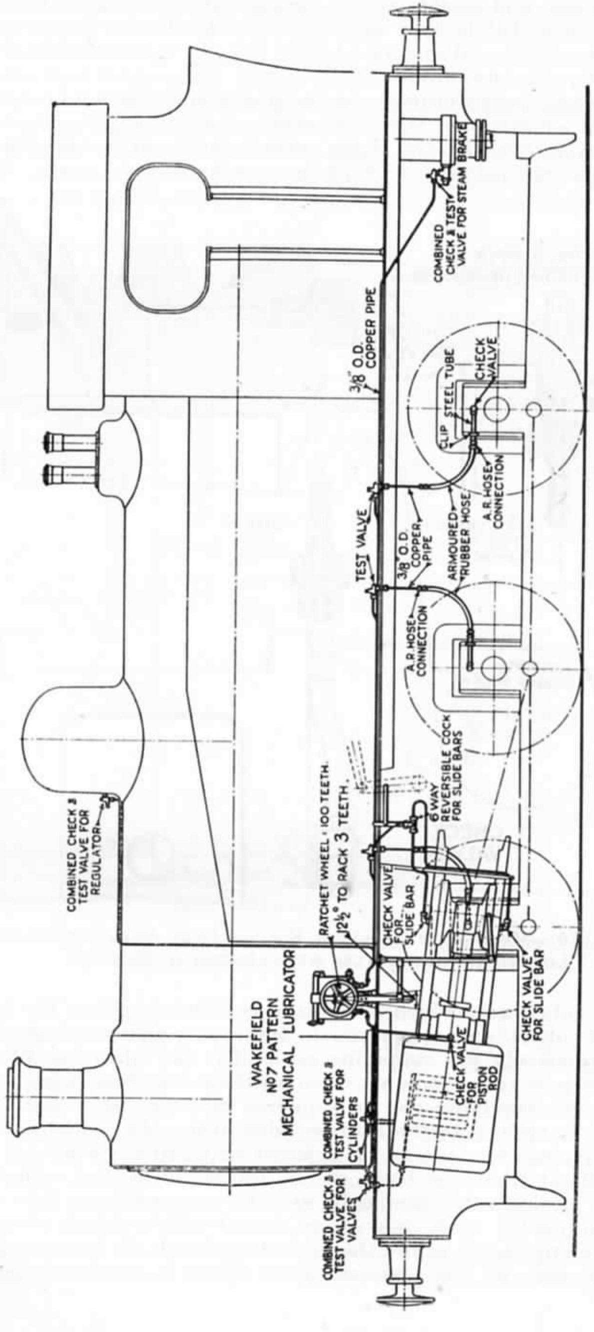


Fig. 220.—Diagram of Locomotive equipped with the Wakefield Mechanical System of Lubrication.

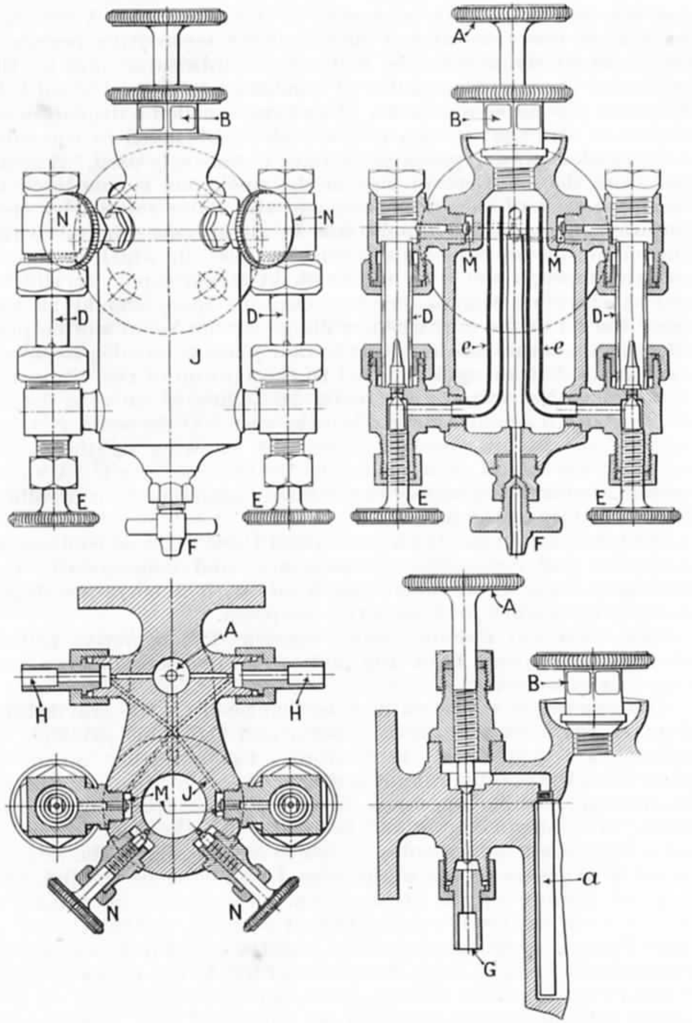


Fig. 221.—Wakefield Double Sight-Feed Lubricator with Auxiliary Feed.

cylinders, so that a little grinding is necessary from time to time, otherwise the steam will leak past, and the resulting condensation eventually will fill the lubricator with water.

Many types of lubricators are made for introducing oil against pressure, as when steam is present in the cylinders. A common method, at one time almost universal for locomotive purposes, was to admit steam into the body of the lubricator, and by the gravity of the resultant water of condensation force the oil into the steam pipe or steamchests. This type is called a displacement lubricator, and that known as the "Roscoe," fitted to the sides of the smokebox, was perhaps the most extensively used. A small pipe from the main steam pipe in the smokebox is connected to the upper part of the lubricator, and the water formed by condensation of the steam supply falls by its specific gravity to the bottom of the oil cup, thus displacing the oil, which is forced outward through the tube to the main steam pipe. It will be evident therefore that a small amount of space should be left above the oil in the cup when refilling, so that room will be provided for the initial condensation to take place before displacement can begin. A drain cock is fitted to the bottom of the lubricator for draining the water. It should be tightened only by hand, and not with a spanner, as is often the case. If the seating is not damaged already it may be injured by screwing up too tight, and if faulty should be attended to by the shed staff. A small valve regulates the oil supply to the main steam pipe by controlling the steam inlet to the lubricator.

Modern improvements have rendered these external condensers or slender coil connections unnecessary, and consequently the lubricators have been much simplified, with a correspondingly greater adaptability for locomotive purposes.

The Wakefield Patent Double Sight-feed Locomotive Lubricator, with Auxiliary Feed (Fig. 221), is a very popular type and is used extensively.

The manner in which oil may be displaced by the gravitation of water has been described already, and the same principle is applied to "sight-feed" lubricators; the necessary steam is taken from the combination stand or some such fitting to obtain the nearest possible approach to the absolute pressure in the boiler. The steam enters the lubricator by the connection G, and is controlled by the valve A, which also regulates the flow of the oil as it passes to the outlet pipe H, and thence through the oil pipes leading to the steamchests. The steam inlet tube *a* terminates in the lower part of the oil vessel J, so that the oil is forced upward by the condensation, and through a delivery tube *e*, which stands vertical with its open end inside the upper portion of the vessel J. This delivery tube, which is connected to the passage leading into the nipple in the bottom of the "sight-feed" glass D, stands full of oil when the lubricator is working, ready to be delivered at any desired rate as regulated by the small wheel valve E, which controls the oil passage *e* leading to the nipple. The water in the sight glass, subjected to pressure at both the inlet and delivery side, is practically in equilibrium, so that the oil when discharged from the nipple rises by its levity through the water past the valve M to the pipes H leading to the parts

to be lubricated. A small automatic check valve M is fitted into the passage leading from the sight glass to the outlet H, so that when the equilibrium is disturbed by the bursting or breaking of a glass the valve is held tight on its seat by the pressure behind, thus protecting the driver and fireman from scalding by preventing the escape of steam. When a break occurs the valve E must be closed, and the auxiliary feed valve N, which is closed when the lubricator is working normally, should be put into operation by opening it the same proportion of turn that obtained with the valve E. By-pass passages controlled by the valve N lead from the upper portion of the oil vessel to the outlet H, so that when opened the auxiliary valve continues to feed the oil as before until the broken glass has been replaced. Normal working is resumed by closing N and opening the valve E.

The method of filling and starting is practically the same in all types of "sight-feed" lubricators. With all valves closed, remove the plug B and fill the vessel full. It is good practice to fit a small gauze strainer or sieve into the mouth of the vessel, so that it will retain any grit or foreign substance in the oil, which would tend to choke up the passage in the lubricator. After replacing the plug, release the valve A slowly from its seat, to allow condensation gradually to fill the "sight-feed" glass. When the glass is filled with water regulate the oil supply with the valve E; six drops per min. are usually ample for ordinary conditions. The starting of the lubricator should not be performed hurriedly, as the oil is liable to become agitated and mix to a certain extent with the water, thus obscuring the sight glasses before steady working has begun. To refill the vessel, close the valves A and E, loosen drain cock F to draw off the water, and remove plug for filling as before. The seat of the drain cock should be maintained in good order, so that sufficient pressure can be applied with the hand for closing the drain and preventing any drip. The remarks previously applied to a lubricator drain cock are equally applicable here. As the oil is fed by the condensation of the steam, care should be taken that the oil vessel is not emptied entirely before refilling, or the lubricator may get too hot for condensation to take place efficiently, and it would have to be cooled before displacement could begin. On the other hand, in frosty weather the water should be drained from the oil vessel and the drain cock left open before putting the engine away, to guard against the liability of bursting the oil vessel by the freezing of the water.

Fig. 222 shows sectional views of a more modern type of lubricator, of the hydrostatic principle previously described. This lubricator, which is manufactured by C. C. Wakefield & Co. Ltd., is compact and well designed, and over the ordinary model has several advantages such as bull-eye glasses D, which with ordinary everyday use are unbreakable and, therefore, protect the driver from the danger of burst glasses which is present with lubricators fitted with tubular sight-feed glasses. These bull-eye glasses are about 1$\frac{5}{8}$ in. thick, and so designed that the greater the pressure on the glass, the tighter the joint. Blow-through plugs K are provided for the cleaning of the sight-feed glasses D; steam is allowed to flow down the sight-feed chambers to the atmosphere.

The lubricator is fitted also with a main oil shut-off valve F, which is used for shutting off or starting the feeds without interfering with the set regulation of the individual feeds. This valve is very useful when standing in a station or siding, as it is necessary only to give the valve hand wheel half a turn, to shut off completely or immediately to start the feeds. A filling plug B and patent oil-expansion valve C are fitted, as it is necessary to provide means of exit for the oil, should it become heated to such a degree that the expansion becomes too great for the oil reservoir, which is liable to crack unless such provision is made. The steam jets L, which meet the oil at the outlets J and carry it forward, through the steamchest connections, to the points of application, are arranged above the oil reservoir A, which has the effect of keeping the oil reservoir A cool, and so prevents accidental burns to the enginemen. The condensing chamber P is fitted above the oil reservoir A, and is made in the one casting so that the usual condensing coil is not required.

A steamchest and cylinder connection (Fig. 223) is fitted as near to the part to be lubricated as possible. It is fitted with a choke, the object of which is to enable the lubricator to work against a constant boiler pressure in the feed pipes, and also to ensure that the oil is delivered to the steamchest or cylinder in an emulsified state.

The lubrication of locomotives using superheated steam is a most important matter, and the Wakefield mechanical lubricators (Figs. 214 and 215) have been designed specially to meet the severe conditions as to steam pressures, temperatures, tractive effort, and speed which obtain in modern locomotive practice.

Fig. 224 shows sectional views of the same firm's improved modern type of lubricator, operating on the hydrostatic displacement principle. This is known as the Eureka Type "E" locomotive lubricator, designed for the specific purpose of easy manipulation of the controls. To this end the main oil shut-off valve and main steam valve are coupled together by an arm fitted with a suitable operating handle, thus providing simultaneous action in starting and shutting off of the lubricator. The operating lever has three positions, *i.e.*, (1) steam and oil "off," (2) steam only "on," and (3) steam and oil "on." This lubricator thus provides quick manipulation of the controls, an advantage which will be appreciated greatly by enginemen.

A lubricator of the single acting type is shown in Fig. 225. This lubricator is used extensively for axlebox lubrication and, in conjunction with the anti-carboniser (Fig. 226), for valve and cylinder lubrication.

A reciprocating motion is given to the pump plunger by the eccentric shaft L rotating in its bearings. When the pump plunger D and sleeve valve E are at the outer end of the stroke, oil flows into the pump barrel C through the ports F. As soon as the ports F are covered by the plunger and sleeve valve on the return stroke, the oil in the pump barrel is forced away under pressure to the outlets K. If the oil-regulating plug G is screwed right down, the pumps are working at their full capacity. One full turn outwards of the oil-regulating plug G decreases by one-fifth the amount of oil pumped.

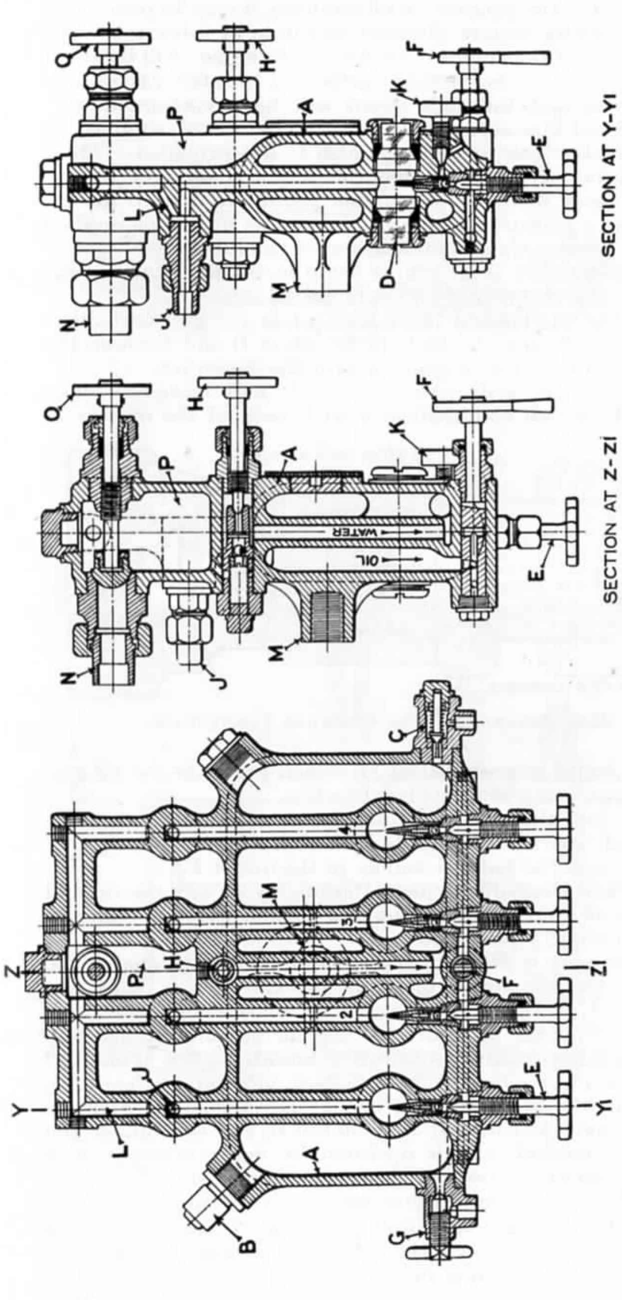


FIG. 222.—SECTIONS OF WAKEFIELD'S PATENT 4-FEED "EUREKA" HYDROSTATIC DISPLACEMENT LOCOMOTIVE LUBRICATION.

A, oil reservoir; B, filling plug; C, patent release valve to prevent excessive pressure in oil reservoir due to oil expansion; D, sight-feed glasses; E, oil regulating valves; F, oil shut-off valve, has two positions, "all open" and "all closed"; G, drain valve; H, water valve; J, oil outlets; K, blow-through plugs for cleaning sight glasses; L, steam jet; M, fixing lug; N, steam inlet from boiler; O, main steam valve; P, condensing chamber.

(NOTE.—A third position is provided where a feed is required for the air brake pump.)

With regard to the quantity of oil required, it may be mentioned that different parts require different amounts of lubricant. The rubbing surfaces of the engine cylinders, for example, will be about four times the area of the rubbing surface on the slide valves, and the piston rods and tail rods again will have correspondingly smaller frictional contact. So that the oil may be supplied in suitable quantities the regulating plugs G are provided. These plugs should be adjusted to give the required amount as, for instance, $1\frac{1}{4}$ drops of oil to the engine pistons to 1 drop for the slide valves and $\frac{1}{4}$ drop to the tail rods, and so on. This method of regulation ensures the economical use of the lubricant.

The anti-carboniser (Fig. 226) is fitted in the pipe line as near as possible to the steamchest and cylinder oil inlet.

Oil from the mechanical lubricator enters the anti-carboniser at A and is forced past the ball check valves B and through the passage C, when it comes in contact with the steam jet.

Steam enters the anti-carboniser at D and branches along the passage E, which communicates with each of the outlets F.

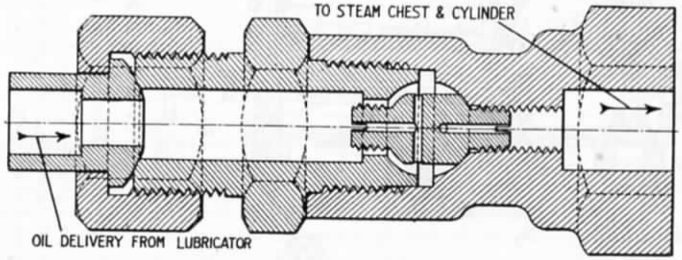


Fig. 223.—Steamchest and Cylinder Connection.

A check ball valve is provided at G, which prevents the oil and steam from traversing in a reverse direction.

It will be seen that the point of contact of the oil and steam is in the small space or cavity H. The oil and steam together then pass through the baffle J and so to the outlet F.

The object of the baffle is more thoroughly to mix the oil and steam, which, of course, would not mix so well were they merely to pass out through a plain hole.

An oil test plug is fitted in the position shown, to enable the engineman to test the flow of oil in the pipes.

A combined check and test valve, as shown in Fig. 227, is usually fitted when the lubricator is used for bearing lubrication.

An ingeniously designed lubricator, known as the Wakefield patent fountain type locomotive axlebox lubricator (Fig. 228), provides a method of lubricating locomotive axleboxes which is simple, safe, and efficient. It is mounted in the cab, under the driver's direct control, and is operated by one movement of a lever which opens or shuts all feeds simultaneously. The easy manipulation of this lever encourages the driver to shut off the lubricator when running into and standing at stations, which ensures oil economy. When the lubricator is shut off, a small quantity of oil accumulates in an auxiliary chamber, where it

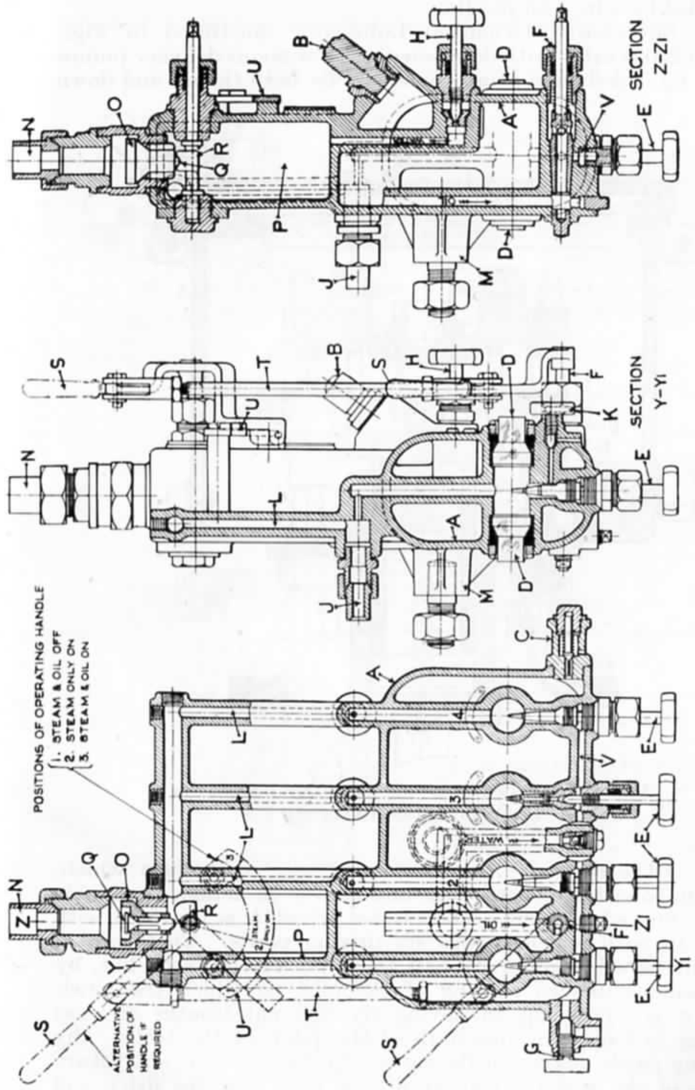


Fig. 224.—Wakefield "Eureka" Lubricator, Type "E."

A, oil reservoir; B, filling plug; C, patent release valve to prevent excessive pressure in oil reservoir due to oil expansion; D, sight-feed glasses; E, oil-regulating valves; F, main oil shut-off valve; G, drain valve; H, water valve; J, oil outlets; K, blow-through plugs; L, steam to oil outlets; M, fixing lug; N, steam inlet from boiler; O, main steam valve; P, condensing chamber; Q, jockey valve; R, camshaft operating jockey and main steam valves; S, operating handle (three positions; steam and oil off, steam only on, steam and oil on); T, connecting lever operating steam and main oil control valves; U, indicator plate; V, oil feed chamber.

remains ready to flow quickly down to the journals immediately the operating lever is moved into the " on " position.

The lubricator is designed to maintain a constant oil level in the pipe line, assuring a regular rate of feed. The oil feed is controlled by wire feed needles.

The Silvertown Mechanical Lubricator illustrated in Figs. 229 and 230 is fitted with double-acting continuous delivery pumps so that oil is delivered at an equal rate on both the up and down

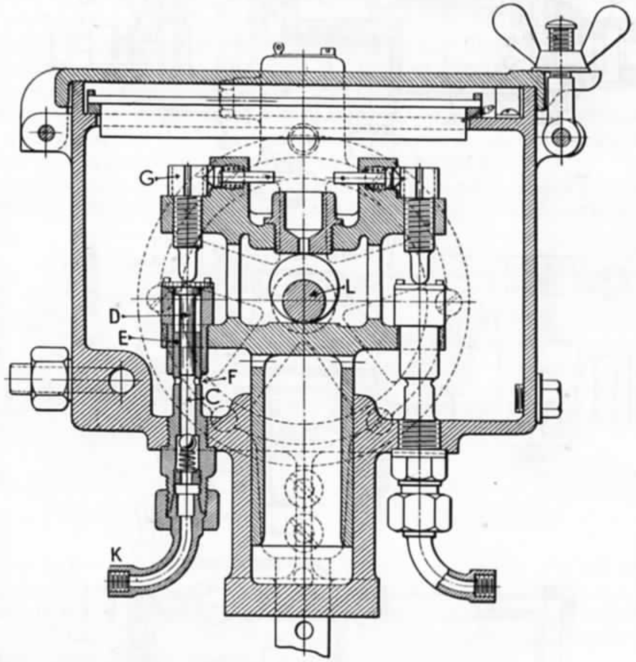


Fig. 225.—Wakefield Mechanical Lubricator (Single-Acting Pattern).

strokes. The drive is through ratchet-gear mechanism which, although robust in construction and certain in action, is capable of very fine adjustment. The ratchet wheel A is provided with 120 teeth with which engage six driving pawls. These are of two lengths which differ by half the pitch of the teeth but, by an ingenious uneven spacing of the pins on which the pawls work, it is equivalent to having six different lengths of pawl differing in length by one-sixth of the pitch of the teeth. Six retaining pawls, acting on the same principle, prevent any return motion of the wheel. Thus it will be seen that the drive will operate with an angular movement of the clutchbox as small as half a degree. The design by this means secures an infinitely fine variation in the feed of the lubricator yet retains the simplicity and reliability of the ordinary ratchet and pawl.

The double-acting pumps comprise a plunger E of two diameters ; the large end fits the pump cylinder, and the top end passes through a sleeve F, seated loosely in the gland nut G, against which it is held by a leather washer. This arrangement affords absolute tightness combined with flexibility.

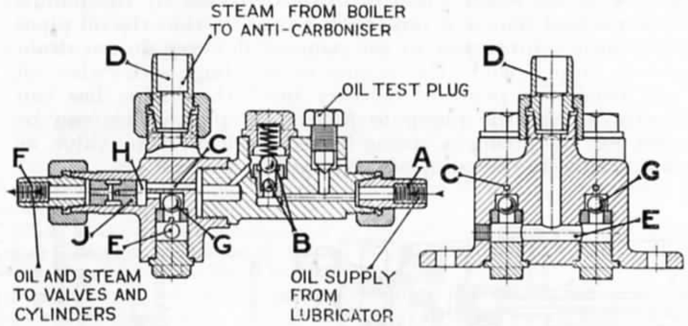
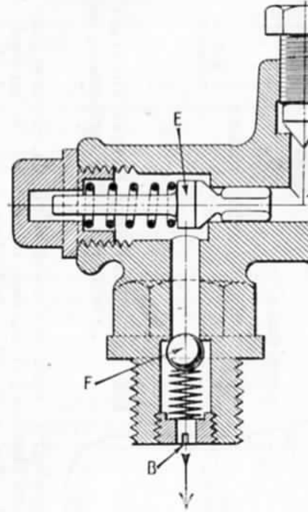


Fig. 226.—Anti-Carboniser (Wakefield Pattern).



A, oil inlet from lubricator; B, oil delivery to valves and cylinders; C, oil test plug; D, oil release hole; E, non-return valve (mushroom type); F, non-return valve (ball type).

Fig. 227.—Combined Check and Test Valve for Wakefield Mechanical Lubricators.

One suction and two delivery ball valves are used, and so arranged that on the up stroke the oil above the enlarged portion of the plunger is delivered past the valve H. On the return stroke the charge passes valve J, half of it following the descending plunger and the remainder being delivered past the valve H, thus maintaining a constant flow of lubricant through the outlet. The driving frame K operating the pumps is reciprocated by eccentrics on shaft L.

A cylindrical strainer M enclosing the suction valve is fitted to each pump, in addition to the main strainer N. A warming pipe O for use in cold weather and a drain plug P are provided in the bottom of the main casing. The handle Q allows the pump to be operated by hand for initial charging of the pipes.

In view of the small quantity of oil delivered by the pumps it will be realised that it is important to ensure that the oil pipes leading from the lubricator to the point of delivery do not drain themselves empty while the engine is standing; otherwise oil will not reach the point of delivery until the engine has run sufficiently far for the pump to fill the oil pipe. This can be provided for by fitting a spring-loaded back-pressure valve as close as possible to the point of delivery.

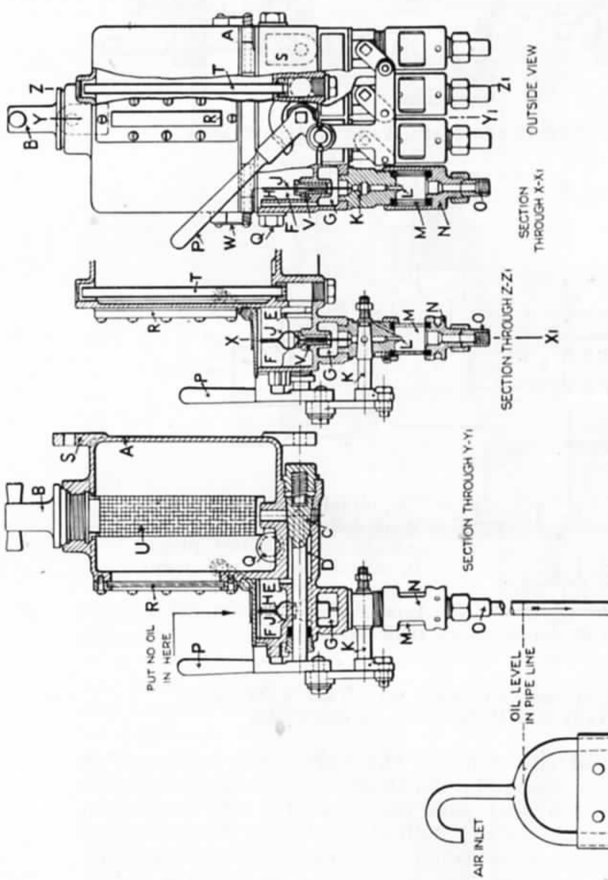


FIG. 228.—WAKEFIELD PATENT FOUNTAIN TYPE AXLEBOX LUBRICATOR. (For Instructions, see p. 359.)

A, oil reservoir; B, filling plug; C, main oil shut-off valve D, oil outlet from reservoir to feed chamber; E, baffle; F, oil-feed chamber; G, auxiliary oil chamber; H, air vent; J, feed-regulating needle; K, shut-off valve; L, drip nozzle; M, sight-feed glass; N, sight-feed fitting; O, oil outlet; P, operating handle (two positions, "off" and "on"); Q, drain plugs; R, oil-level gauge glass; S, fixing lug; T, air-inlet tube; U, wire-gauge strainer; V, feed nipple; W, return spring for lid of feed chamber F.

A typical driving arrangement is shown in Fig. 231. It is so arranged that the drive is constant for all positions of the reversing gear. Motion is derived from the die block of the expansion link in the Walschaerts valve gear, the mechanism consisting of a small crank attached to the die with suitable rods and linkage, by means of which the lever attached to the shaft of the lubricator is actuated. The feed of the lubricator can be regulated as required by increasing or decreasing the angular

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INSTRUCTIONS FOR OPERATING THE LUBRICATOR

TO FILL.—Set handle P in "off" position. Remove filling plug B and fill reservoir with *clean* oil. Replace filling plug B, making sure that it is screwed down and airtight.

TO OPERATE.—Examine needles J to see that they are clean, and that no foreign matter is accumulated around or in the nipples V. Then replace needles J and move handle P to "on" position.

SPECIAL NOTE.—Handle P has two positions, "on" and "off." It does not regulate the oil feed. Feed regulation is obtained by varying the size of needle J. NO OIL MUST BE POURED INTO CHAMBER F. Lid of chamber F is for inspection purposes only.

Move handle P into "off" position when running into terminal stations, or during any lengthy stoppage. Do not move handle P into the "on" position until the steam regulator is again opened. The small quantity of oil accumulating in each chamber G from feed chamber F flows quickly down the oil pipes to the journals immediately the lubricator is set to work again. When shunting, operate lubricator at intervals sufficient to maintain an oil film on the journals.

Should an axlebox heat, remove needle J of the axlebox feed concerned to increase temporarily the oil delivery until conditions improve, then replace needle J or fit a smaller size needle.

TO DETECT STOPPAGE IN PIPE LINE.—Should oil flood sight glass, it indicates that the feed pipe is choked between the lubricator and the air inlet in the pipe line. If oil appears at the air inlet in the pipe line it denotes an obstruction in the pipe between the air inlet and axlebox. Air inlets should be examined periodically and kept free from dirt.

HOW IT FUNCTIONS.—When handle P is set in the "on" position, oil from the reservoir A passes through main shut-off valve C and along passage D into feed chamber F, where it rises to a level just above top of outlet passage D and is fed through the nozzle L in drops regulated by the needle J fitted in the nipple V. As soon as the oil level in chamber F drops below top of passage D, air enters the reservoir A through the air tube T, destroys the partial vacuum, permits the oil to flow through until it again rises to a level above the top of passage D, and cuts off the air. This cycle of operations is repeated the whole time the handle P is in the "on" position.

When handle P is in the "off" position the main shut-off valve C and shut-off valves K are closed, and oil in the chamber F continues to feed to each auxiliary chamber G until the oil level in chamber F falls to the level of the top of the nipple V.

Immediately handle P is set in the "on" position the oil accumulated in each chamber G quickly flows down the pipes to the journals, while the cycle of operations between the reservoir A and chamber F has allowed the level in chamber F to rise and feed oil past the needle J.

The air tube T regulates the expansion or contraction arising from variation of temperature in reservoir A.

By strictly observing the above instructions an appreciable economy in oil consumption will be effected.

movement of the clutchbox for each revolution. During the period of breaking in, after an engine has first been put to work, the oil delivery can be increased temporarily by placing the pin in the alternative holes provided in the lever on the clutch box or in the lever of the intermediate rocking shaft. Where it is desired to vary the quantity of oil supplied by different pumps the drive should be arranged so that a full stroke of the pump delivers the maximum quantity required. Pumps which are required to give less than the maximum quantity can have their delivery reduced by increasing the distance between the flanges on the driving thimbles R (Figs. 229 and 230) so as to reduce the effective stroke of the pump.

At full stroke each pump delivers ·0276 cub. in. of oil per revolution of the lubricator shaft.

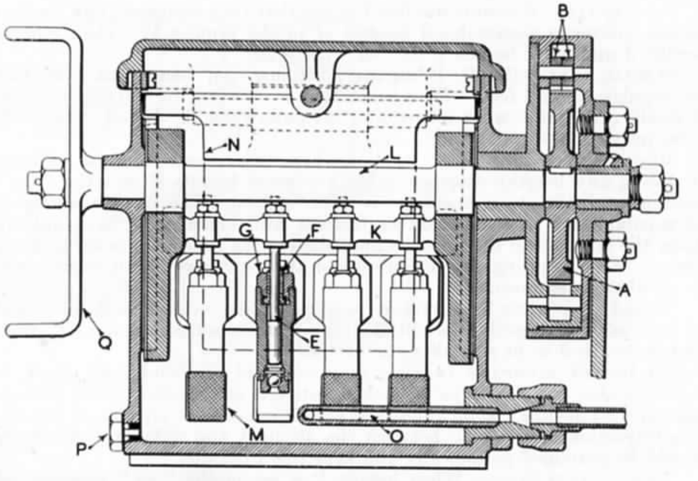


FIG 229.—SILVERTOWN MECHANICAL LUBRICATOR IN SECTIONAL ELEVATION.

Fig. 232 shows the footplate fittings used on G.W.R. locomotives.

It will be seen from the drawing of the backplate in the Appendix that the driver has the regulator and reversing handles, brake, ejector, and lubricator cocks all close together on his side of the footplate.

The fittings are simple but strong, and all have been designed especially for working pressures up to 250 lb. per sq. in.; they are made in the company's works at Swindon.

It will be noticed that all the steam supplies are taken from one fountain, which is fixed on the top of the firebox. Figs. 232 and 233 are detail drawings of the regulator handle, stuffing-box and rod. The regulator handle, because of the height of the firebox, points downwards, and is provided with a tail-piece or indicator which works over the usual quadrant-face with "open"

and "shut" stops. The indicator A is prolonged upwards and fitted with a pin which works in a curved slotted link pivoted at one end and connected at the other to the lubricator controlling valve W. This valve is fixed (Fig. 232) immediately below the regulator shaft centre by a light bracket on to the flange of the stuffing-box.

By this means the supply of oil to the cylinders is controlled by the movements of the regulator handle, and the first steam to reach the cylinders on starting the engine comes through the auxiliary steam pipe and brings with it a supply of oil. The shape of the slot in the link is such that the lubricator controlling valve W is not opened until the indicator has moved away $\frac{3}{4}$ in. from the "shut" stop, and this position is marked by a groove in the guide, into which fits a spring button fitted on the indicator (see Fig. 232).

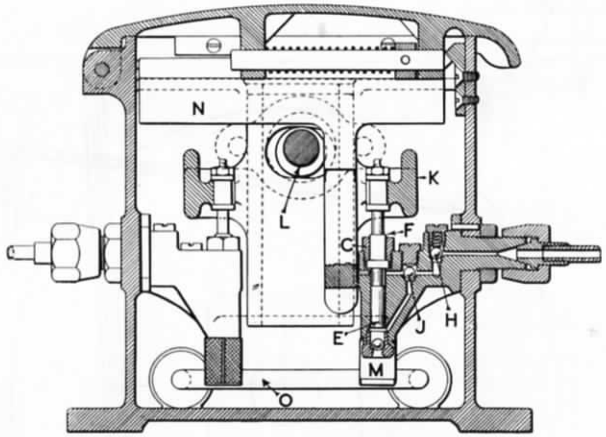


FIG. 230.—SILVERTOWN MECHANICAL LUBRICATOR IN CROSS-SECTION.

The regulator jockey does not admit steam to the cylinders until the pointer on the regulator handle has been moved about $\frac{3}{4}$ in. from its stop, but the valve W is arranged to open just before this occurs.

Fig. 234 gives details of the five sight-feed lubricator, which is of large size (10 pints capacity). It is strengthened with two ribs, which also act as radiators from the steam passage through the centre of which the warming steam passes. The lubricator pipe connections are shown on Fig. 235.

The lubricator works by simple displacement. The steam for this is taken from a small tee-cock T on the "fountain," from which two $\frac{3}{8}$-in. pipes C (both seen in Fig. 232) are made into a spiral coil which acts as a condenser on the inside of the cab roof; the pipes then lead to a two-way cock on the top of the lubricator. The oil rises and flows to the sight-feed control valves, through the aperture from the top of the inside of the lubricator; the oil to the regulator then flows through a small pipe S to the connection for the valve in the smokebox.

The oil supply for the cylinders flows through small pipes D (Fig. 232) to the lubricator controlling valve W, and is picked up by the steam coming from the cock J on the "fountain" through the $\frac{1}{2}$-in. auxiliary steam pipes E to the controlling valve W, and thence by two pipes F, one on each side of the boiler, to the oil distributor nipples in the main steam pipes on the cylinder side of the superheater.

When coasting or drifting, a little steam and oil must be fed to the cylinders without moving the regulator handle far enough to open the "jockey" or regulator. When the regulator handle is fully closed on its stop the lubricator will feed a few drops and

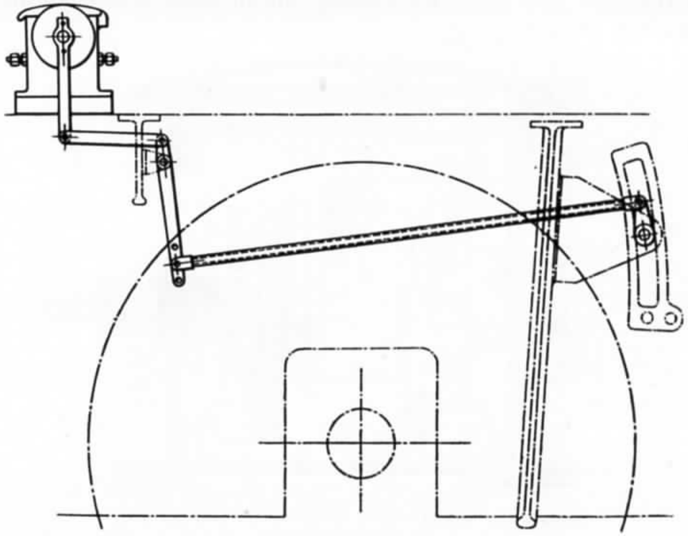


Fig. 231.—Method of Operating Mechanical Lubricator from Die Block of Walschaerts Valve Gear. (See also Figs. 216 and 217.)

then stop altogether. This small quantity of oil will remain in the pipes ready to be distributed to the cylinders when the engine is started again.

The steam supply for warming the oil, when necessary, is taken from a fitting M on the backplate just above the lubricator, and passes through it; the condensation is led to the waste pipe Q below.

It will be seen from the foregoing descriptions and drawings that force feed methods of lubrication for locomotives have reached a highly efficient stage, and that the apparatus used, although differing in form, aims in all cases at ensuring adequate lubrication of the parts concerned. Other aspects of the same subject may now be referred to.

The thick oil which is used for cylinder lubrication is apt to cling to the passages or pipes contained in a lubricator, thereby

impeding the free movement of the oil, and causing the lubricator to show signs of sluggishness, when cleaning out becomes necessary. This can be done by passing petroleum through the various passages and afterwards blowing steam through, to remove the dirty substances which have been loosened by the petroleum. Little more need be said about lubrication, providing the driver adapts himself to the various conditions and circumstances affecting the efficiency of his methods.

The carbonising of the lubricating oil by high-temperature superheated steam interferes with the proper working of piston

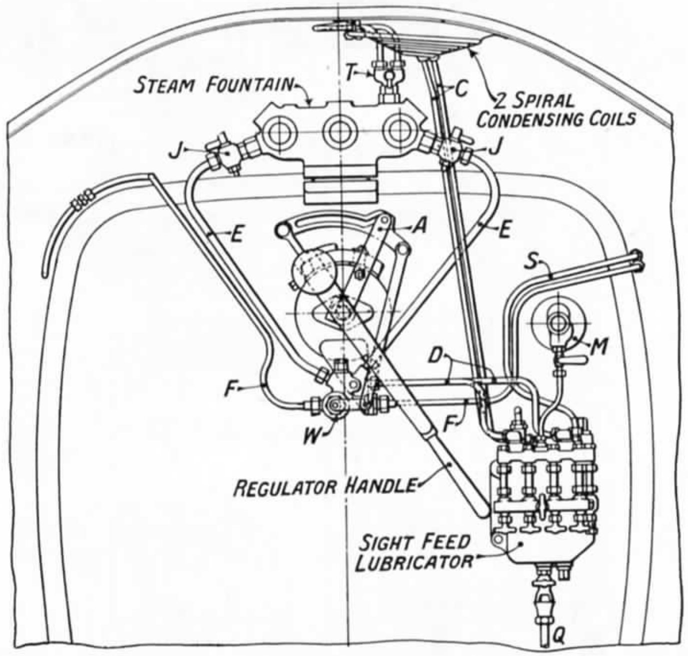


Fig. 232.—Lubricating Fittings in Cab, G.W.R.

rings, piston valves, and so on, causing hardened deposits to adhere to these parts as in a motor-car engine, this action taking place mostly while the engine is drifting. To overcome this carbonisation, what are termed "atomisers" are employed, the action of which causes a jet of steam to be impinged on the pistons and valve when the main regulator is closed.

It is with the object of combining the best points of the two methods of lubrication—the mechanical and the displacement lubricators—that the atomiser valve, as illustrated in Figs. 236 and 237, has been developed for use in connection with the mechanical lubricator on locomotives of the L.M.S.R. These two drawings, if studied in conjunction with each other, clearly show the method of operation. Briefly, the atomiser valve C is introduced in the pipe line between the mechanical lubricator and the steamchest oil inlets. In this valve the oil meets steam coming from a boiler stop-valve A, through the control cock B. Here the oil is broken up into extremely small globules in the manner described below, and then is carried forward by the steam as a kind of spray or oil mist, and delivered in this form through small holes in the periphery of the steamchest liner, so disposed that the incoming steam blows it on to the working surfaces of the valve and piston.

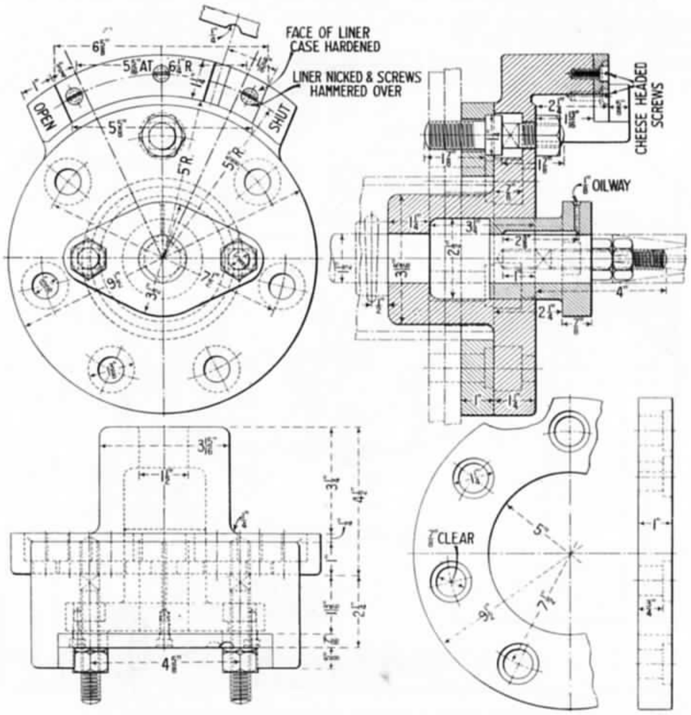


FIG. 233.—DETAILS OF STUFFING-BOX AND OTHER FITTINGS, G.W.R.

Fig. 237 is a detailed drawing of each of the parts used. The boiler stop valve A is placed usually on the side of the smokebox, and represents the master valve controlling the inlet of steam into the system. Its normal position is fully open while the engine is under steam, and a tell-tale hole is incorporated in the valve, so that if the latter inadvertently has been left closed, the driver has immediate evidence of the fact and there is, therefore, no possibility of the engine running for any length of time without the necessary steam supply to the atomiser. The steam, on its way to the atomiser, passes through the control valve B, which is coupled up to the cylinder drain cock gear in such a way that it is in a closed position when the cylinder drain cocks

are open. A notice exhibited in the cab of the locomotive instructs the driver that these cocks must be open every time the engine is brought to a stand, but if for some reason this notice should be ignored, it is possible still to prevent pressure building up in the steamchest by fitting a small ball-type pressure release valve

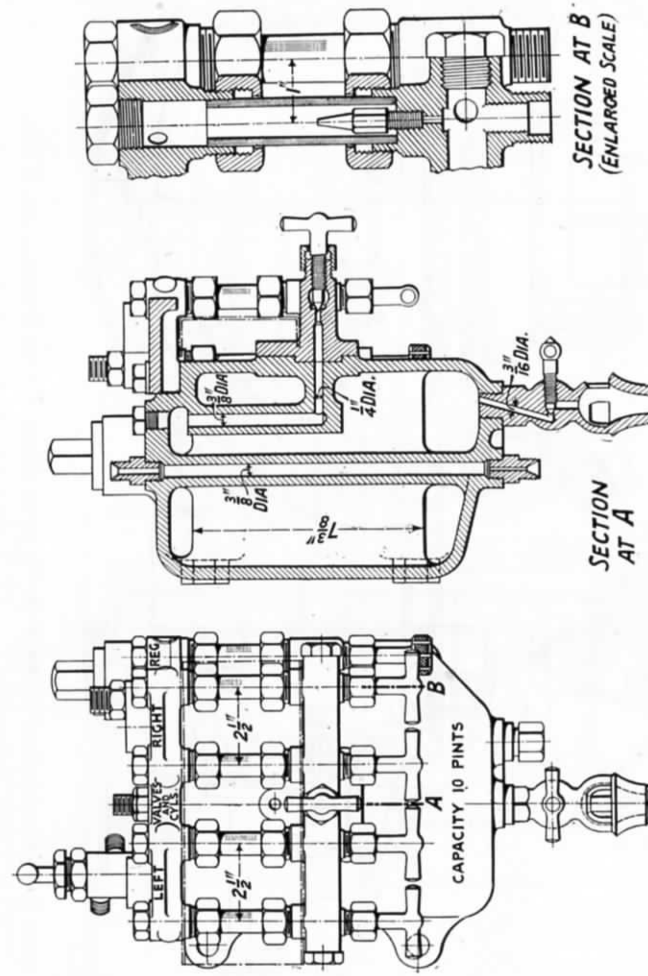


FIG. 234.—DETAILS OF SIGHT-FEED LUBRICATOR FOR REGULATOR AND CYLINDERS, G.W.R.

on to the cylinder air valves, which are connected directly to the steamchest. These release valves open automatically when the engine regulator is closed.

It will be seen from the drawing that the control valve is of very simple and sturdy construction; a small mushroom valve is lifted from its seat by a rocking cam formed on the spindle of the valve. A short lever on the spindle end is coupled by suitable

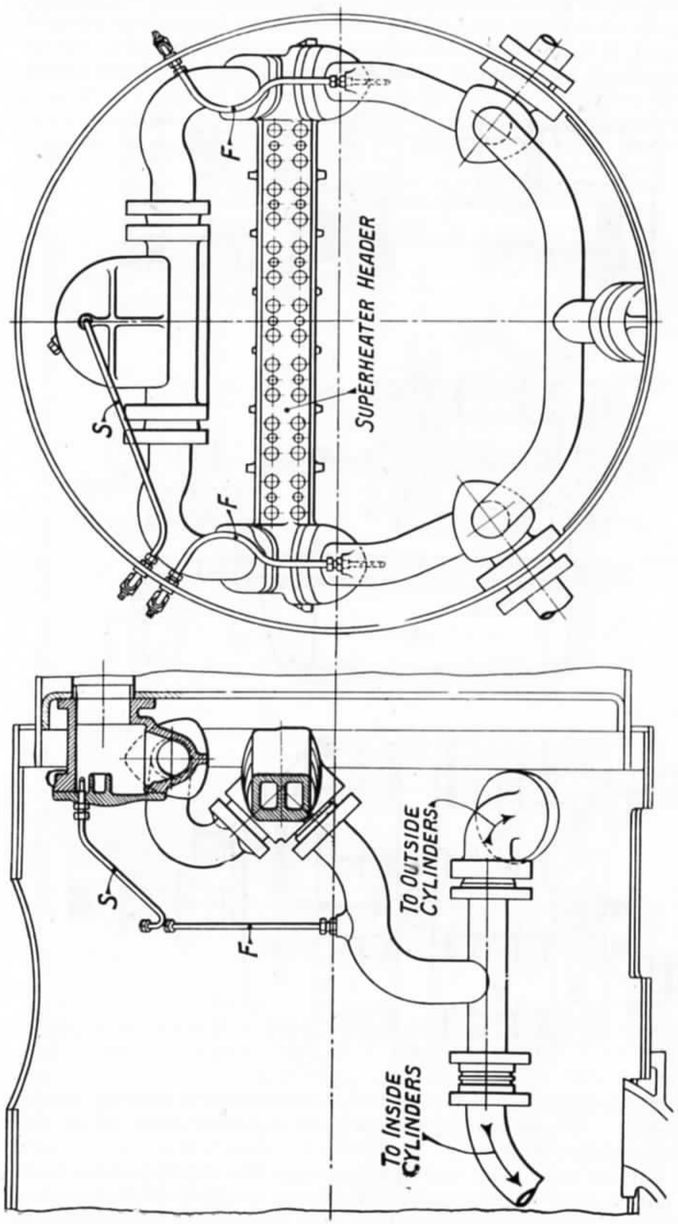


FIG. 235.—LUBRICATION OF FOUR-CYLINDER ENGINES WITH SUPERHEATER, G.W.R.
(Additional piping omitted in two-cylinder engines.)

rodding to the cylinder cock gear, and a return spring bears on the top of the steam valve to ensure that it will remain firmly seated even in the absence of any steam pressure upon its upper face. Consequently, it must bear always upon the face of the cam.

The atomiser C itself takes the form of a casting which may

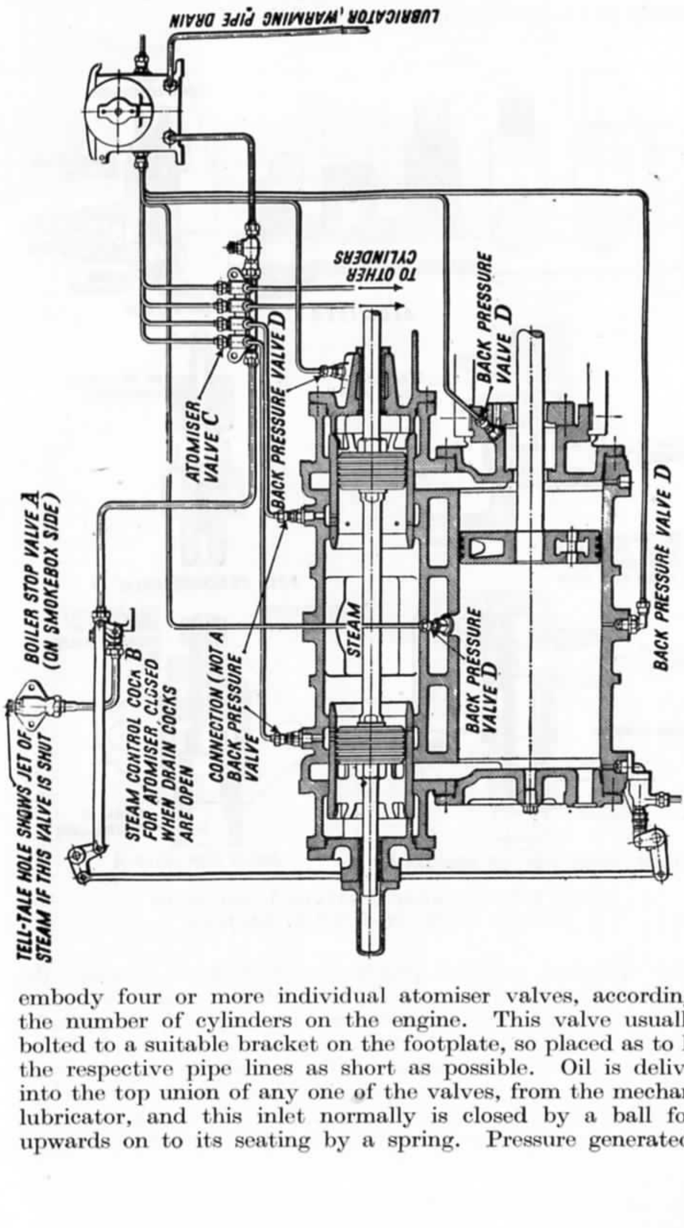


FIG. 236.—SECTION THROUGH LOCOMOTIVE CYLINDER AND STEAMCHEST, SHOWING ARRANGEMENT OF ATOMISER LUBRICATION SYSTEM, L.M.S.R.

embody four or more individual atomiser valves, according to the number of cylinders on the engine. This valve usually is bolted to a suitable bracket on the footplate, so placed as to keep the respective pipe lines as short as possible. Oil is delivered into the top union of any one of the valves, from the mechanical lubricator, and this inlet normally is closed by a ball forced upwards on to its seating by a spring. Pressure generated by a pump in the mechanical lubricator overcomes the effect of this spring, and oil is allowed to enter the mixing chamber. Steam delivered through valves A and B also is led into this mixing chamber. Because of the circular shape and the angles of the ports through which the oil and steam are introduced, a violent swirling motion is imparted to the steam and oil in this chamber, resulting in a very thorough mixture of the two.

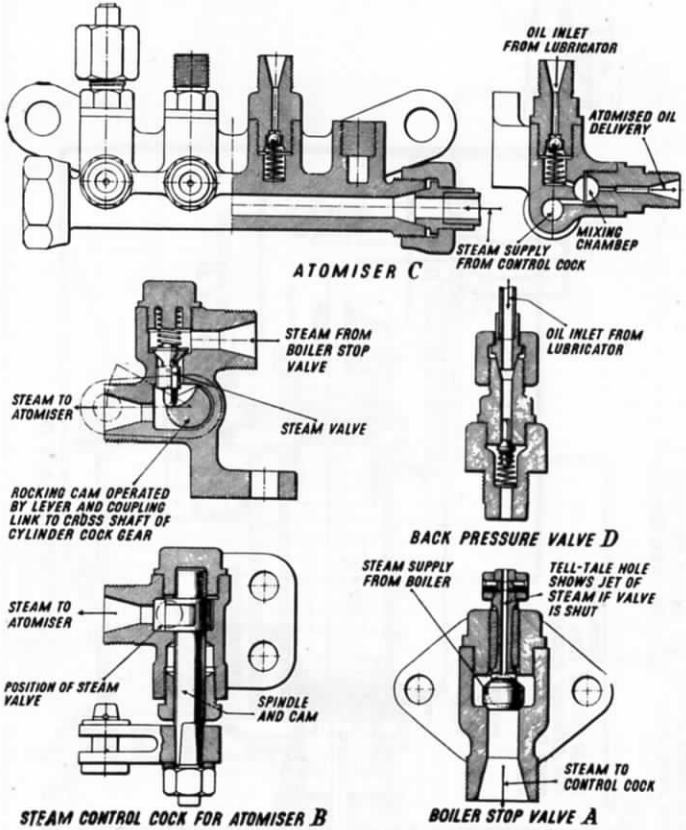


Fig. 237.—Atomiser Cylinder Lubrication System fitted to L.M.S.R. Engines.

The atomised mixture finally passes forward through the horizontal union for delivery to the steamchest; in the steamchest itself the atomised mixture is delivered into a port in the cylinder casting, which surrounds the periphery of the piston-valve liner at its inner end. Small holes are drilled radially through the liner at this point, so that the atomised oil is blown into the steamchest at a number of points in the periphery. The effect of the incoming steam at the main steam pipe is such that the oil is carried forward

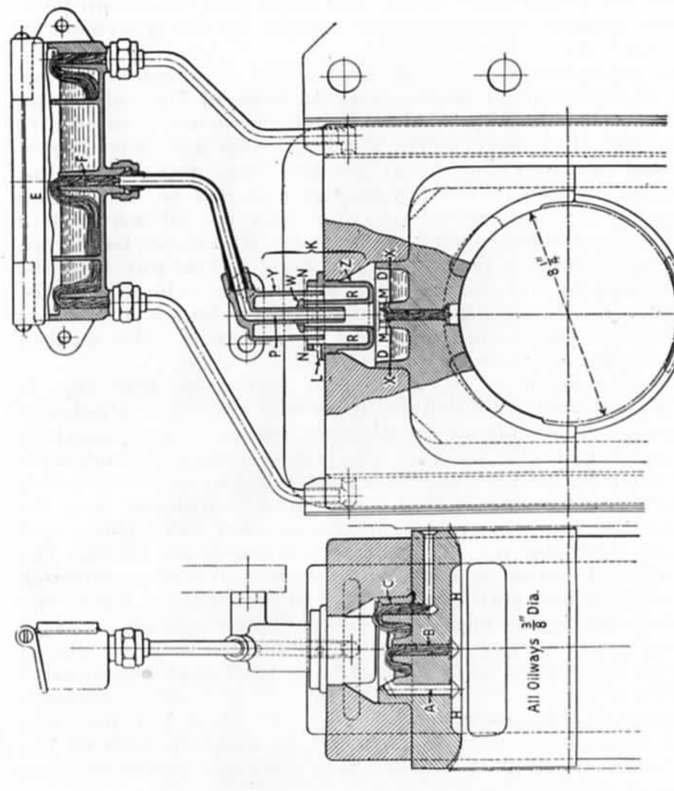


Fig. 238.—Oiling Arrangement for Driving and Trailing Axleboxes, L.M.S.R. (Midland Section).

The oil reservoir D D and the oilways A, B, and C are formed in the bearing brass as shown. The height of the oil outlets above the bottom of the reservoir D D varies. C is the highest and A is slightly higher than B. The oilways B and C are fitted with trimmings, and A is left free. The reservoir D D is filled by pouring oil into the tube F of the auxiliary box E. The normal oil level of D D is shown by the line X——X; as this level is reduced by the oil syphoning through the trimmings B and C, it is restored by the oil syphoned from the middle compartment of the auxiliary box through the trimming in F.

The functions of the trimmings B and C are apparent; the function of the oilway A is to provide means for giving an increased supply of oil to the main bearings as occasion arises. This is accomplished (1) by removing the trimming and pouring oil into F, which will raise the level in D D until the oil overflows into A and so into the gutter H H. (2) Oil can also be made to pass down A by increasing the capacity of the trimming in F so that it will pass more oil than can be carried over by the trimmings B and C.

The arrangement K consists essentially of two parts—the upper part Y is secured to the engine main frames, the lower part Z being screwed into the top of the axlebox. The object of this arrangement is to prevent water and dirt from entering the oil reservoir D D. The drawing shows the axlebox in its normal position, and the lines M M and N N show the position of the tube P for the extreme rise and fall of the axlebox.

In the event of water getting into the chamber R R, the hole L, which must be kept clean, is provided to keep the water level as low as possible.

The washer W slides freely on the tube P, rising and falling with the part Z. Care must be taken to see that this washer is always properly replaced after any of the parts have been disturbed for examination or other cause.

The auxiliary box, as will be noticed, is divided into three parts—the middle compartment being solely for oil to lubricate the main bearings, the two end compartments to provide oil for the axlebox cheeks.

The number of strands in the trimming C should be from 4 to 6, and in B from 8 to 10; these numbers, however, are not hard and fast, and may be made to suit requirements. The trimming F must be made to supply the oil that is necessary for the proper lubrication of the axle.

towards the piston-valve heads, and down into the steam ports into the cylinder, when these are opened by the movement of the piston valve.

The arrangement described ensures that a consistent volume of oil is deposited on the working surfaces of the valves and pistons, so that the wear of these important details is reduced to a minimum. It is found at the same time that less carbonisation is formed on the valves and pistons than with mechanical lubrication working without atomisers. It will be noted from the general-arrangement drawing that only the oil delivered to the steamchest is subjected to atomising. Experience has shown that no advantage is derived from dealing in this way with the oil delivered to the stuffing-boxes and to the cylinder barrels, and consequently these parts are fed directly from a mechanical lubricator through a normal type of back-pressure valve marked D, and shown in section in Fig. 237.

Referring again to the subject of lubrication generally, it may be said that attention to detail and system is absolutely necessary. A bearing or journal, for instance, maintained in good order will give little trouble under ordinary conditions, but if subjected to the slightest neglect is apt to get out of hand. Having once become heated, the rubbing surfaces may be damaged by the seizing or scoring that may take place, and sufficient heat also may be generated seriously to damage the parts affected by the expansion of the metals, so that considerable time, trouble, and patience will have to be sacrificed before the refractory bearing assumes its normal working condition.

Dust or grit picked up whilst running often may damage so seriously the surface of a bearing or journal that considerable attention is absolutely essential to prevent permanent abrasion or scoring of the wearing surfaces. Under these circumstances special methods of lubrication should be adopted, such as the introduction of graphite or some such material, otherwise over-heating or seizure is likely to occur.

At the same time it should be pointed out that, however careful a driver may be, if the various journals or bearings are not properly fitted together in the shops no amount of lubrication will make them run cool. If, therefore, any doubt exists as to the proper adjustment of the different parts because of any particular bearing persistently running warm, a driver should not hesitate to report the matter.

Fig. 238 illustrates the oiling arrangement for driving and trailing axleboxes on the L.M.S.R. (Midland Section). This is retained on a number of the older engines, although all the modern types are equipped with mechanical lubricators.

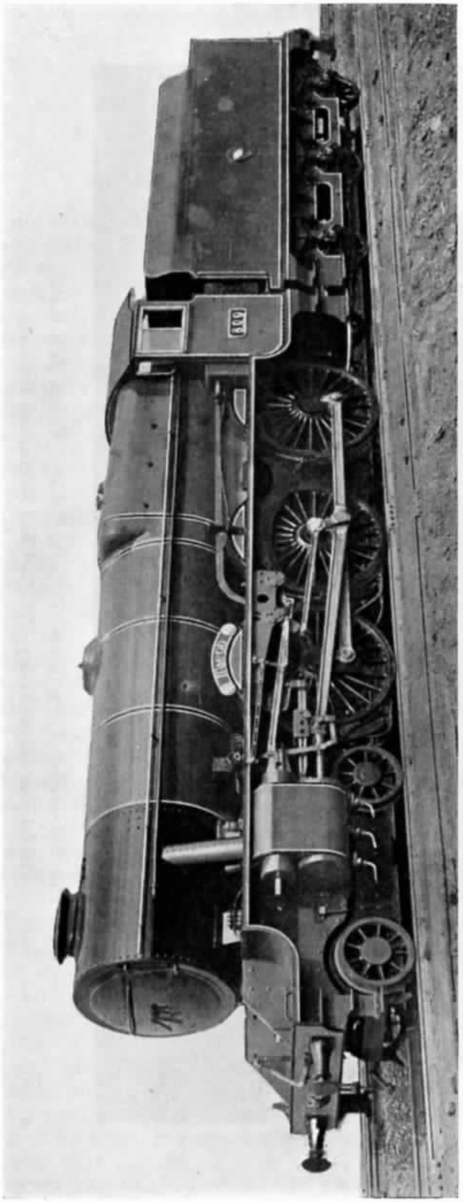


Fig. 239.—4-6-0 Locomotive No. 800, *Maeve*, Coras Iompair Eireann.

Mr. E. C. Bredin, Chief Mechanical Engineer (*retired*).

Cylinders (3), 18½ in. by 26 in. Coupled wheels, 6 ft. 7 in. diameter. Coupled wheelbase, 15 ft. 9 in. Boiler pressure, 225 lb. per sq. in. Total heating surface, 2,338 sq. ft. Grate area, 33·5 sq. ft. Weight of engine in working order, 135 tons. Tractive effort (at 85 per cent. b.p.), 33,000 lb.

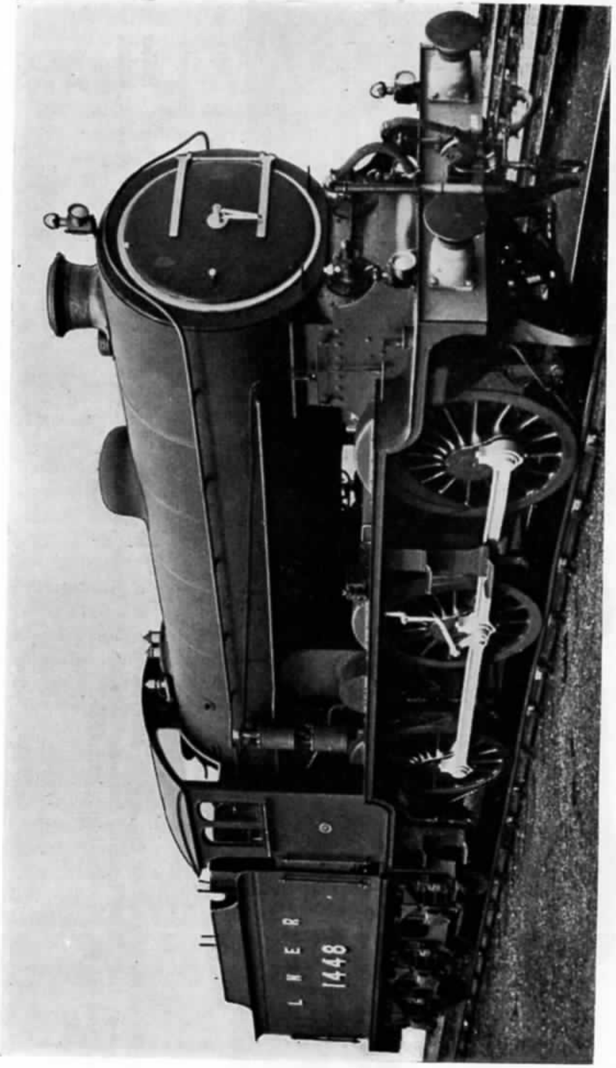


FIG. 240.—0-6-0 TYPE GOODS ENGINE, "J.39" CLASS, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders, 20 in. by 26 in. Wheels, 5 ft. 2 in. diameter. Engine wheelbase, 17 ft. Boiler pressure, 180 lb. per sq. in. Total heating surface, 1,669·58 sq. ft. Grate area, 26 sq. ft. Weight of engine in working order, 57 tons 17 cwt. Weight of engine and tender in working order, 110 tons 7 cwt. Tractive effort (at 85 per cent. b.p.), 25,664 lb.

CHAPTER 15

CLEARING HOUSE RULES

THE importance of a thorough knowledge of the rules cannot be over-estimated, and the following extracts have been made from the Clearing House rule book to form a ready means of reference to all the more important rules covering the duties of drivers and firemen. These are extremely comprehensive, and are designed to cover as far as possible every difficulty that may arise. For his own guidance and protection in cases of emergency, as well as everyday working, the driver or fireman will recognise that an intimate knowledge of the rules is essential.

	Rule No.
PUBLIC SAFETY of first importance	2
MISCONDUCT PUNISHABLE	4
REGULATIONS: notices and working time-table, etc., to whom supplied	7
NO PERSON TO RIDE ON ENGINE without special authority	9
SERVANTS NOT TO EXPOSE THEMSELVES TO DANGER	11, 126 (vii)
OBSERVANCE OF DISTANT SIGNALS	36
HOME SIGNALS	37
SIGNALS and verbal instructions	37 (*b*), 38, and 39
DRIVERS TO UNDERSTAND CLEARLY VERBAL INSTRUCTIONS or communications	40, 41
CALLING-ON SIGNALS	44
STARTING SIGNALS not to be passed *except*	44, 45, 55 (*g*), and 197
TRAINS BROUGHT TO A STAND at starting or advanced starting signals	39 (*a*), 39 (*c*), and 41 (*b*)
SHUNTING SIGNALS	46 and 47
SIDING SIGNALS	48
TRAIN STANDING OR ON WRONG LINE, DRIVER TO WHISTLE and signalman to be reminded by guard, shunter, or fireman of position of train	55
GUARD, SHUNTER, OR FIREMAN TO GO TO SIGNAL BOX	55 (*a*) and (*f*)
WHEN TWO TRAINS APPROACH A JUNCTION at the same time, reversing of signals	70
SIGNALS NOT IN USE	80
DEFECTIVE HOME, STARTING, ADVANCED-STARTING, OR SIDING SIGNAL, and duties of hand signalman	78, 81
SIGNALS IMPERFECTLY SHOWN	82

	Rule No.
DETACHING ENGINE from train standing on wrong line. Driver responsible for seeing that guard places red light on front vehicle before moving his engine	152 (*b*)
SHUNTING OPERATIONS. Driver not to move his engine during shunting until he has received hand signal from person in charge, although the fixed signal may be lowered .	108, 109
IN CASE OF A LIGHT ENGINE unaccompanied by guard or shunter, driver to satisfy himself that points are in proper position . .	111 (*c*)
IRREGULARITY IN WORKING OF SIGNALS. Cattle on line, etc.	155 (*a*), (*b*)
ENGINE RUNNING ROUND A GOODS TRAIN, to remove it from running line	154
PROTECTION OF TRAIN. Place one detonator at $\frac{1}{4}$ mile, one at $\frac{1}{2}$ mile, and three 10 yd. apart $\frac{3}{4}$ mile from obstruction and exhibit the hand danger signals while going along .	179 (*a*)
PLACE THREE DETONATORS opposite signal box, explain circumstances to signalman, and return to train unless necessary to take an assisting engine	181 (*a*)
WHEN BOTH LINES ARE OBSTRUCTED . .	179, 180
ENGINE DISABLED	180 (*a*)
BOTH LINES OBSTRUCTED and driver not aware of accident	180 (*d*)
TRAIN DIVIDED	182
TRAIN OR PORTION OF TRAIN left on running line from accident or failure of engine .	183 (*a*) to (*k*)
DIVIDING GOODS TRAIN	〃
TAIL LAMPS	〃
TWO GUARDS WITH TRAIN	〃
ONE GUARD WITH TRAIN	〃
ENGINE RETURNING ON WRONG LINE to rear portion	〃
TRAIN STANDING ON RUNNING LINE because of failure of engine or other causes . .	〃
FIREMAN GOING FOR ASSISTANCE	〃
DRIVER NOT TO PASS SIGNAL BOX without permission	〃
TRAIN OR PORTION OF TRAIN PASSING ON WRONG LINE for a short distance in case of accidents	184
WHEN MOVING IN WRONG DIRECTION . .	185
CATCH POINTS	186, 195, 196
FAILURE OF, OR ACCIDENT TO some part of a train	187
IF ENGINE DEFECTIVE	187 (*b*)
IF REAR GUARD DOES NOT APPLY BRAKES PROMPTLY	187 (*c*)
IF CONTINUOUS BRAKE NOT IN OPERATION .	187 (*d*), (*e*)
VEHICLE ON FIRE	188

	Rule No.
SINGLE-LINE WORKING BY PILOTMAN. The signalman at each end of the single line must advise the signalman at the box in the rear, and the latter must stop each train proceeding in that direction and inform the driver of the circumstances. When worked as single line a hand lamp should be placed outside the distance signal applicable to that line and three detonators placed on the rail for each approaching train. The pilotman, wearing a distinctive badge or red flag tied round his left arm, must be present and ride upon the engine unless two or more trains are going in the same direction, when he must order the trains to proceed and ride on the last engine going in that direction .	189, 193
LIMIT OF SINGLE-LINE WORKING . . .	190, 191, 192
NO TRAIN MUST BE ALLOWED TO ENTER on the single line unless the engine driver and guard have been first informed by the pilotman that the single line is being worked and the points between which it is in operation .	202
TWO OR MORE TRAINS FOLLOWING. Driver of each train following must be told by the pilotman how long the preceding train has been gone	202 (*b*)
DRIVERS MAY PASS SIGNALS ON SINGLE LINE when so instructed by the pilotman . .	197 (*a*), (i) to (iv)
WHEN BLOCK WORKING IS MAINTAINED the fixed signals at intermediate boxes must be worked for trains passing over the single line in both directions. When block working is suspended the fixed signals must be kept at danger and the signalman must hand-signal the driver past the signals when the line is clear for the train to proceed . .	197 (*b*)
TRANSFER OF PASSENGERS when both lines are blocked, etc.	207
SPEED OF TRAIN ON SINGLE-LINE WORKING. Trains must be run cautiously and at reduced speed. Drivers must use the engine whistle frequently when passing through tunnels, or after sunset, in foggy weather, or during falling snow; a red headlight must be carried also	204
CATCH POINTS. When a train is approaching catch points in the facing direction, the man at the points, when they are right for the train to pass over them, must give the driver a green all-right signal held steadily in the hand; the pilotman also must satisfy himself that the driver is aware of the position of the catch points . . .	195 (*a*), (*b*), 196 (*a*)

	Rule No.
DRIVER TO SATISFY HIMSELF that the catch points are in proper position	196 (*b*)
PROTECTION OF TROLLEY on running line .	215
PROTECTION OF RUNNING LINE in case of obstruction	194, 217
SIGNALS DURING RELAYING, ETC.	216 (*a*) to (*d*)
REDUCTION OF SPEED FOR PERMANENT-WAY WORK. Warning board with green and white light at night placed ½ mile from the place to be protected for a long period. Man with detonator out ½ mile, or farther if rendered necessary by circumstances; green hand-signal for shorter periods. Where indicators are provided which are illuminated at night, the letter "C" in black on a white background denotes the commencement of the speed restriction. The letter "T" in white on a black background denotes the termination of the speed restriction	218
WORKING OF BALLAST TRAINS. Entering and running through tunnels	216, 235, 236
See special book for working single lines of railway by electric staff or staff and ticket.	

Some companies have special rules for tunnels, and so on, which are not inserted in the foregoing, and the rule numbers as quoted also may be varied.

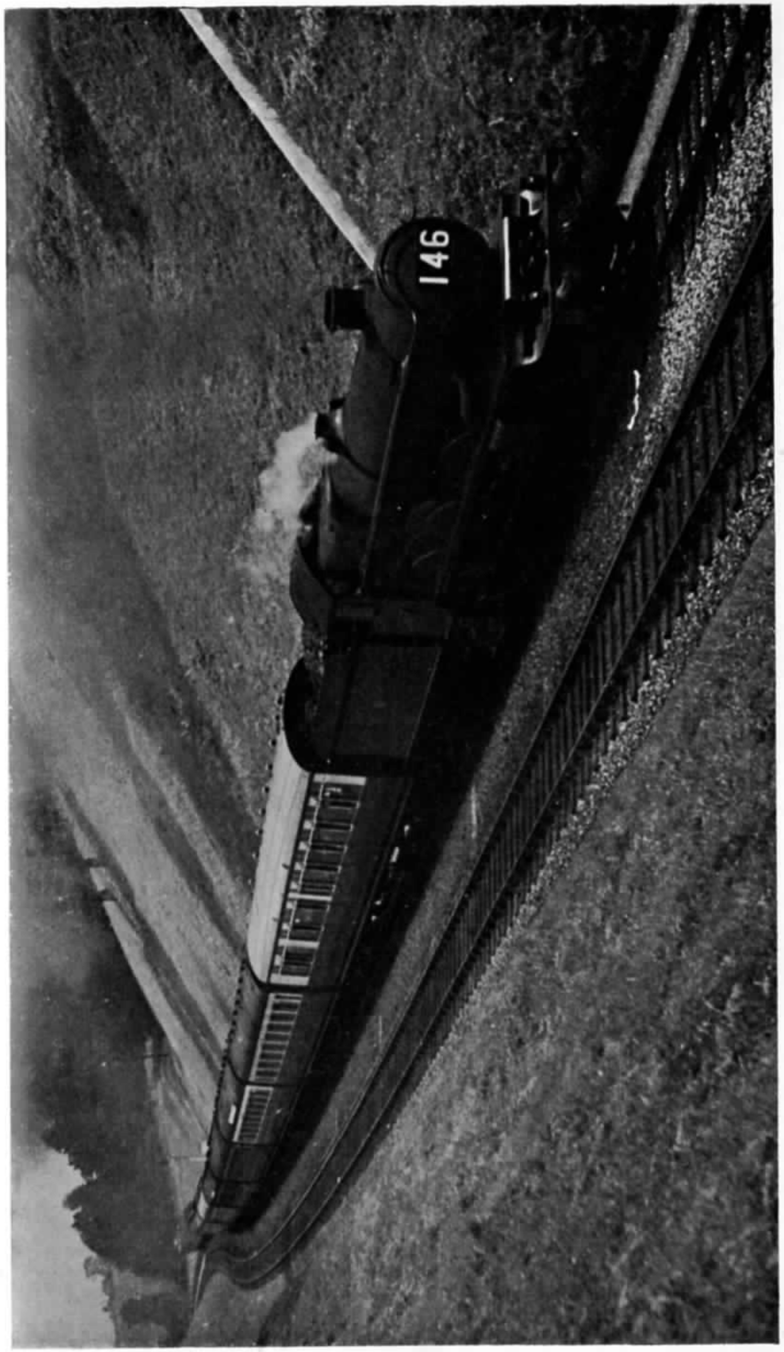


FIG. 240A.—PADDINGTON-NEWQUAY EXPRESS APPROACHING WHITEBALL TUNNEL, G.W.R., HAULED BY 4-6-0 LOCOMOTIVE No. 5021, *Whittington Castle.*

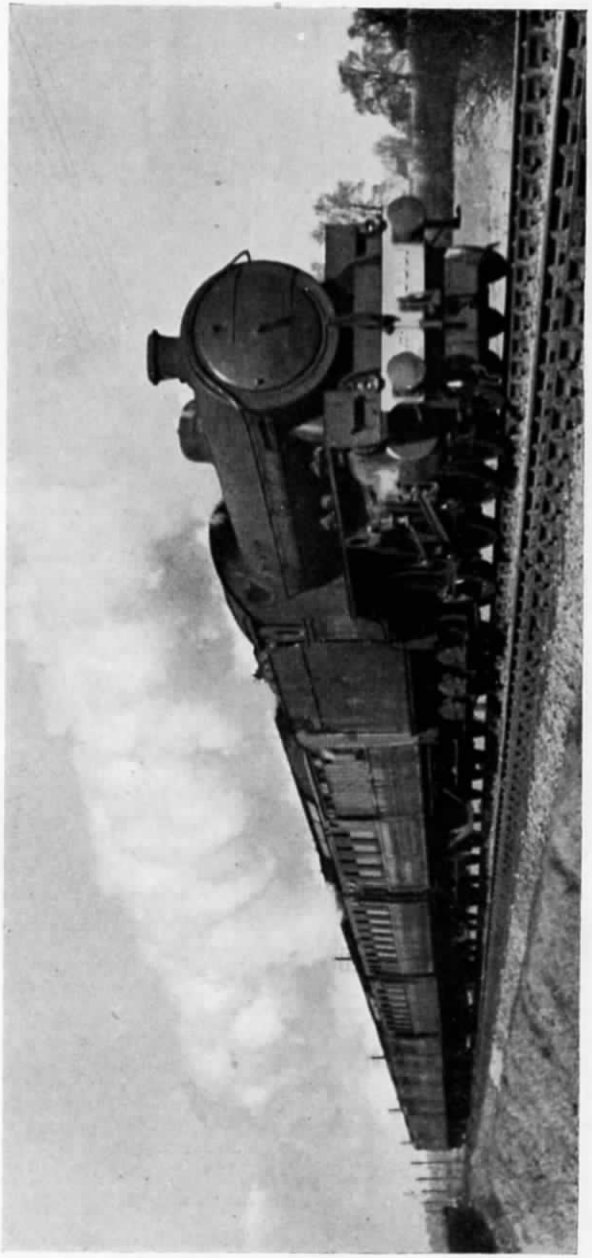


Fig. 241.—Marylebone-Manchester Express near Rugby, L.N.E.R., hauled by "B1" Class Engine No. 8301, *Springbok.*

Chapter 16

DUTIES OF THE DRIVER

Having successfully passed through the cleaning and firing stages of his career, the spare driver, by virtue of the time he has spent upon the footplate, will have gained sufficient experience to know that it is practically impossible to obtain or to give information beforehand regarding every difficulty that may present itself during his daily work. So much depends upon outside circumstances, such as signals, amount of traffic on the line, engine failures, etc., that his individuality and discretion, combined with the manner in which he attends to the various details connected with his duties, will always have a direct bearing on his success or failure as a driver. It is during the first twelve or eighteen months that the young driver will have to show that his promotion was merited, and a few slight mishaps or casualties during that period may greatly retard his progress and seriously impair his future prospects. His record will be compared to some extent with that of others who have had many more years of experience, and he may often find himself on an engine not in the best of condition, or with a fireman for mate who is sometimes new to his duties. The following is therefore intended to emphasise the importance of a few of the various details connected with daily work, and which, when properly applied, go to make the successful driver by giving the necessary confidence for the proper discharge of his duties, leaving absolutely nothing to chance.

After having signed the appearance book, and obtained the number of his engine from the sheet, the driver should see what is entered for his engine in the report book. Any special bills or road book that may be necessary should be signed for, and the notice boards examined carefully for orders respecting water, repairs to the line, alterations to signals, etc. To prevent the occurrence of any mishap for which he would be held responsible, the driver should write out on paper the stops and running of his train. In this way any detail affecting the daily work, whether in time book, rules, or special bills, will be committed to memory before the beginning of the journey.

After the various notices and instructions have been noted, he will go to his engine and first examine the gauge glasses to ascertain the amount of water in the boiler. The water level should be verified by blowing the gauges through. At the same time, a glance at the pressure gauge will show whether steam is generating in sufficient quantities, and the fire may be regulated accordingly. A brief glance into the firebox will show the state of the fire, and the condition of the tube ends, fusible plugs, and brick arch should be noted. The tanks should next be inspected to make sure that there is sufficient water for the boiler, and the coal examined as to supply and mode of stacking. The injectors should be tested to see that both are in proper working order, and the tools, lamps, fire-irons, detonators, etc., overhauled, so that a complete set may be at hand. The engine, assuming it to be "right hand," *i.e.*, right-hand crank leading when running in fore gear, should be placed on the pit with the right-hand crank on the bottom centre, brake hard on, reversing lever in mid-gear and cylinder drain-cocks open. The driver should pass underneath with suitable spanners, testing all nuts on glands and rod-ends. Make sure that they are securely locked in position. Lock nuts, split pins, and all such devices are specifically adopted as a safeguard for retaining the various pieces of motion-work, etc., in proper position, and the loss of the least of these may lead to dangerous consequences or serious delay. A cursory or incomplete examination is therefore little or no better than none. With the cranks as stated the whole of the crank axle, big ends, motion-work, etc., may be examined and oiled. At the same time the big ends may be tested for adjustment and the wear taken up if necessary. This should be done by degrees, so that the tendency to knock may be prevented by maintaining the brasses in proper contact with the journals and thus reducing the risk of melting the anti-friction metal by the journal heating-up, as would be likely to occur if neglected, or the cotter driven home too tightly. The back and front slide-bar bolts, eccentric sheaves, straps, rods, bearing-spring connections, and the long reversing rod, etc., should be examined in a systematic manner. Look into the ashpan to see whether ashes have been cleared properly, and note the condition of firebars. Having been satisfied that there is a suitable supply of sand, the driver should make sure that the sanding gear and brake gear on engine and tender are in proper working order, noting at the same time that the hose connections are intact and in good condition. The plug on the vacuum reservoir should also be removed occasionally for draining the accumulated water.

The drip valves and all brake connections having been examined, the driver should then mount the footplate and pull ejector handle in the "full on" position before opening the small ejector steam valve, otherwise a certain amount of water is invariably discharged from the ejector exhaust pipe in sufficient quantities to dirty the smokebox and boiler.

With the ejector handle in "full on" position, it will be found that this water is mostly deposited in the smokebox and not up the chimney, as when steam is first admitted with the handle in "running" position. Having returned his handle to the latter position, the driver, by observing the pointer of the vacuum gauge, can assure himself that the brake is in proper working order. This is also particularly applicable after an engine has been coupled to a passenger train, insomuch that the time occupied in creating the vacuum would denote whether the whole or part of the train had been left uncoupled inadvertently.

The double-acting air-pump on engines fitted with the Westinghouse brake should be examined and the plug in the main reservoir, as well as the bottom cap of the drip cup, should be unscrewed at least once a week, or more frequently in frosty

weather. The air cylinder of the pump should be lubricated sparingly and the oil cup, provided on the top of the cylinder, should therefore be filled not more than once a day with a suitable lubricant; tallow or vegetable oils are unsuitable for this purpose.

The best mineral oil should be used for the steam cylinder, and the pump should be started slowly to allow the condensation to escape from the cylinder, thereby preventing the knocking which is likely to occur when the air pressure in the main reservoir is low. The gland packing on the piston rod should be maintained in good condition to avoid the leakage of condensation down the rod and into the air cylinder. The driver's brake valve should be tested in the different positions, and an inspection made to see that the proper pressure is retained in the main reservoir when the handle is placed in the "Position Whilst Running."

The underside inspection being finished, the engine may be moved so that both cranks are at the top, that is, equidistant from the top centre, in which position, with the reversing lever put in mid-gear, the remainder of the motion-work, little ends, drag links, axleboxes, and side rods, etc., may be examined and oiled. This position of the side rods is also suitable for the examination of the motion-work and big ends, etc., of an outside cylinder engine. After an engine has been standing for any length of time, it is important that the driver or fireman should make sure the cylinder drain cocks are open, to allow the escape of any water, due to condensation, that may be present in the cylinders when the regulator is opened.

It is also good practice, after a wash-out, or when the engine has become thoroughly cooled, to blow steam through the cylinders, not only that they may be drained properly but also to heat up the cylinder metal, thus reducing initial condensation when the engine begins working.

The driver should see that the right lamps are exhibited when he is leaving the shed, and should back up to his train carefully. He will also be expected to start away without jerking, whether it be goods, mineral, or passenger train, carelessness in this respect often resulting in broken drawbars, etc. The fireman should be instructed how to work his fire to obtain the best results, and should also be taught when and where to fire, so that both he and the driver can be on the look out for signals at the proper places.

The geography of the road should also be explained, and the fireman shown how to prepare his fire when approaching a rising gradient. Special attention should be paid to the regulation of the boiler-feed supply, and the dangers of too much or too little water in the boiler explained clearly to the fireman. The locality of the junctions, crossings, and curves must be known thoroughly so that the speed may be reduced to its proper limit at the right time. This point should not require emphasising, as the consequences of disobedience to the regulations are so serious.

A driver will require to have been on the road some considerable time and to have also been very observant before he can form anything like an accurate estimate of speed from the swing of his engine, the velocity at which standing objects are passed, or the sound of the rails, etc. The instinct by which speed is estimated is acquired only after years of experience, and it is advisable to use some precise method to assist in acquiring the necessary power of judgment. The telegraph poles alongside the line, for instance, are usually placed from 60 to 70 yd. apart where the road is straight, and thus form a ready means whereby the distance travelled by the engine in a given time may be determined. There are 1,760 yd. in a mile, and taking the distance between the poles as 60 yd. there will be 29·33 poles fixed to the mile, so that after allowing for slight curvatures or deviations in the road 30 poles will be a fairly accurate and very convenient unit upon which the calculations may be based. The speed of a train is generally expressed in miles an hour, and it is therefore obvious that if the train is travelling at the rate of 60 miles, which equals one mile a minute, 30 poles must be passed in that time. From this we obtain the general expression that double the number of poles passed in a minute gives the speed in miles an hour. Under certain conditions of weather and locality, the poles will be invisible or otherwise not available, and some other means of measuring the rate of speed will be necessary.

The number of rail lengths traversed in a given time provides a ready basis of calculation. Rails 60 ft. (20 yd.) long are now the standard practice on British railways, although the older 45-ft. (15-yd.) rails are still to be found on many main lines, and experimental lengths of 120-ft. (40-yd.) rails have been laid. With 60-ft. rails, there are 88 rail lengths to the mile ; and with 45-ft. rails, 117·3 rail lengths. Hence, with 60-ft. rails :

88 rail lengths per min.	=60 m.p.h.
44 ,, ,, ,,	=30 ,,
22 ,, ,, ,,	=15 ,,

If divided up with 88 rails and 60 sec. as constants, it will be found that the number of rails passed over in 41 sec. is approximately equal to the speed in miles an hour.

The relation between the number of rails and the number of telegraph poles may be found by dividing the average distance between the poles by the length of the rails. Thus, with poles 60 yd. apart, and 60-ft. (20-yd.) rails, there would be three rail lengths between each pole ; and with 45-ft. (15-yd.) rails, four rail lengths.

As the number of poles per mile, and the length of the rails, vary in different localities, some general rule adaptable to all circumstances will be appreciated. It will be noted that the number of seconds bears a constant ratio to the number of poles or length of rail ; hence, when travelling at 60 m.p.h., each pole, when there are 30 to the mile, represents 2 sec. in time. From this, it is evident that, whatever the spacing of the poles may be, the number of poles passed in as many seconds as the poles are yards apart (or the number of rails passed in as many seconds as the rails are yards in length) multiplied by 2, will give the speed at which the engine is travelling in miles per hour. Thus,

by using the equal yards and seconds, any speed may be calculated approximately, such as :

Poles.		Yd. apart.		Sec.		M.p.h.		Poles.
30	at	60	passed in	60	=	60	or	30×2
30	,,	65	,,	65	=	60	,,	30×2
30	,,	70	,,	70	=	60	,,	30×2

or

Rails.		Yd. long.		Sec.		M.p.h.		Rails.
15	at	20	passed in	20	=	30	or	15×2
10	,,	20	,,	20	=	20	,,	10×2
5	,,	20	,,	20	=	10	,,	5×2

This formula may be used for 45-ft. rails, or other rail lengths, which still survive on certain branch lines. For example, with 45-ft. (15-yd.) rails, 20 rails at 15 yd. long passed in 15 sec.= 40 m.p.h. (or 20×2).

It should be emphasised that complete familiarity with the spacing of the telegraph poles or the length of the rails is essential before the estimation of speed by these methods is attempted.

SPEED INDICATORS

The continued growth of traffic and increase in the speed of trains have called for the strictest adherence to the prescribed running times, and a corresponding demand has arisen for a reliable apparatus by means of which a check can be kept on the locomotive's movements.

With a reliable speed indicator a driver is relieved from the necessity of continually having to gauge his speed, and can concentrate on the look-out. Moreover, the knowledge that excessive speed at any point of the run will be automatically recorded is a safeguard against the disregard of the regulations.

The Teloc speed indicator and recorder, manufactured by the Hasler Telegraph Works (Fig. 242), together with the Tel RT835 speed indicator and recorder, and a slightly modified instrument, the Teloc RT935 (Fig. 243), were introduced to meet the requirements of a number of locomotive engineers, who desired a paper feed on a mileage basis in preference to the original Hasler instrument, which has a paper feed on a time basis. These instruments are constructed on the same fundamental principle as the Hasler recorder. The Teloc instrument is driven by gearboxes and rigid shafting, and the Tel RT835 and RT935 instruments are driven by means of a 10 mm. diameter flexible shaft with a steel-lined outer cover, and a small ball-bearing gearbox. The instruments indicate continuously :

1. The speed at which the train is travelling ;
2. The total number of miles since the instrument was installed ;
3. The mileage of each journey (this indicator can be set to zero) ;
4. The time of day in hours and minutes.

The diagram shows a continuous record of :

1. The speed attained at any point of the run ;
2. The time the engine or coach is at work ;
3. The distance covered ;
4. The duration and point of stops ;
5. The time of day in hours and minutes.

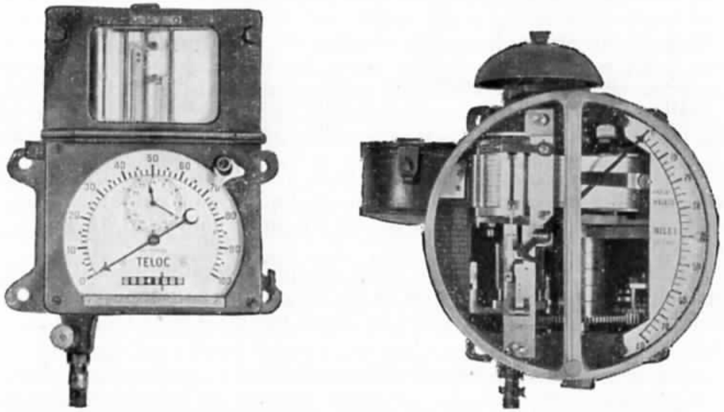


FIG. 242.—THE TELOC AND HASLER SPEED INDICATORS AND RECORDERS FOR LOCOMOTIVES (Hasler Telegraph Works)

FIG. 243. — LATEST PATTERN TEL RT 835 SPEED INDICATOR AND RECORDER.

Teloc speed indicators and recorders have a paper feed on a mileage basis of 5 or 10 mm. per mile, and holes are perforated in the upper and lower edge of the chart every 5 mm. to correspond to half or one mile. Consequently, the length of a diagram of a certain track is always the same irrespective of the speed of the train, as the paper chart moves in proportion to the distance travelled.

The paper feed of the latest speed indicators and recorders is on a distance basis of 5 mm. per mile when the locomotive is travelling, and changes over automatically to 5 mm. per hour when the locomotive is standing. The hours are punched at the top of the paper in figures, and the minutes are recorded in a space 20 mm. wide exactly below the hour by a stylus rising and falling six times during the hour, so that the distance from the bottom to the top of this record is equivalent to ten minutes. Each half-mile or kilometre is punctured at the top and bottom of the paper. A short length of record taken from one of these instruments is illustrated in Fig. 244, from which it will be noted that the

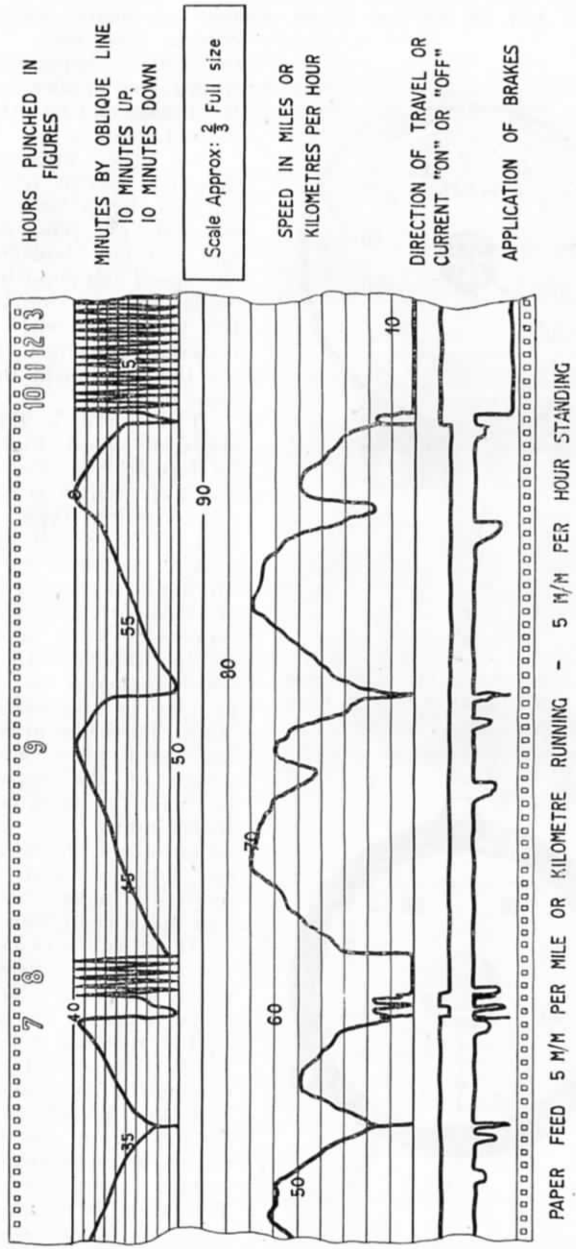


FIG. 244.—SHORT LENGTH OF RECORD TAKEN FROM TELOC RT 935 SPEED INDICATOR AND RECORDER.

instrument can, if desired, be provided to record the direction of travel, and, in the case of an electric locomotive, when the current has been "on" or "off." Apparatus to record the application of the brakes can be fitted if desired.

All the instruments described above are unaffected by vibration or changes of temperature and are not damaged if the speed temporarily exceeds the maximum of the scale. Forward and backward movements actuate the instrument in the same manner.

The Stone-Deuta electrical speed indicator for locomotives (Figs. 245 and 247), which is of the non-recording type, consists of a geared transmitter, actuated by the driving on a coupled wheel of a locomotive, electrically connected to a moving-coil instrument in the cab, which indicates the speed in miles or kilometres per hour. Particular attention has been given to the design of the apparatus to make it suitable for withstanding the severe vibration and shocks which are inherent with locomotives under modern high-speed conditions.

It consists of two essential units: a transmitter, which generates a voltage proportional to the speed of the rotating wheel to which it is coupled, and a moving-coil instrument or indicator, placed at any distance from the transmitter, which measures the voltage thus generated. The scale is marked in miles or kilometres per hour.

FIG. 245.—THE STONE-DEUTA ELECTRICAL SPEED INDICATOR FOR LOCOMOTIVES.

FIG. 246.—STONE-DEUTA MECHANISED SPEED INDICATOR.

The special features of the indicator are:

(*a*) The large dial range, which permits an angular needle deflection of 280° without gearing.

(*b*) Adjustment for varying wheel diameter, the range for which may be as great as 25 per cent. either side of the mean diameter for which the instrument is calibrated initially.

The transmitter generates alternating current, and is built substantially for continuous running. For locomotive applications, the alternator is normally driven through a 1 to 2·5 gearbox from one of the driving wheels by means of a return crank fixed to the crank or coupling-rod pin, Fig. 248. This also shows a typical gearbox suspension bracket, in which the main spindle of the gearbox is coincident with the centre line of the axle. The indicator will read clockwise irrespective of the direction of rotation of the alternator.

The indicator is of the moving-coil type (giving 280° without gearing). The coil moves in the field of a permanent magnet. The dial face is 6 in. diameter.

When the indicator is correctly fixed, *i.e.*, in the position in which it was calibrated and at calibrated temperature, the combined accuracy of the transmitter and indicator is within 0·25 m.p.h. at any part of the scale. Temperature errors are negligible over a wide range.

FIG. 247.—ALTERNATOR AND GEARBOX FOR STONE-DEUTA ELECTRICAL SPEED INDICATOR.

Adjustment for tyre wear is provided by a rheostat incorporated in the instrument itself and is easily accessible from the back by means of a small detachable key (Fig. 249). This key sets the scale, also on the back of the instrument, to conform to the diameter of the wheel. The range of this adjustment is such that the same equipment can be transferred to other locomotives with smaller wheels to facilitate standardisation of speed-indicator equipment.

In addition to the electrically operated speed indicator previously described, this firm also supplies an adjustable indicator (recording or non-recording) of the eddy current or drag type, operated by mechanical transmission. This is shown in Fig. 246.

In this equipment a torsionless wire drive connected directly to a freely suspended gearbox rotates a " C " type magnet enclosing a light weight armature, the angular movement of which, under the influence of the magnet field, is controlled by a spring. Its total deflection is proportional to the speed of rotation of the magnet.

By means of a detachable key, shown on the lower outer edge of the instrument, the scale on the indicator dial is set to conform to the diameter of the wheel off which the indicator is driven.

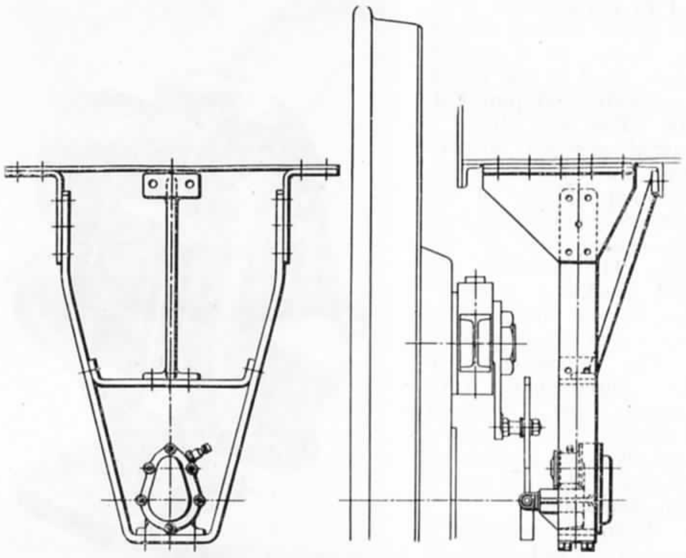


Fig. 248.—Typical Gearbox Suspension Bracket, Stone-Deuta Speed Indicator.

Locomotives of the *King*, *Castle*, *Star*, and *Saint* classes on the G.W.R. are fitted with speedometers (Figs. 250, 251, and 252). The equipment has been adopted as a G.W.R. standard.

It consists of an A.C. generator, and a voltmeter with a scale graduated to read in m.p.h. mounted in the cab. The drive is from a small return crank incorporated in the crank-pin washer of the right-hand trailing coupled wheel. A block on this crank engages in a slotted link mounted on a spindle carried on the same centre line as the driving axle by a bracket suspended from the footplate. The slot is long enough to allow for the greatest possible displacement of the driving wheel relative to the footplate bracket. The drive is transmitted through bevel gears to the generator, the armature of which runs on a vertical axis at two and a half times the driving axle speed. An armoured cable

conveys the alternating current to the voltmeter in the cab, first passing through a rectifier so that the voltmeter gives a unidirectional reading for both directions of running. The coil in the generator has alternative tappings to permit of fitting to engines with wheels of varying diameters.

As will be noted, the driving arm shown in the illustrations (Figs. 251 and 252) is slotted right through and fitted with a distance piece at the end of the slot. The reason for this is that if the arm were made with a closed end, the speedometer gear would have to be dismantled to remove the coupling rods, whereas with a through slot all that is necessary is to remove the distance piece, and the drinving crank can then easily be unscrewed from the crank-pin and the coupling rods taken away.

The generators and voltmeters were supplied by the British Thomson-Houston Co. Ltd., of Coventry, and the driving mechanism made at Swindon works.

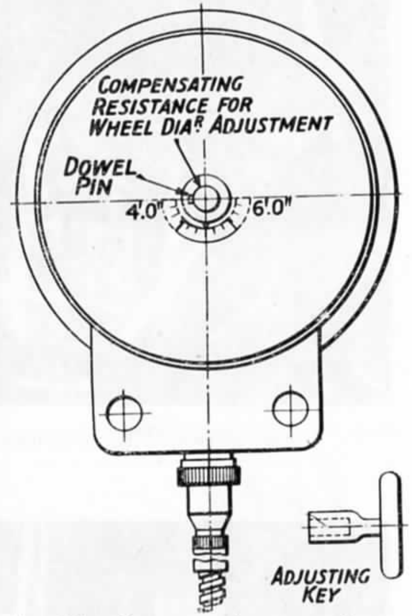


Fig. 249.—Method of Adjusting Tyre Wear, Stone-Deuta Electrical Speed Indicator.

When looking ahead to see that the section is clear, the enginemen should maintain a strict watch on the opposite running line in order that it may be protected properly according to rule should any obstruction or fault be seen. The driver should also look back from time to time, especially when passing through junctions or curves, to see that the train is following intact. When shunted across the road or into a siding with a train the driver should take notice that he has not been backed again on the same line by the signalman inadvertently failing to move the points, and when recrossing the road it should be seen that the train has been turned on the proper running line.

Various details affecting the cleanliness of the engine will be acquired gradually ; the number of black patches on the boiler, for instance, will be reduced greatly by avoiding the use of the large ejector (unless absolutely necessary) when standing or passing under bridges. By measuring the water from time to time, noticing the quantities of coal consumed, taking into consideration the geography of the road, the number of vehicles on the train, and the condition of his engine, the driver will

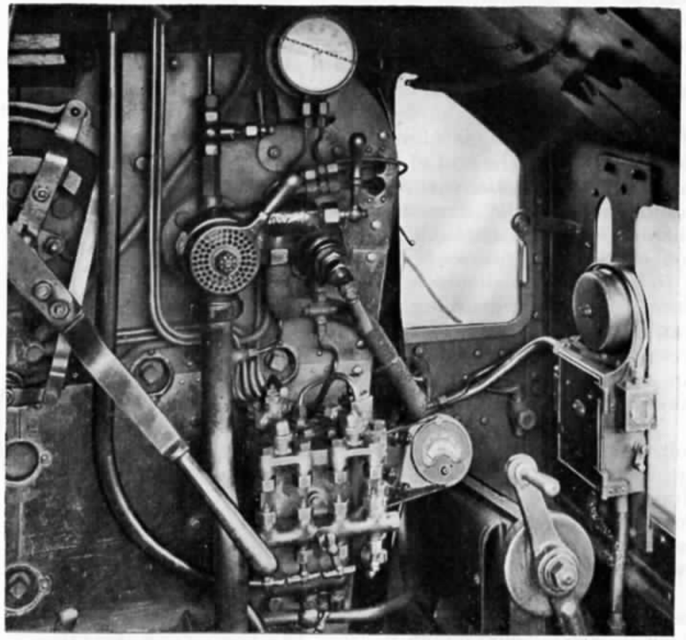


FIG. 250.—G.W.R. SPEEDOMETER, CAB FITTINGS.

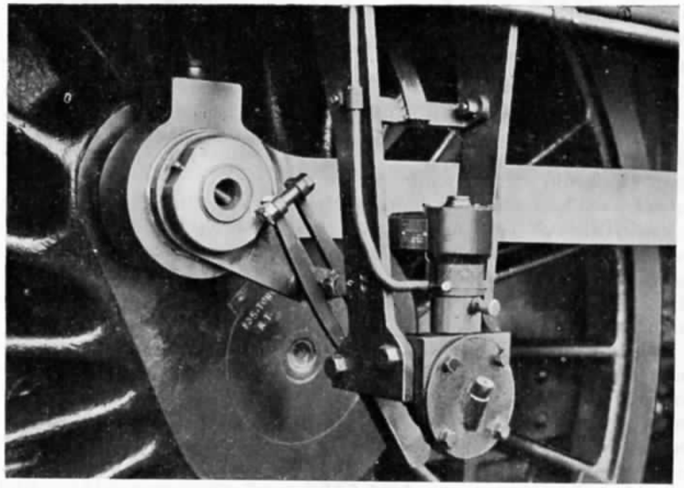


FIG. 251.—DRIVING GEAR AND GENERATOR.

soon be able to form a fairly accurate idea as to the distance he can travel with a given amount of water and coal.

The methods of procedure when starting away with a passenger or other train, manipulation of the brakes when running

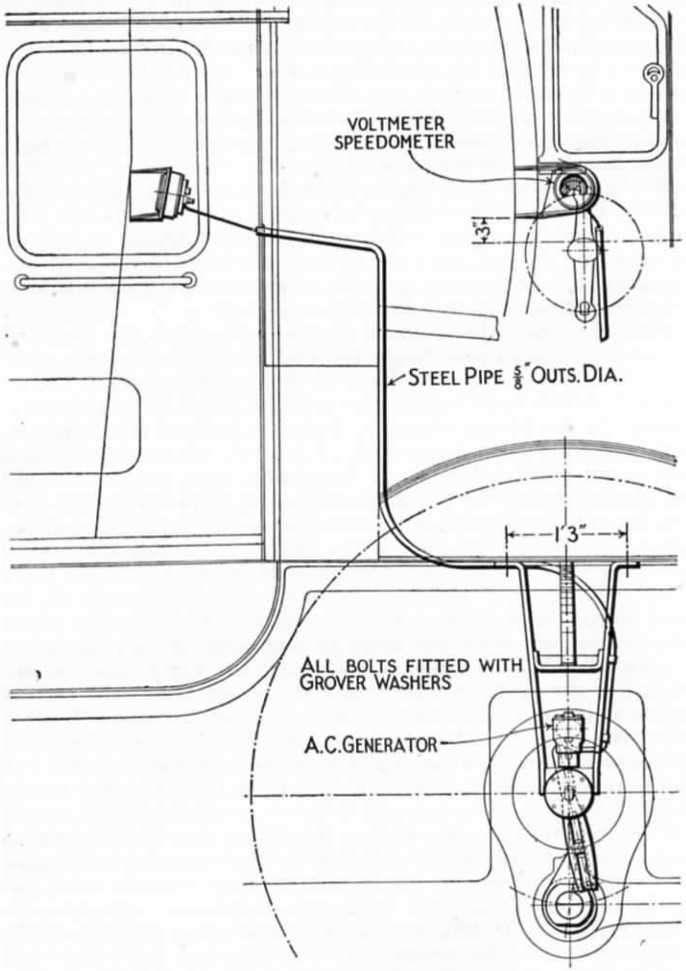


FIG. 252.—ARRANGEMENT OF DRIVING MECHANISM AND GENERATOR; ARMOURED A.C. CABLE AND SPEEDOMETER IN CAB, G.W.R.

down a falling gradient, and regulation of speed when entering a terminus, etc., have already been described.

The engine should be returned to the shed with the fire as low as possible, so that it may be dropped, if necessary, after a proper supply of coal, water, and sand has been obtained.

The boiler should be filled before the fire is dropped, so that the cooling process may be gradual, and reduce the chances of damage by sudden or violent contraction.

Anything of an unsatisfactory nature that may have been observed in the running of the engine during the journey should be attended to at once. If the engine has been steaming badly, for example, the smokebox should be inspected for leaky joints and the pipes tested by admitting steam. If all joints are found tight, and the brick arch is in good condition, a faulty piston may be causing the trouble. This is often indicated by the tube ends in the firebox becoming choked with dirt, and if any doubt occurs the pistons should be tested at once.

If the beats of the engine have been very irregular, or a constant blow up the chimney observed, and there is the least suspicion that something is wrong with the admission or exhaustion of steam to and from the cylinders, the valves should also be tested. The following is a simple method whereby the tests for faulty valves or pistons may be carried out :—

First place right-hand crank on top centre with the reversing lever in full forward gear, brake hard on, and cylinder drain cocks open. With the crank and lever in this position, steam will be admitted to the back end of the cylinder when the regulator is opened. If the piston rings are leaky or broken, steam will be discharged from both drain cocks, but if the rings are good and tight, steam will issue from the back drain cock only. To make sure, the lever may be placed in mid gear. The valve will then be in its middle position with both steam ports closed, and the drain cocks should therefore be free from steam. Then place the lever in full backward gear, thus admitting steam to the front end of cylinder, and through the front drain cock only if the piston rings are in good condition. If a blow from the drain cocks is observed with the lever in mid gear, it may be taken for granted that the valve is faulty or the valve lap broken. The end of the cylinder from which the steam issues will denote whether it is the front or back valve lap that is damaged. If a small piece only is broken from the lap, the constant blow will be observed when running in full forward or full back gear, but will disappear entirely when the engine is notched up to near mid gear.

With the crank on top centre, it will be seen that the valve always travels in the same direction as the reversing lever, and that steam is admitted to the front end of the cylinder with the lever in full back gear, and back end of cylinder with lever in full forward gear. If, however, the piston is tested with the crank on bottom centre the reverse takes place, and the valve will travel in the opposite direction to the reversing lever. In this case, steam will be admitted to the front end of the cylinder with the lever in full forward gear or the back end of the cylinder with lever in full back gear, and the steam from the drain cocks must be noted accordingly. These tests may, of course, be carried out with the cranks in different positions to those given here, but the foregoing is quoted as a very simple and effective method whereby each end may be tested separately.

Erratic or constant blows up the chimney may also be given

from causes other than those already mentioned. A strained or broken valve spindle or buckle, for instance, may give either an erratic or a continuous blow, as the adjustment of the valve is altered, the valve held from its face, or a steam port opened continuously, according to the nature of the failure. The shifting of an eccentric or a break in the division between the steam and exhaust ports will also give an erratic beat. In the latter case a heavy blow will be given up the blast pipe when the damaged port is opened to steam by the valve. A broken valve cavity would give a continuous blow up the blast pipe immediately the regulator was opened. These last failures are, however, rare, and a broken valve cavity would disable the engine completely by the great loss of steam, and assistance would therefore have to be obtained.

To locate a faulty beat or blow it is essential that the driver should possess a knowledge of the relative crank and valve positions. In accordance with the usual method of setting, and for simplicity, the relative positions of valves with cranks on centres have been described.

The diagrams (Figs. 253 to 256) will be useful as showing the relative crank, piston and valve positions on the four centres in forward gear. Fig. 253 shows the crank on the back dead centre, with the back port open $\frac{5}{32}$ in. to lead steam, the front port open to exhaust and the piston at the commencement of its stroke. In Fig. 254 the crank has reached the top centre, with the back port full open to steam and front full open to exhaust. Neglecting the obliquity of the connecting rod, the piston may be said to be in the middle of its stroke.

At Fig. 255 the crank has attained the front dead centre; hence the $\frac{7}{32}$ in. lead steam to the front port and the back port open to exhaust, with the piston at the commencement of the return stroke. With the crank on the bottom centre, as shown in Fig. 256, the front is full open to steam and the back port to exhaust. The piston has returned to the position given in Fig. 254.

The following particulars give the different positions of the valve motion, at the different notches, in forward and backward gear. The relative positions with the left-hand crank leading are given in Fig. 258.

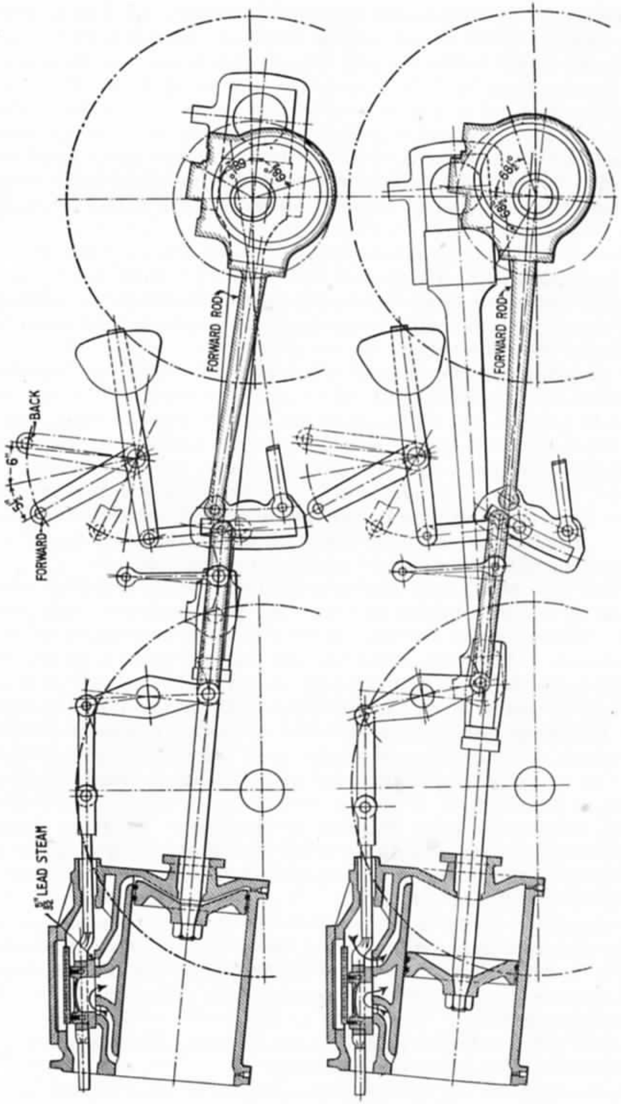
Since examiners may require a candidate to have some knowledge of relative positions with the cranks on angles, it is important that the rising driver should be familiar with valve events in these different positions.

The diagrams (Figs. 258 and 259) should be of assistance in acquiring the necessary information as to the relative positions of cranks, valves, and side rods with Stephenson's link motion, on both centres and angles, for engines with either right or left hand leading cranks.

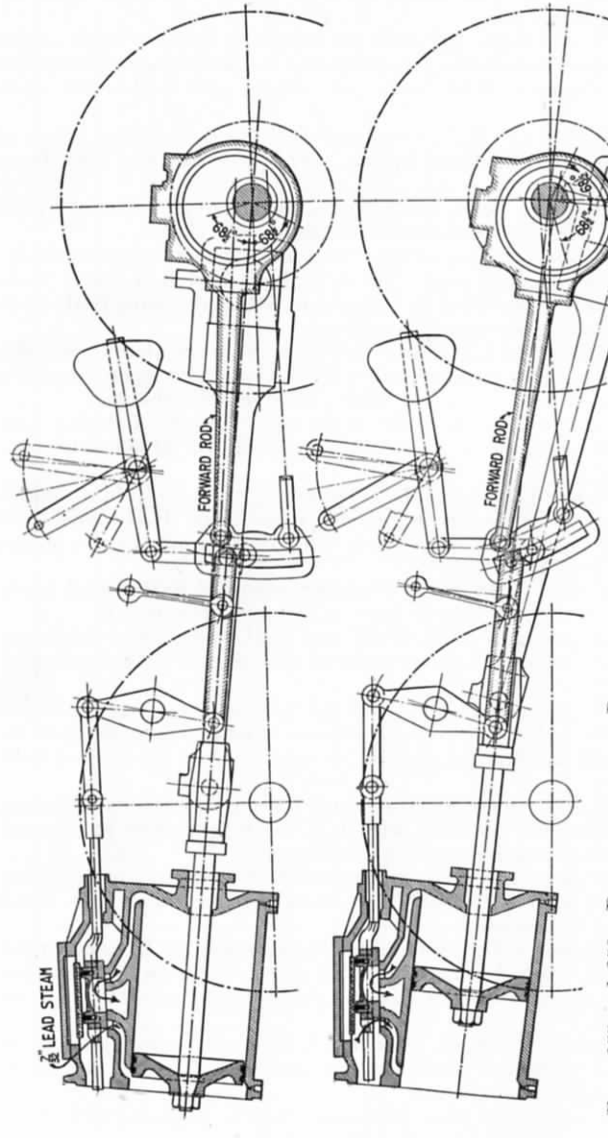
Fig. 259 gives relative positions on centres and angles for an engine with *the right-hand crank leading.*

1. R.H. and L.H. big ends on top and back centres respectively, with lever *in forward gear.* Both front ports open to exhaust, with R.H. back port open to steam and L.H. back port by amount of lead only.

In mid gear, the R.H. front and back ports are closed, since



Figs. 253 and 254.—Diagrams showing Relative Crank, Piston, and Valve Positions in Forward Gear (Back and Top Dead Centres).



Figs. 255 and 256.—Diagrams showing Positions of Crank, Piston, and Valve on Forward and Bottom Dead Centres.

the valve is in middle position, with L.H. front port open to exhaust and the back port to steam by amount of lead only.

In back gear, the R.H. back and L.H. front ports are open to exhaust, with R.H. front open to steam and L.H. back by amount of lead only.

2. R.H. and L.H. big ends on top front and top back angles respectively, with *lever in forward gear*. R.H. and L.H. front ports open to exhaust; R.H. back port closed and L.H. back open to steam.

In mid gear, the R.H. front and L.H. back steaming edges of valves and ports are about in line, with R.H. back and L.H. front open to exhaust.

In back gear, both back ports are open to exhaust, with R.H. front open to steam and L.H. front port closed.

3. R.H. and L.H. big ends on front and top centres respectively, with lever *in forward gear*. The L.H. back and R.H. front ports open to steam, the latter by amount of lead only, with R.H. back and L.H. front ports open to exhaust.

In mid gear, the L.H. front and back ports are closed since the valve is in middle position, with R.H. front port open to steam by amount of lead only, and back port open to exhaust.

In back gear, both back ports are open to exhaust and both front ports open to steam, the R.H. by amount of lead only.

4. R.H. and L.H. big ends on bottom front and top front angles respectively, with lever *in forward gear*. The R.H. back and L.H. front ports open to exhaust, with R.H. front open to steam and L.H. back port closed.

In mid gear, both front steaming edges of valves and ports are about in line, with both back ports open to exhaust.

In back gear, the R.H. front and L.H. back ports are open to exhaust, with L.H. front open to steam and R.H. back port closed.

5. R.H. and L.H. big ends on bottom and front centres respectively, with lever *in forward gear*. Both back ports open to exhaust and front ports open to steam, L.H. by amount of lead only.

In mid gear, the R.H. front and back ports are closed since valve is in middle position, with L.H. back port open to exhaust and front to steam by amount of lead only.

In back gear, the R.H. front and L.H. back ports are open to exhaust, with R.H. back port open to steam and L.H. front by amount of lead only.

6. R.H. and L.H. big ends on back and front bottom angles respectively, with lever *in forward gear*. Both back ports are open to exhaust, with L.H. front open to steam and R.H. front port closed.

In mid gear, the R.H. back and L.H. front steaming edges of valves and ports are about in line, with R.H. front and L.H. back ports open to exhaust.

In back gear, both front ports are open to exhaust, with R.H. back open to steam and L.H. back port closed.

7. R.H. and L.H. big ends on back and bottom centres respectively, with lever *in forward gear*, R.H. front and L.H. back

NOTCH	FORWARD											BACKWARD										
	TRAVEL	LEAD		OPENING		CUT-OFF		RELEASE		ANGLE		TRAVEL	LEAD		OPENING		CUT-OFF		RELEASE		ANGLE	
		B	F	B	F	B	F	B	F	B	F		B	F	B	F	B	F	B	F	B	F
Full	$4\frac{49}{64}$	$\frac{5}{32}$	$\frac{7}{32}$	$1\frac{3}{8}$	$1\frac{25}{64}$	79	$79\frac{1}{2}$	$92\frac{1}{2}$	$93\frac{1}{4}$	29	33	$4\frac{13}{16}$	$\frac{1}{8}f.$	$\frac{7}{32}f.$	$1\frac{7}{16}$	$1\frac{3}{8}$	$80\frac{3}{4}$	83	$93\frac{1}{2}$	95	28	29
3rd.		$\frac{7}{32}$	$\frac{9}{32}$	$\frac{15}{16}$	1	69	$68\frac{1}{2}$	$88\frac{1}{2}$	$88\frac{3}{4}$	37	$42\frac{1}{2}$		$\frac{3}{16}f.$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{31}{32}$	72	$74\frac{1}{4}$	$88\frac{1}{4}$	$91\frac{1}{2}$	36	$37\frac{1}{4}$
2nd.		$\frac{1}{4}f.$	$\frac{5}{16}f.$	$\frac{9}{16}$	$\frac{21}{32}$	$51\frac{1}{2}$	52	81	81	48	$55\frac{3}{4}$		$\frac{1}{4}$	$\frac{11}{32}$	$\frac{11}{16}$	$\frac{5}{8}$	58	58	$32\frac{1}{2}$	$85\frac{1}{2}$	$46\frac{1}{4}$	$48\frac{1}{2}$
1st.		$\frac{9}{32}$	$\frac{3}{8}b.$	$\frac{3}{8}$	$\frac{15}{32}$	29	32	70	$68\frac{1}{2}$	62	$72\frac{1}{2}$		$\frac{9}{32}$	$\frac{3}{8}b.$	$\frac{13}{32}$	$\frac{7}{16}b.$	$35\frac{1}{2}$	31	$70\frac{1}{2}$	$73\frac{1}{4}$	$61\frac{1}{4}$	67
						—	$\frac{1}{2}$	—	$\frac{3}{4}$	—	4						—	$2\frac{1}{4}$	—	$1\frac{1}{2}$	—	1
						$\frac{1}{2}$	—	—	$\frac{1}{4}$	—	$5\frac{1}{2}$						—	$2\frac{1}{4}$	—	$3\frac{1}{4}$	—	$1\frac{1}{4}$
						—	$\frac{1}{2}$	—	—	—	$7\frac{3}{4}$						—	—	—	3	—	$2\frac{1}{4}$
						—	3	$1\frac{1}{2}$	—	—	$10\frac{1}{2}$						$4\frac{1}{2}$	—	—	$2\frac{3}{4}$	—	$5\frac{1}{4}$

Clearance at top of Link $\frac{1}{2}''$ Slip full Forward $1\frac{1}{4}''$. Angle of Forward Eccentric $68\frac{1}{2}°$ Top of Valve . . . . $1''$

Clearance at bottom of Link $\frac{3}{8}''$ Slip full Backward $1''$ Angle of Backward Eccentric $68\frac{1}{2}°$ Centre of Connecting-Rod $6'\ 8\frac{7}{8}''$

FIG. 257.—TABLE OF POSITIONS OF VALVE MOTION IN FORWARD AND BACKWARD GEAR.

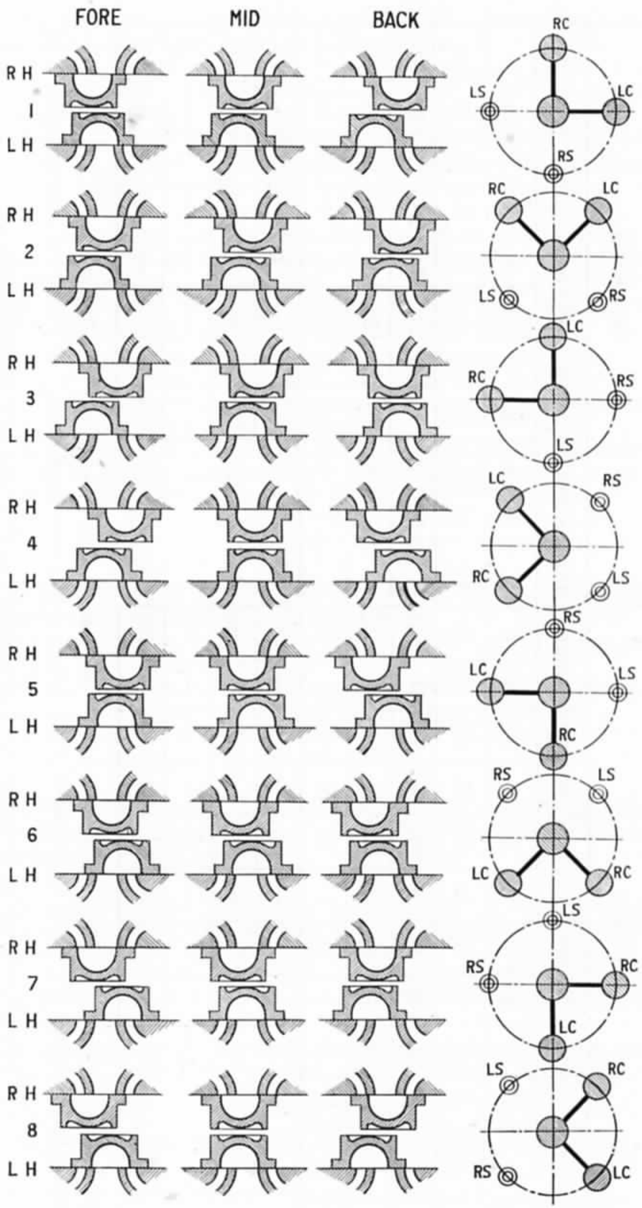


FIG. 258.—RELATIVE POSITIONS OF CRANKS, VALVES, AND SLIDE RODS.

Engine with Right-Hand Crank Leading.

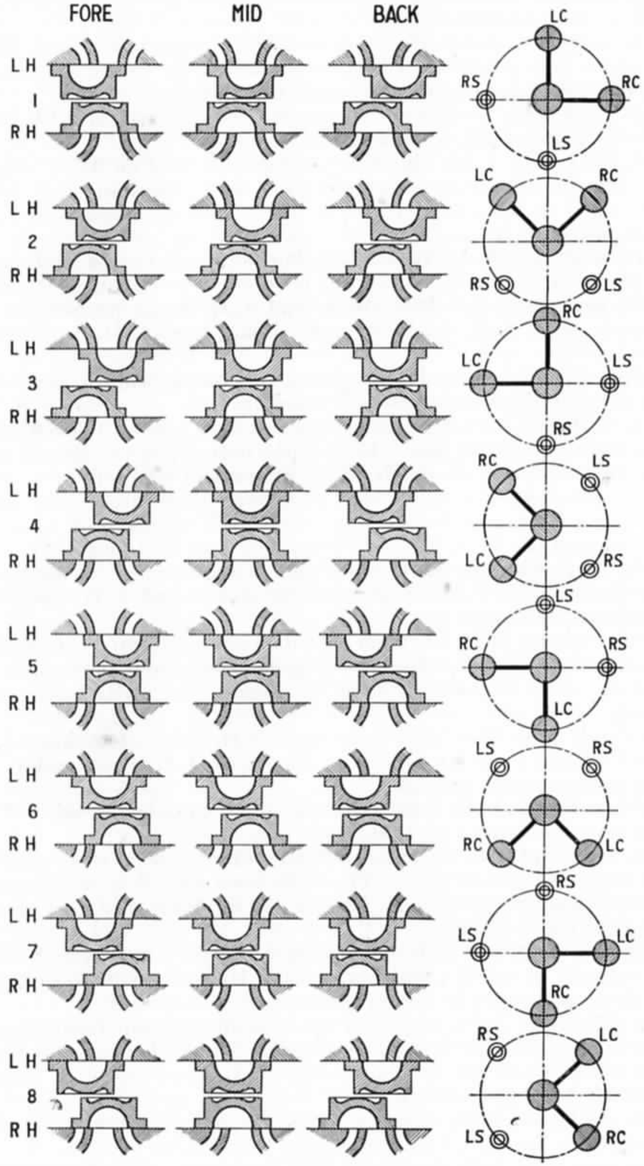


FIG. 259.—RELATIVE POSITIONS ON CENTRES AND ANGLES.

Engine with Left-Hand Crank Leading.

ports open to exhaust, with L.H. front open to steam and R.H. back by amount of lead only.

In mid gear, the L.H. front and back ports are closed, since the valve is in middle position, with R.H. front open to exhaust and back port to steam by amount of lead only.

In back gear, both front ports are open to exhaust with back ports to steam, R.H. by amount of lead only.

8. R.H. and L.H. big ends on top and bottom back angles respectively, with lever *in forward gear*. R.H. front and L.H. back ports open to exhaust, with R.H. back open to steam and L.H. front port closed.

In mid gear, both back steaming edges of valves and ports are about in line, with both front ports open to exhaust.

In back gear, the R.H. back and L.H. front ports open to exhaust, with L.H. back open to steam and R.H. front port closed.

Fig. 258 gives relative positions of cranks, valves, and side rods for an engine with *left-hand crank leading*.

1. L.H. and R.H. big ends on top and back centres respectively, with lever *in forward gear*. Both front ports open to exhaust and back ports open to steam, R.H. by amount of lead only.

In mid gear, the L.H. front and back ports are closed since the valve is in middle position, with R.H. front port open to exhaust and the back to steam by amount of lead only.

In back gear, the L.H. back and R.H. front ports are open to exhaust, with L.H. front open to steam and R.H. back by amount of lead only.

2. L.H. and R.H. big ends on top front and top back angles respectively, with lever *in forward gear*. Both front ports open to exhaust, with R.H. back open to steam and L.H. back port closed.

In mid gear, the L.H. front and R.H. back steaming edges of valves and ports are about in line, with L.H. back and R.H. front ports open to exhaust.

In back gear, both back ports are open to exhaust, with L.H. front open to steam and R.H. front port closed.

3. L.H. and R.H. big ends on front and top centres respectively, with lever *in forward gear*. The L.H. back and R.H. front ports open to exhaust, with R.H. back open to steam and L.H. front by amount of lead only.

In mid gear, the R.H. front and back ports are closed since the valve is in middle position, with L.H. back open to exhaust and front port open to steam by amount of lead only.

4. L.H. and R.H. big ends on bottom and top front angles respectively, with lever *in forward gear*. The L.H. back and R.H. front ports open to exhaust, with L.H. front open to steam and R.H. back port closed.

In mid gear, both front steaming edges of valves and ports are about in line and back ports open to exhaust.

In back gear, L.H. front and R.H. back ports open to exhaust, with R.H. front port open to steam and L.H. back port closed.

5. L.H. and R.H. big ends on bottom and front centres respectively, with lever *in forward gear*. Both back ports open to exhaust, and front ports to steam R.H. by amount of lead only.

In mid gear, the L.H. front and back ports are closed since the valve is in middle position, with R.H. back open to exhaust and front port to steam by amount of lead only.

In back gear, the L.H. front and R.H. back ports are open to exhaust, with L.H. back open to steam and R.H. front by amount of lead only.

6. L.H. and R.H. big ends on bottom back and bottom front angles respectively, with lever *in forward gear*. Both back ports are open to exhaust, with R.H. front open to steam and L.H. back port closed.

In mid gear, the L.H. back and R.H. front steaming edges of valves and ports are about in line, with L.H. front and R.H. back ports open to exhaust.

In back gear, both front ports are open to exhaust, with L.H. back open to steam and R.H. back port closed.

7. L.H. and R.H. big ends on back and bottom centres respectively, with lever *in forward gear*. L.H. front and R.H. back ports open to exhaust, with R.H. front open to steam and L.H. back by amount of lead only.

In mid gear, the R.H. front and back ports are closed since the valve is in middle position, with L.H. front open to exhaust and back port open to steam by amount of lead only.

In back gear, both front ports are open to exhaust and back ports to steam, L.H. by amount of lead only.

8. L.H. and R.H. big ends on top and bottom back angles respectively, with lever *in forward gear*. L.H. front and R.H. back ports open to exhaust, with L.H. back open to steam and R.H. front port closed.

In mid gear, both back steaming edges of valves and ports are about in line, with front ports open to exhaust.

In back gear, the L.H. back and R.H. front ports open to exhaust, with R.H. back open to steam and L.H. front port closed.

It has been mentioned already that with inside admission piston valves the steam is admitted to the engine cylinders when the valves are travelling in a direction opposite to that for ordinary outside admission slide valves. This should be borne in mind particularly when testing for faulty valves or pistons. The diagram, Fig. 260, will be useful as showing the relative positions of the steaming and the exhausting edges of inside admission piston valves and ports.

The cranks are, however, first placed in the positions indicated for testing outside admission valves, as, for example, with the L.H. big end on top centre and the lever in mid gear, the L.H. valves will be in good order if no steam issues from the drain cocks when the regulator is opened. A discharge of steam from the front or the back drain cocks will indicate that the valve at the respective end of the cylinder is passing steam. The right-hand valves are tested in a similar manner.

In order to ensure efficient lubrication of the piston valves, drivers have been known to use excessive quantities of oil, and the suplus oil has become carbonised by contact with the high-temperature steam. In this manner the rings become fouled and are prevented from making efficient contact with the working faces, with an escape of steam to one or both ends of the engine cylinder.

Superheated engines are often fitted with pressure release valves. In this case it is essential that the three-way cock fitted to the steamchest should be closed before the valves are tested, otherwise steam will be allowed to enter the front or the back end of the cylinder. It will therefore be seen that, unless this

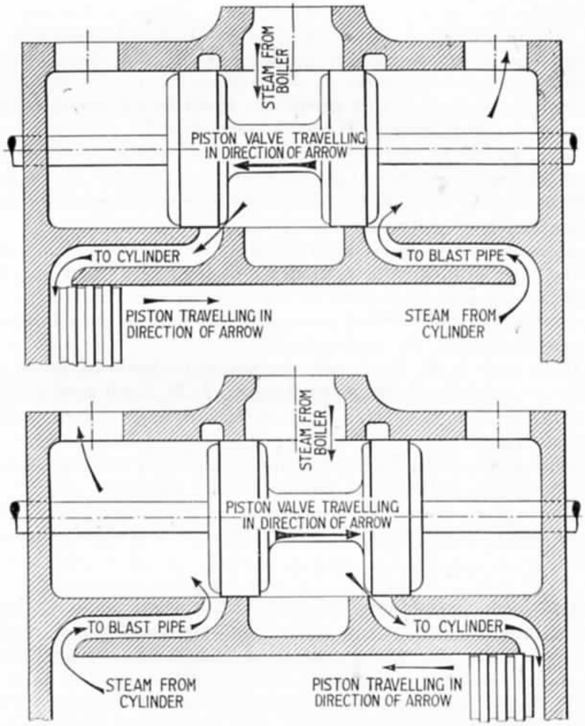


FIG. 260.—RELATIVE POSITIONS OF STEAMING AND EXHAUSTING EDGES; INSIDE ADMISSION PISTON VALVES AND PORTS.

three-way cock be closed fully, steam will pass direct from the steamchest to the cylinder, and the consequent discharge through the cylinder drain cocks may lead the driver to assume that the piston valves are faulty. In the case of engines fitted simply with a by-pass and without a three-way cock, steam may be prevented from passing from the steamchest to the cylinder by the insertion of a blank washer, or a halfpenny, at the joints connecting the pipes to the steamchest.

In the event of a breakage of one of the pipes connecting the release valves, the three-way cock should be closed by turning

the handle to the vertical position, which not only avoids a waste of steam, but also ensures an unobstructed look-out for the driver and fireman. The caps on the release valves should also be taken off, and a packing piece, or a $\frac{7}{8}$-in. nut, inserted to hold the valves tight on their seats, and thus permit the engine to be worked forward or home to its depot. Should the plug of the three-way cock work out and be lost, a $\frac{1}{2}$-in. bolt with washers at each end may be fixed in place of the plug, or a temporary wood plug, tapered to suit, could be driven tightly in the body of the cock.

Before leaving the shed, the driver should see that the handle of the three-way cock is in its proper position, otherwise the beats of the engine will be irregular, and give the impression that the valves or the gear are faulty.

Assuming that nothing unusual has been observed during the journey, and a supply of coal and water obtained, the engine should be placed over the pit with the right-hand crank on the bottom centre, the brake hard on, the cylinder drain cocks open, and the lever in mid gear, for a thorough and systematic examination. The driver should then leave the footplate on his own side and pass round the engine and tender with his right hand nearest the motion-work. All tyres should be sounded with the hand hammer, and side rods, axleboxes, springs, brake hangers, shackles, etc., inspected closely. Passing underneath, the brake and sanding gear, big and little ends, axles, eccentrics, straps and rods, slide-bar bolts and glands, etc., should be examined closely. Pass under the ashpan to inspect the damper rods and brake gear under the footplate, etc., and see that the hose connections are uncoupled in frosty weather.

The cranks should afterwards be moved to the top position, *i.e.*, equidistant from the top centre, so that the big ends, etc., will be well out of the way when raking out the ashes. Any defect, however trifling, should be noted carefully and entered in the repair book. Reports as to loss of time, the state of the road, etc., are most effective when to the point, and will be appreciated more fully by the head of the department when clearly and concisely written.

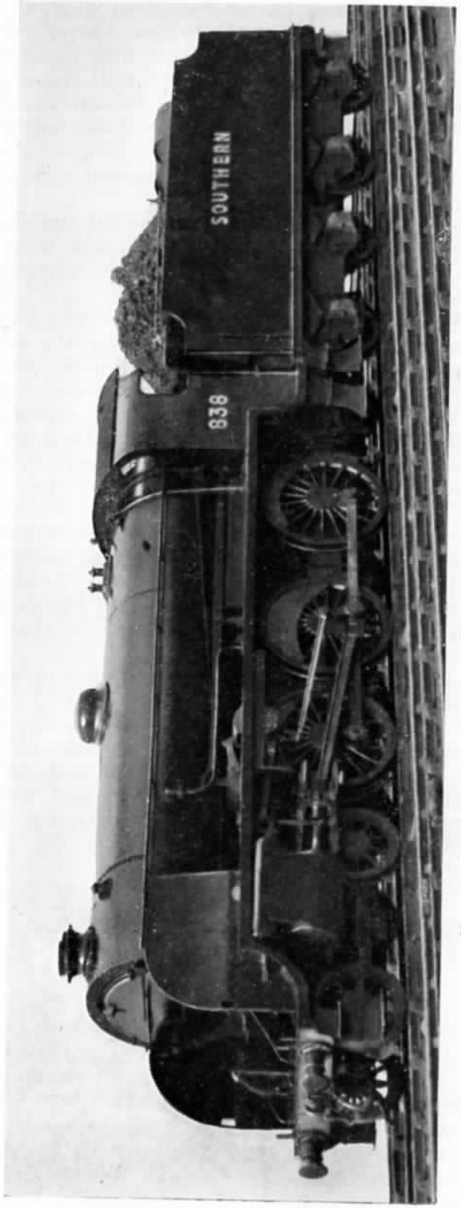


Fig. 261.—4-6-0 Type Mixed Traffic Engine, Southern Railway.

The late Mr. R. E. L. Maunsell, C.B.E., Chief Mechanical Engineer.

Cylinders, $20\frac{1}{2}$ in. by 28 in. Coupled wheels, 5 ft. 7 in. diameter. Coupled wheelbase, 13 ft. 9 in. Total engine wheelbase, 26 ft. $7\frac{1}{4}$ in. Boiler pressure, 200 lb. per sq. in. Total heating surface, 2,215 sq. ft. Grate area, 28 sq. ft. Weight of engine in working order, 79 tons 5 cwt. Weight of engine and tender in working order, 135 tons 13 cwt. Tractive effort (at 85 per cent. b.p.), 29,860 lb.

Chapter 17

DEFINITIONS AND EQUIVALENTS OF TECHNICAL TERMS AND LOCOMOTIVE DATA

Absolute Pressure is reckoned from zero or vacuum, *i.e.*, 14·7 lb. below atmospheric pressure.

Back Pressure is the term generally used to indicate the loss due to the retarding effect of atmospheric pressure acting on the exhaust side of the piston. Throttled exhaust either in the pipes or port passages will produce this effect.

Boiler or Gauge Pressure is that above the pressure of the atmosphere; hence boiler pressure+14·7 lb.=absolute pressure.

Brake Horse-power (B.H.P.) represents the amount of useful power at the crankshaft, and is equal to the indicated horse-power, minus the losses due to friction of the engine, etc.

British Thermal Unit (B.Th.U.), or unit of heat, is the heat required to raise the temperature of 1 lb. of water at about 39·1° F. through 1° F.

The mechanical equivalent of the B.Th.U. is known as Joule's equivalent, and is equal to 778 ft.-lb. or units of work. Heat and mechanical energy are therefore convertible, a definite number of units of work being obtainable from each thermal unit.

British Unit of Work is the "foot-pound," *i.e.*, 1 lb. raised through a height of 1 ft.

Clearance.—The clearance of a cylinder is the amount of space between the piston and cover, together with the volume of the steam port when the piston is at the end of its stroke.

Conduction of Heat is the transmission of heat through different bodies or metals, and is due to the difference of temperature between the bodies or metals.

Convection of Heat is the transference or conveyance of heat, as from the heating surfaces through the water in a boiler.

Indicated Horse-power (I.H.P.) is the power exerted by the steam in the cylinders as shown by the indicator diagram. It is obtained by multiplying the mean effective pressure (M.E.P.) by the area of the piston, by the speed of the piston in feet per minute (or twice the number of revolutions by the length of the stroke in feet), and dividing the product by 33,000. Thus we have :—

Indicator.—An instrument which may be attached to the engine cylinders to indicate in the form of a diagram the variations of steam pressure throughout the stroke. The diagram thus obtained is used for computing the amount of work performed by the engine.

P=M.E.P. in pounds per square inch.
L=Length of stroke in feet.
A=Area of piston in square inches.
N=Number of strokes per minute.

Hence $P \times L \times A \times N$ 33,000=I.H.P. developed by the engine.

INITIAL PRESSURE is the pressure of steam in a locomotive cylinder at the beginning of a stroke.

INSIDE OR EXHAUST LAP is the amount by which the inside edges of a valve overlap the steam ports, thus partly covering the port bridges when the valve is in its middle position.

INSIDE OR EXHAUST LEAD is the amount by which the inside edges of the valve are open to exhaust when in the middle position.

LAP is the term used to denote the amount by which the valve overlaps the outside edges of the steam ports when the valve is in the middle position.

LEAD is the distance that the port is open to steam with the crank on the dead centre.

MEAN EFFECTIVE PRESSURE (M.E.P.) is the average pressure per square inch on the piston during the full length of the stroke. The actual amount is obtained from the indicator diagram.

ONE HORSE-POWER (H.P.) is a unit of power equal to 33,000 ft.-lb. of work per minute, *i.e.*, 33,000 lb. lifted a height of 1 ft., or 1 lb. raised 33,000 ft. in one minute.

PERIOD OF ADMISSION is that portion of a stroke during which the valve is opening and closing the port, thus admitting steam to the cylinder.

PERIOD OF COMPRESSION is between the point of compression and point of admission, during which time the retained steam is compressed in the clearance spaces, thus acting as a cushion for bringing the piston to rest gradually at the end of the stroke.

PERIOD OF EXPANSION is that portion of the stroke between the point of cut-off and the point of release. During this period the valve covers the ports, and the expanding steam forces the piston forward with a gradual loss of pressure as the space in the cylinder occupied by the steam increases.

PERIOD OF RELEASE, or exhaust, occurs between the point of release and point of compression, during which time the valve is opening and closing to exhaust.

POINT OF ADMISSION is that point relative to the stroke at which the valve begins to open for the admission of steam to the cylinder.

POINT OF COMPRESSION is that point relative to the stroke at which the valve closes the exhaust, thus usually retaining a certain amount of steam for compression.

POINT OF CUT-OFF is that point relative to the stroke at which the valve closes, thus cutting off the admission of steam to the cylinder.

POINT OF RELEASE is that point relative to the stroke at which the valve opens to exhaust, thus releasing the expanded steam from the cylinder.

RADIATION OF HEAT is said to occur when heat passes from

a body into the atmosphere, or when heat is transferred in the form of radiant energy, as in the case of incandescent fuel on a firegrate.

SENSIBLE HEAT is the heat of a substance as denoted by the thermometer.

SATURATED STEAM.—Steam is said to be saturated when in contact with the water in the boiler, under which conditions a rise of temperature cannot take place without a corresponding rise of pressure.

SUPERHEATED STEAM.—Steam is said to be superheated when heat has been added after the steam has been removed from contact with the water in the boiler. Under these conditions, by providing for the increase of volume, a rise of temperature may be obtained without a corresponding increase of pressure.

TEMPERATURE is the intensity of heat in bodies, and is measured by thermometers thus :—

Temperature of

Melting ice	= 32° F.
Boiling water at atmospheric pressure	=212° F.
Steam at 50 lb. absolute pressure .	=281° F.
,, 100 ,, ,, ,, .	=327·9° F.
,, 150 ,, ,, ,, .	=358·3° F.
,, 200 ,, ,, ,, .	=381·7° F.

The boiling point of a liquid varies with the pressure at which evaporation or vaporisation takes place, and is known as the temperature of ebullition, thus :—

Temperature of ebullition at

14·7 lb. absolute pressure	=212° F.
30 ,, ,, ,, ...	=249° F.
60 ,, ,, ,, ...	=291° F.
90 ,, ,, ,, ...	=319° F.

WIRE DRAWING is the term generally used to indicate any loss due to reduction of pressure between the boiler and cylinder. This may be caused by throttling in the steam pipes or ports, or by an insufficient opening of the regulator.

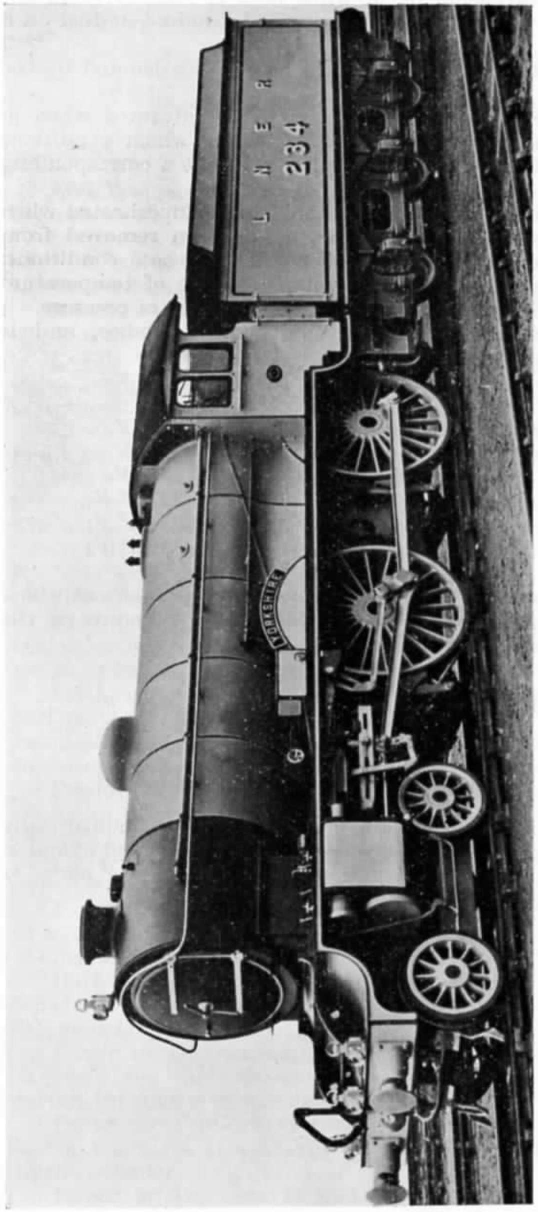


FIG. 262.—4-4-0 LOCOMOTIVE No. 234, *Yorkshire*, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 17 in. by 26 in. Coupled wheels, 6 ft. 8 in. diameter. Coupled wheelbase, 10 ft. Total engine wheelbase, 24 ft. 11 in. Boiler pressure, 180 lb. per sq. in. Total heating surface, 1669·58 sq. ft. Grate area, 26 sq. ft. Weight of engine in working order, 66 tons. Weight of engine and tender in working order, 118 tons 13 cwt. Tractive effort (at 85 per cent. b.p.), 21,556 lb.

CHAPTER 18

RULES: EXAMINATION [1]

THE examination for firemen to act as drivers is practical and oral. To pass this examination successfully, the candidate will require to be acquainted thoroughly with the following subjects :—

1. Care and manipulation of the engine.
2. Reading of signals and judgment of distances.
3. Manipulation of boiler adjuncts and methods of controlling the fire.
4. Constructional details of the locomotive and the liability of casualties thereto.
5. The making and use of trimmings.
   Methods of lubrication generally and the importance of proper attention to oiling.
7. Methodical examination of the engine and the reporting of defects.
8. General knowledge of, and the proper application of, Rules and Regulations.
9. The construction and action of automatic and steam brakes.
10. The examination may include the disconnecting of some part of the engine, and the making of such temporary repairs as will enable the engine to travel to its destination, shed, or depot, as the case may be.

In some districts a scheme has been introduced whereby all drivers and passed firemen are to be re-examined in their knowledge of the essential Rules and Regulations as affecting enginemen, at intervals of about two years.

The following examination is suggested as a method whereby the more important rules can be committed to memory by applying them as nearly as possible to the working conditions. The whole of the rules applicable to driver and fireman are not quoted for examination, since these have been fully dealt with, and it should be remembered that the examiner may ask the candidate questions about any of the rules affecting his duties. Questions affecting daily routine work have been quoted already in the examination for firemen, and these, in addition to questions relative to road repairs, water, signals, etc., as indicated in the chapter on "Driver's Duties," may be asked.

The driver may also be expected to make a full set of trimmings.

The method here adopted, viz., starting with the train from a station or siding, will, from the ease with which the questions

[1] As the various railway companies have their own—sometimes very important—modifications and additions to the standard rules issued under the authority of the Railway Clearing House, it is possible to give here only the essential principles involved. All readers should therefore consult very carefully the Rule Book issued by their own line and ascertain what further information it may have to give.

are answered, give a fair indication of the candidate's general knowledge of the whole of the rules.

1. *What should the driver do when starting away with a train from a goods yard or siding ?*

First see that the proper fixed signals are "off," but do not start without receiving the guard's signal, in accordance with rule 142 (*b*). After starting the driver should make sure that the whole of the train is following and that the fireman has exchanged hand signals with the guard, in accordance with rule 142 (*d*). If necessary a short whistle should be given to attract the guard's attention.

2. *How are signals exchanged with the driver of an assisting engine ?*

When starting in circumstances in which a signal from the guard is first required, such signal is—unless there are special instructions to the contrary—given to the driver of the *assisting* engine, who must call the attention of the driver of the front engine by giving two "crow" whistles; these must then, provided the necessary fixed signal is "off," be acknowledged by repetition. If stopped by fixed signal on the journey no guard's signal is required to restart, and when the fixed signal comes "off" the "crow" whistles must first be given by the driver of the *front* engine and the rear driver must acknowledge them. In *neither* case may the train be set in motion until the whistles have been duly exchanged, in accordance with rule 133 (*c*).

3. *When detained at a stop signal, what must you do ?*

Sound the engine whistle *immediately* in accordance with rule 55 (*a*), then—except where track circuit or other protective apparatus, as indicated by the prescribed sign on or near the signal post, or as announced in special instructions, is provided, or except when detained at a home signal on a single line when carrying a train staff or electric token—see that the fireman, if nearer to the signal box than either guard or shunter (clause (*c*) of the rule)—unless printed instructions exist to the contrary—proceeds to the box to remind the signalman of the position of the train. He must remain there until it can be allowed to proceed, unless he can obtain an assurance from the signalman that he has made use of his train reminder appliances, where provided. This duty of sending the fireman to the signal box must be performed *immediately* in foggy weather and in clear weather *not later than three minutes* after whistling. (If either the guard or shunter is nearest to the signal box the duty of going there devolves on him.)

4. *When your train is shunted from one running line to another, what must be done ?*

The guard, shunter, or fireman, as laid down in rule 55 (*c*), must satisfy himself that the line from which the train has been shunted is clear, and then proceed immediately to the signal box and act as already explained. (Rule 152 (*b*) may also apply.) The object of going to the signal box is, in all cases, to remind the signalman of the position of the train and guard against another being allowed to approach on the same line by mistake,

5. *What does a green hand signal waved slowly from side to side by a signalman denote, and what precautions must be taken after it is seen ?*

This signal denotes that the train has become divided. Great caution must therefore be exercised, in accordance with rule 182, and a watch kept for the detached portion. The green hand signal will not be exhibited unless it is intended that the train shall enter the block section in advance and gives authority for it to do so, against the fixed signals if necessary, in which case a very careful lookout ahead must be kept.

6. *How would you proceed when both portions have been brought to a stand ?*

If the front portion has not reached the home signal at the box in advance, and provided both portions can be recoupled, send the fireman back to the guard, who should be protecting the detached vehicles, for a white wrong-line order, form "C," authorising setting back towards them, in accordance with rule 183 (*i*). If, however, the front portion *has* reached the home signal the guard must be asked to issue the pink form "A," addressed to the signalman, and not form "C," and the wrong-line movement must not take place until the signalman gives permission.

7. *How many wrong-line forms are there and how are they used ?*

There are four. Form "A" (pink) is used by a guard when requesting the signalman in advance to allow the train engine, or, if such has been removed from the line, another engine or the breakdown van train, to come along the wrong line to the remaining portion, in accordance with rule 183 (*f*). Form "B" (green) is used by the driver of a disabled engine to request the signalman in advance to allow an assisting engine or breakdown van train to come towards him in the wrong direction (rule 183 (*g*)). Form "C" (white) is used by a guard, after his train has become divided, to authorise his own driver to set back to the rear portion (rule 183 (*i*)). Form "D" (yellow) is used by a signalman to authorise a movement to be made towards his box in the wrong direction through the section, for either part or all of the way from the signal box in advance (rules 175 (*c*), 183 (*f*), 183 (*g*), 184, and 203). Form "B" (green) is therefore the only one that can be issued by a *driver*, who should have a supply of it. If, however, he has none in his possession, he may write out the prescribed wording, as given in the rule book, on a piece of paper and make use of that in a case of necessity.

8. *What must a driver do if his train by accident fouls the opposite running line or is dangerously near to it ?*

If his engine can travel he must at once detach it and run forward not less than three-quarters of a mile from the scene of the mishap, where the fireman must place three detonators, 10 yd. apart, to protect the opposite line, as laid down in rule 180 (*a*), and rejoin the engine, which must be taken forward to the nearest signal box, where the signalman must be informed of the obstruction. The engine whistle must be sounded and a red hand signal exhibited to stop any train approaching on the other line. In addition a red head light must be carried through tunnels, after sunset, and during fog or falling snow. Should a train be seen approaching on such other line the driver must stop at once to allow his fireman to put down detonators on it.

9. *If your train fouls the opposite running line and your engine is disabled or there is any difficulty or delay in detaching it, what should be done ?*

The fireman must be sent forward at once and he must put down one detonator a quarter of a mile ahead, another a further quarter of a mile ahead, and the three detonators at a distance of three-quarters of a mile from the train. He must continue to go forward, showing a red hand signal, to the nearest signal box and advise the signalman of the circumstances, as laid down in rule 180 (*a*). In either case, the protection of the train in rear devolves on the guard, provided he is available.

10. *In the case of a light engine, how would you act ?*

Send the fireman forward and proceed to provide the protection in rear oneself, or send some competent person to do so, should he be available, as laid down in rule 180 (*c*).

11. *Should your engine be unable to take the whole of the train forward, necessitating its being divided, what would you do ?*

Send the fireman to inform the guard and arrange for the train to be divided suitably. Then proceed forward with the first portion. Unless there is a second guard available, the fireman must ride on the last vehicle or nearest suitable one to it, as laid down in rule 183 (*d*). No tail lamp may be carried on the last vehicle until the signal box in advance is reached, where the signalman must be informed of the circumstances, but if it is necessary to proceed beyond it, one must be placed in position before so doing. If the fireman does not ride on the last vehicle he must be able to tell the signalman that the front portion is complete.

12. *How should the remainder of the train be removed ?*

By crossing to and returning along the proper line, in accordance with rule 183 (*a*), and recrossing at the nearest point behind the rear portion, which must be propelled forward until it is convenient to go in front again. If, however, there is a crossover immediately in front of the train, and within sight of the signalman, this should be made use of to attach the engine in front.

13. *If it should be necessary or more convenient to return on the wrong line to the rear portion, what must be done ?*

The fireman must be sent to the guard for a wrong-line form " A " (pink), authorising the signalman in advance to allow such movement to be made, in accordance with rule 183 (*f*). If, owing to there being no crossover or convenient siding at his signal box, it is necessary to proceed to the next one and return on the wrong line from there, then a wrong-line form " D " (yellow) must be obtained from the first signalman, authorising the next signalman in advance of him to allow such movement to be made.

14. *When a train stops on a running line through engine failure, how does the driver obtain assistance ?*

If it is necessary for the assisting engine or breakdown van train to travel on the wrong line from the signal box in advance, the driver must send the fireman with a wrong line form " B " (green) to the signalman there, and the fireman must accompany the assisting engine or breakdown van train and point out the position of the disabled train, which must not be moved in the meantime. If there is no crossover at such signal box and assistance has to come from the next one in advance, then the fireman must obtain a wrong-line form " D " (yellow) from the signalman, authorising the next signalman in advance of him to allow the necessary movement to be made, as laid down in rules 183 (*g*) and 184.

15. *If it should be more convenient to get assistance from the rear, how would you obtain it ?*

By requesting the guard to go back and accompany the assisting engine, as laid down in rule 179 (*c*). Except in fog or falling snow the signalman in rear may, if he has received a message for assistance, allow it to leave without waiting for the guard to arrive, if he is known to be coming back ; the driver of the assisting engine must be instructed to look out for the guard and pick him up. If it will be necessary, however, for this engine to return on the wrong line the guard must be provided with a wrong-line form " D " (yellow), in accordance with rule 184, before it proceeds.

16. *If a vehicle in your train is found to be on fire, what must be done ?*

The train must be stopped, as laid down in rule 188 ; the guard must duly protect it if it is not protected by fixed signals. The fireman, or front guard should there be one, must then detach the vehicles in rear of the one on fire. This vehicle must at once be drawn forward at least 50 yd. and uncoupled and left properly secured until the fire can be extinguished. Every effort must be made to extinguish the fire.

17. *If your engine explodes a detonator in clear weather, other than at a fixed signal or signal box, how must you act ?*

Bring the train under complete control, in accordance with rule 60, to be able to stop at once if required, then proceed cautiously up to the obstruction or until a further signal is received. In fog or falling snow the train must be stopped before proceeding cautiously as described.

18. *If, after exploding a detonator, a green hand signal, waved slowly from side to side, is seen, what does it indicate ?*

That speed must be reduced to 15 m.p.h.—or such other reduced speed as may be prescribed—over the portion of line to which the signal applies.

19. *What does a green hand signal waved slowly from side to side by a hand signalman indicate ?*

That speed must be reduced as explained already, in accordance with rule 127 (xxi).

20. *What arrangements are made when the necessity for trains to travel at a reduced speed continues for some time?*

The hand caution signal is replaced by a warning board, fish-tailed at one end and pointed at the other, painted green with a white border, as prescribed by rule 218 (*a*). This carries one green and one white light at night and is placed at least half a mile from the beginning of the length over which reduced speed has to be observed. This section is indicated by a hand signalman or by an indicator bearing the letter "C" in black on a white background. In the latter case the termination is marked by another indicator bearing the letter "T" in white on a black background. The warning board may carry an indicator bearing figures denoting the speed which is not to be exceeded.

21. *What is meant by station-yard working?*

That the absolute block regulations are not in force and that two or more trains may be allowed in a section or station line at one time, under suitable precautions, provided the line is clear to the point to which a train requires to run. In such circumstances, the train will be stopped at the signal controlling the entrance to the section of line concerned, and a green hand signal held steadily in the hand will be exhibited by the signalman. If, however, there is a calling-on signal, this will be used instead of the hand signal.

22. *What is a track circuit?*

A safety device in which the rails form part of an electric circuit, so arranged that the presence of a vehicle—even only one axle of it—between the ends of the track-circuited section is indicated automatically in the signal box. This device locks signal levers and block instruments, operates level-crossing warnings, controls automatic and semi-automatic signals, etc., as the case may be.

23. *How does the existence of track-circuiting chiefly affect enginemen and the carrying out of certain rules, such as Nos. 55, 78, and 182?*

When standing at a signal where track circuit is provided, as indicated by a sign on or near the signal post, or as notified to trainmen by instructions, there is no need to carry out the provisions of rule 55 beyond sounding the whistle. A track-circuit failure will result in signals being locked at danger, although the line they control may be unoccupied and thus necessitate the employment of hand signalling, as laid down in rule 78. Such a failure, or the occupation of the line, will also prevent a signal from being pulled off for the front portion of a divided train to proceed past it. In this case the green hand signal prescribed in rule 182 gives permission to do so under the observance of the precautions there laid down and with the understanding that the line ahead may be obstructed. (The same result can be produced by the failure of certain forms of block apparatus in which the block instruments are interlocked with the signal levers.)

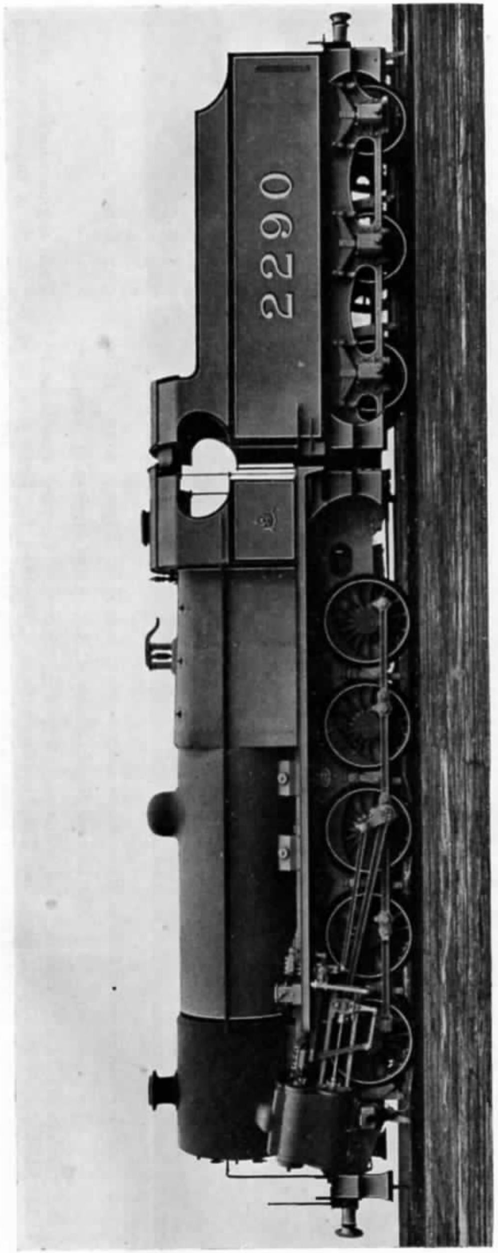


FIG. 263.—FOUR-CYLINDER 0-10-0 BANKING ENGINE, L.M.S.R.

The late Sir Henry Fowler, K.B.E., Chief Mechanical Engineer.

Cylinders (4), 16¾ in. by 28 in. Coupled wheels, 4 ft. 7½ in. diameter. Coupled wheelbase, 20 ft. 11 in. Boiler pressure, 180 lb. per sq. in. (Boiler designed for 200 lb. per sq. in.) Total heating surface, 2,163·25 sq. ft. Grate area, 31·5 sq. ft. Weight of engine in working order, 73 tons 13 cwt. Total weight of engine and tender in working order, 105 tons 4 cwt. 3 qrs. Tractive effort (at 85 per cent. b.p.), 43,313 lb.

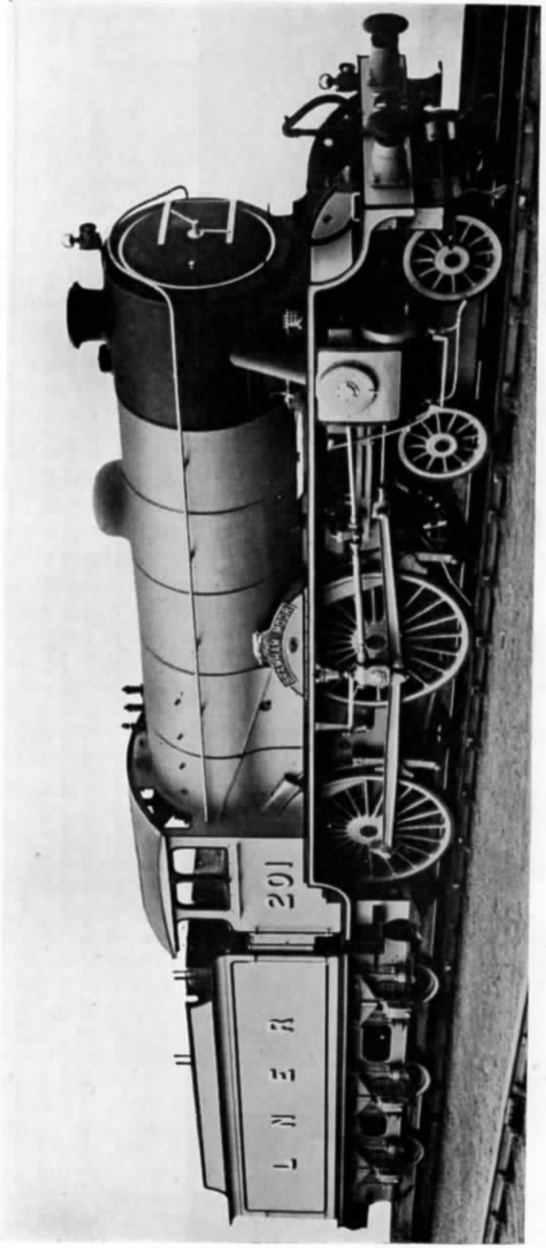


FIG. 264.—4-4-0 EXPRESS PASSENGER LOCOMOTIVE, L.N.E.R. (FITTED WITH "R.C." POPPET VALVE GEAR).

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 17 in. by 26 in. Coupled wheels, 6 ft. 8 in. diameter. Coupled wheelbase, 10 ft. Total engine wheelbase, 24 ft. 11 in. Boiler pressure, 180 lb. per sq. in. Total heating surface, 1,669·58 sq. ft. Grate area, 26 sq. ft. Weight of engine in working order, 65 tons 11 cwt. Weight of engine and tender in working order, 118 tons 4 cwt. Tractive effort (at 85 per cent. b.p.), 21,556 lb.

CHAPTER 19

EXAMINATION ON BOILER

1. *Name the principal parts comprising the shell of a locomotive boiler.*

The inner firebox, which includes the copper tubeplate; the barrel; the front tubeplate; the firebox outer shell; and the frontplate.

2. *Indicate one or two points affecting the design of a locomotive boiler.*

The boiler must be compact, to suit the width of the road and height of bridges, and of sufficient strength to withstand the heavy firing necessary for the rapid production of steam.

3. *Describe the means employed to secure rapid steam production.*

By using a large amount of heating surface for evaporative purposes; by subsequently drying the steam and increasing its temperature and volume in the superheating apparatus; and by the production of a sufficiently strong draught for the rapid combustion of fuel.

4. *State how the large amount of heating surface is obtained, and give approximately the area of such surfaces in a large modern locomotive boiler.*

The hot gases from the fire are passed through a large number of tubes, which are entirely surrounded by water, and these, with the top, sides, and copper tubeplate comprising the inner firebox, constitute the evaporative heating surface. The steam is then further heated by being passed along tubes inserted in the smoke tubes which are specially enlarged to accommodate them. The size and number of tubes employed in a large modern boiler often give a heating surface of over 1,885 sq. ft., and this, added to the areas of the inner firebox, and the superheater surface, will in many cases give a combined heating surface of over 2,300 sq. ft.

5. *Which parts of the heating surfaces are the most efficient, and which least, for evaporative purposes?*

The top of the inner firebox is the most efficient part of the heating surfaces, as it is horizontal and in direct contact with the fire. The sides of the inner firebox are slightly sloped towards the top to assist circulation, and these with the copper tubeplate, by their proximity to the fire, come next in order of efficiency. The evaporative power of the tubes is greatest near the copper tubeplate, and the efficiency gradually decreases with the falling temperature of the gases as the smokebox end of the tubes is approached.

6. *How is the strong draught necessary for the rapid combustion of the fuel obtained ?*

By discharging the exhaust steam from the cylinders through an exhaust pipe which is slightly contracted at its delivery end. This pipe is known as the blast-pipe, and is fixed inside the smokebox under and central with the chimney. The exhaust steam leaves the cylinders at a pressure considerably higher than that of the atmosphere, which, together with the contracted area of the blast-pipe, gives the steam a high velocity of discharge. The steam, expanding as it rises through the chimney, expels the waste products of combustion, and induces a partial vacuum by its velocity and the displacement of the smokebox contents. In this manner the atmosphere is induced to enter the firebox at the dampers and firehole door, as it rushes forward to fill up the vacuum created in the smokebox by the exhaust discharges, and thus produces the strong draught necessary for rapid combustion.

7. *How and to what extent may the blast be varied ?*

By reducing the size of the blast-pipe outlet the velocity of the escaping steam is increased, with a resultant sharper blast upon the fire. This reduction in the blast-pipe area should be done judiciously, as it increases the back pressure on the pistons by retarding the free escape of steam from the cylinders when exhaust takes place. Another method is to brick up a portion of the smokebox to its volume. The blast will then have a more direct effect upon the fire. This gives a keener blast, but if overdone will continually lift the fire, and a wasteful and dangerous quantity of sparks will be discharged through the chimney. The force of the blast can also be varied or equalised over the surface of the fire by raising or lowering the height of the blast-pipe orifice.

8. *Where would you look for the causes of an inefficient draught before proceeding to alter the size of the blast-pipe orifice or brick up the smokebox ?*

Examine the smokebox door for air leaks. Test the blast-pipe or petticoat pipe for alignment with the chimney. Examine all steam pipes and joints in the smokebox for escape of steam due to faulty joints or pipes.

9. *What are the chief contents of the smokebox ?*

The main steam pipe ; the blast-pipe ; the blower ; the vacuum ejector or air-pump exhaust pipe ; and the superheater header and spark arresters when fitted.

10. *What are the principal parts contained within the boiler barrel ?*

The fire tubes, and, where superheating apparatus is employed, the flue tubes. These together may be from 200 to 250 in number, according to the size of the boiler.

11. *Why is the dome fitted on the top of the barrel ?*

For the prevention of priming by giving an increased steam space above the water level in the boiler. The dome acts as a receiver for the collection of dry steam.

12. *What is meant by priming, and how can it be detected ?*

Priming occurs when water is carried with the steam from the boiler to the cylinders. It is usually detected by a discharge of water in the form of spray with the exhaust from the chimney, or by the changed sound of the exhaust and by the disturbed appearance of the water in the gauge glasses.

13. *Give one or two causes of priming, the danger arising therefrom, and its effect on the coal and water consumption.*

Priming may be caused by having too much water in the boiler, or by the unsuitability of the feed water. The cylinders may be damaged or the cylinder ends broken by the violent shock which occurs when the piston head strikes the incompressible water at the end of the stroke, and the sudden strains thus set up may result in sheared cotters or broken rod-ends. When priming takes place a certain amount of water is lost, and coal is consumed wastefully in heating up the discharged water from which no value in the form of energy has been obtained.

14. *What means should be taken to check priming when it occurs ?*

When priming is taking place the water is either in a violent state of ebullition, or lifting with the steam. The firebox temperature should therefore be lowered by checking the draught with the dampers. The cylinder drain cocks should be fully opened, and the quantity of steam leaving the boiler should be reduced by closing the regulator as much as possible.

15. *What connections are fixed inside the dome ?*

The regulator, and pipes for steam to the injectors, feed pump, steam sanding cock, jet cock, and vacuum ejector or other brake valve.

16. *Name the principal fittings usually fixed on the frontplate of a modern locomotive.*

The regulator handle, water-gauge fittings, injectors, jet cock, steam sanding cock, warming cock, and brake fittings.

17. *How is the regulator handle made to control the admission of steam to the main steam pipe ?*

The handle is secured to a long rod or shaft, which passes through a gland in the frontplate and is connected at its other end inside the boiler to the regulator in the dome, thus controlling or regulating the admission of steam to the main steam pipe.

18. *What is the use of the water-gauge glasses and how are they connected, and what determines the height at which they are fixed ?*

To show the height of the water in the boiler. They consist of a glass tube connected by suitable fittings to the steam space in the boiler at the top end and to the water space at the bottom. The gauge should be fixed so that the bottom of the glass tube is a little above the crown of the inner firebox.

19. *What conditions are liable to cause the water gauge to give a false indication of the water level in the boiler?*

Dirt or scale choking up the passages leading to the glass tube, or violent ebullition, as when priming.

20. *How would you test the water gauge in order to ascertain whether the level shown was correct or not?*

By shutting off both ends leading to the boiler and opening the drain cock. After the glass is emptied, and the drain cock has been closed and the steam and water cocks reopened, the water should resume its normal level in the glass. If any doubt still exists, the drain cock should be opened and the steam and water cocks blown through separately.

21. *What would you expect to occur if the water-gauge readings were improperly verified and the boiler ran short of water?*

The fusible plug would be melted, or the inner firebox crown become overheated and eventually collapse. When this occurs it is often accompanied by a disastrous explosion.

22. *In the event of the boiler becoming short of water, what steps would you take to reduce the firebox temperature?*

Close the dampers tightly and smother the fire by covering it with a good thickness of ballast or earth. A bucket or other obstruction placed upon the top of the chimney will further reduce the draught.

23. *If front and back dampers are fitted, which damper is it preferable to use providing one is sufficient for raising the steam required?*

The back damper, so that the cold air will be admitted to the firebox at the point farthest from the tubeplate.

24. *Name the principal parts contained in a modern injector and its attachments.*

The steam cock; the steam cone or nozzle; the water cock; the combining cone or nozzle; the delivery cone or nozzle; the clack box and delivery valve; the overflow valve; and screw-down valve for shutting off the injector from the boiler.

25. *Describe briefly the action whereby an injector is enabled to deliver water against the boiler pressure.*

The action of the injector is due to the high velocity with which a jet of steam from the steam nozzle strikes the water entering the combining nozzle, thus imparting its momentum to the water and forming with it during condensation a continuous jet, which has sufficient velocity to overcome the boiler pressure.

26. *Give a few faults which might cause an injector to deteriorate or fail entirely in its action.*

Leaky suction pipes; suction pipes throttled with dirt; imperfect condensation due to hot feed; or a heated injector due to a faulty steam valve; boiler scale or other obstruction in the nozzles; throttled steam supply or wet steam caused by priming; obstruction in the delivery pipe; faulty clack valve, etc.

27. *What is an exhaust injector?*

An exhaust injector is a boiler feeding apparatus in which the waste steam from the blast-pipe is used to heat the feed water and force it into the boiler at a high temperature.

28. *What does the complete apparatus consist of?*

The grease separator, isolating valve, exhaust portion and supplementary portion.

29. *What is the use of the grease separator?*

To remove all particles of grease and condensed water from the exhaust steam.

30. *What is the use of the isolating valve?*

To admit and shut off the supply of exhaust steam to the injector. This valve should always be shut when the injector is not working with exhaust steam.

31. *For what purpose is the live-steam pipe attached to the isolating valve?*

For working the injector when the regulator is shut.

32. *What are the uses of the exhaust and supplementary portions?*

The exhaust portion receives its feed water from the tender, and by the use of the exhaust steam delivers it into the supplementary portion under a pressure of about 70 lb. and at a temperature of 160° to 190° F. The supplementary portion receives its feed from the exhaust portion and by means of a jet of live steam forces it into the boiler at a temperature of 280° F.

33. *What is the use of the inducer nozzle?*

This is a small steam nozzle fixed inside and concentric with the exhaust nozzle. Its object is to induce a greater flow of exhaust steam into the injector.

34. *What is the use of the water regulator?*

This is an eccentric spindle which moves the exhaust nozzle backwards and forwards to regulate the supply of water to the injector.

35. *What is the use of the flap or split nozzle?*

To enable the injector to start and restart automatically. Until the jet is continuous within the nozzle, the flap remains open and allows the nozzle to clear itself. When the injector starts the working the flap closes, and forms a solid nozzle.

36. *What is the exhaust overflow valve?*

A small hanging valve fixed in the overflow casing to keep all the air out of the injector, which would otherwise spoil the vacuum.

37. *If anything should interrupt the jet, how does the injector restart ?*

The pressure in the delivery falls, so that the weight under the piston is reduced and the overflow valve opens. The flap also opens and the steam and water pass into the overflow until the jet is again continuous or established. The flap then closes, and pressure is obtained again in the delivery. The piston is forced up and closes the overflow valve, so that the feed passes into the boiler.

38. *How much exhaust steam does a No. 9 injector use per hour ?*

It uses or returns more than half a ton of steam to the boiler every hour.

39. *What would be the result of a faulty steam sanding cock ?*

The moisture leaking past the cock would damp or cake the sand in the trap, and cause imperfect or intermittent sanding, which would ultimately choke up the sanding pipes.

40. *What is meant by atmospheric pressure ?*

Atmospheric pressure is the pressure of the air surrounding the earth. It averages 14·7 or roughly 15 lb. per sq. in. at sea level.

41. *Is this atmospheric pressure denoted on a boiler-pressure gauge ?*

No. The pressure recorded by a boiler-pressure gauge is known as the effective steam pressure, and is always the pressure available above the atmospheric pressure. Steam pressure and the atmospheric pressure combined are known as the absolute pressure.

42. *What is steam, and at what temperature is it generated under atmospheric pressure ?*

Steam is the vapour of water, and is generated by heat when the temperature of 212° F., or boiling point, has been attained under atmospheric pressure conditions.

43. *Does the boiling point or temperature of ebullition remain constant at all pressures ?*

No. The temperature of the boiling point and the temperature of the steam increase with the pressure.

44. *Is there any fixed ratio between the temperature of steam in contact with water and the pressure ?*

Yes ; so long as the steam is enclosed in a boiler a given temperature always corresponds to a certain pressure—thus the boiling point at atmospheric pressure is 212° F., at 100 lb. pressure 327° F., and at 200 lb. pressure 381° F.

45. *Describe briefly the construction and action of a Ramsbottom safety valve.*

The Ramsbottom safety valve consists of two circular valves held in position by a lever connected to a spiral spring, which is adjusted to exert a pressure on the valves equal to the working pressure in the boiler. When the boiler pressure exceeds that of the springs the valves are forced upward and the steam is allowed to escape until the excess of pressure in the boiler is relieved. One end of the lever which controls the valves is extended into the cab, so that the driver, by setting the valves in motion, can see for himself that they are free and in proper working condition.

46. *The flat surface of the frontplate would be distorted by the internal pressure if it were not suitably stayed. Describe the method of staying usually adopted.*

The frontplate is secured to the inner firebox by the foundation ring, and by the firebox stays and the mouthpiece ring at the lower part. In addition to the firebox stays above the mouthpiece ring, the upper part is also stayed by longitudinal stay bolts which pass directly over the top of the inner firebox to the front or iron tubeplate.

47. *How are the inner and outer firebox shells secured together ?*

By the foundation ring, which defines the width of the intervening water space at the bottom, and by riveted stays threaded through both shells at the top and sides.

48. *Why is the inner firebox made almost invariably from copper in this country, and what does it contain ?*

Copper is very ductile, and consequently most suitable for withstanding any unequal expansion that may take place between the inner and outer firebox shells or upon the tubeplate. It is also a good conductor of heat and almost non-corrosive. The firegrate and brick arch are contained in the inner firebox.

49. *What advantages are claimed for the Belpaire type of firebox ?*

The flat top and sides give a larger heating surface, and direct stays for supporting the crown of the inner firebox, arranged so as to allow for the variable expansion between the inner and outer shells, can be used. With direct stays the circulation is not retarded and the crown of the inner firebox can easily be washed and cleaned.

50. *How are the flat sides of the Belpaire type of firebox outer shell stayed above the level of the inner firebox crown ?*

By stay bolts fitted through threaded holes in the outer shell which pass transversely from side to side above the crown of the inner firebox.

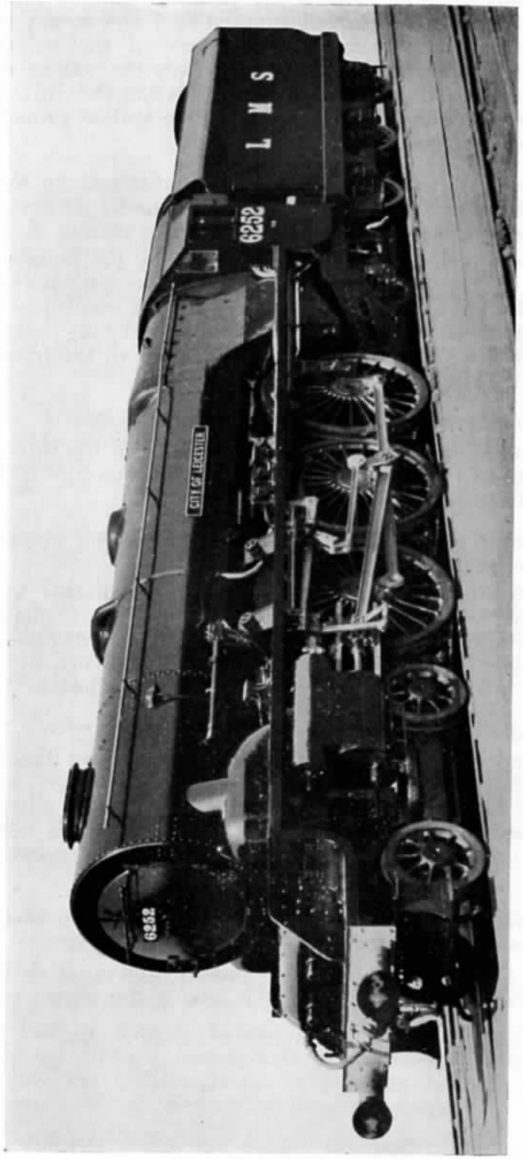


FIG. 265.—NON-STREAMLINED 4-6-2 TYPE FOUR-CYLINDER EXPRESS LOCOMOTIVE, "DUCHESS" CLASS, L.M.S.R.

Sir William Stanier, Chief Mechanical Engineer (*retired*).

Cylinders (4), 16½ in. by 28 in. Coupled wheels, 6 ft. 9 in. diameter. Coupled wheelbase, 14 ft. 6 in. Total engine wheelbase, 37 ft. Boiler pressure, 250 lb. per sq. in. Total heating surface, 3,637 sq. ft. Grate area, 50 sq. ft. Weight of engine in working order, 105 tons 5 cwt. Weight of engine and tender in working order, 161 tons 12 cwt. Tractive effort (at 85 per cent. b.p.), 40,000 lb.

CHAPTER 20

EXAMINATION ON ENGINE

1. *Name the principal parts comprising the engine of a modern locomotive.*

The cylinders; piston heads; piston rods; crossheads; slide bars; connecting rods; crank axle; eccentric sheaves, straps, and rods; valve gears, including rocking motion when fitted; valve spindles and buckles; and slide valves.

2. *Describe a cylinder and its functions.*

A cylinder is an iron casting with the necessary steamchest and portways to suit the particular design of engine. It is bored to receive the piston head, and the steamchest is machined to suit the type of valve to be used. The functions of a cylinder are to receive the steam from the boiler and confine it during the time that its energy is being exerted against the piston head.

3. *Describe a piston head and the means employed to make it steamtight.*

The piston head is usually an iron or a steel casting turned to an easy fit in the bore of the cylinder, and secured by a nut on the tapered end of the piston rod. To make it steamtight, two or more rings, usually made of cast iron, are employed, which are turned a little larger in diameter than the cylinder. These rings, after being fitted into grooves turned in the piston head, are cut so that they can be sprung into the cylinder. The pressure of the rings against the cylinder walls as they endeavour to regain their original diameter is sufficient to prevent the passage of the steam past the piston head.

4. *How is a piston rod maintained steamtight in passing through the cylinder end?*

By means of a gland and stuffing-box, which is filled with fibrous packing tightened up by gland nuts, or by special metallic gland packings held tight to the rod by gland nuts or suitable steel springs.

5. *How is a crosshead connected to the piston rod?*

By a tapered cotter which, when driven home, draws the crosshead securely on to the rod end. The socket and rod are coned carefully to obtain the best possible fit. Nuts are sometimes used instead of a cotter, and the rod is screwed and tapered as described for piston head.

6. *Why are slide bars necessary ?*

If unrestrained by slide bars, the angular thrust and pull of the connecting rods, due to the sweep of the cranks, would bend the piston rods. It is also necessary for the piston rods to be maintained in perfect alignment with the centres of the cylinders, otherwise the gland packings would soon be destroyed.

7. *When running in forward gear, which slide bars would be most liable to get hot, assuming the engine to have top and bottom bars ?*

The top bars, because the force exerted by the connecting rods in moving the engine forward tends to push or pull the crossheads in an upward direction.

8. *What is the duty of a connecting rod, and what parts of the engine does it connect ?*

The connecting rod assists in converting the reciprocating movements of the piston into the rotary motion of the crank axle. It is connected at the little end to the crosshead by a strong gudgeon pin and to the crank axle or crank-pin at the big end.

9. *Describe briefly one or two types of connecting-rod ends.*

The little ends are often fitted with a strap which retains a pair of half brasses, and have gibs and cotters to take up wear. Solid little ends are also fairly common in which solid renewable bushes may be fitted or half brasses adjusted by a screw and wedge block. Solid big ends are used frequently for outside cylinders with screw and wedge block, or cotters and bolts for adjusting the brasses. Big ends for inside cylinders may be of the strapped or the open-jaw type, with the brasses adjusted by cotters, which can be locked securely in position. The big end brasses are lined with anti-friction metal and bedded carefully to their respective journals.

10. *Explain the difference between the crank axle for an inside cylinder engine and the driving axle for an outside cylinder engine.*

The cranks for inside cylinders are placed between the frames and form part of the driving axle ; hence the term crank axle. For outside cylinders the crank-pins are fitted into the centres of the driving wheels, so that the driving axle is made from a plain, straight forging.

11. *What is the duty of the eccentrics, and how are the sheaves attached to the crank or driving axles ?*

The eccentrics convert the rotary movement of the axle into a reciprocating motion for working the valves, which admit steam to each end of the cylinders alternately. The sheaves are made in halves and held together by cotter bolts. They are attached to the axle by means of sunk keys and set screws.

12. *Why are two eccentrics provided for each set of valve motions ?*

One eccentric in each pair runs the engine in the forward direction, and the other in the reverse direction. These are known as forward and back gear eccentrics respectively.

13. *What is meant by the angular advance of an eccentric, and what determines the amount of this advance ?*

The angular advance of an eccentric is the number of degrees in excess of 90 by which the centre line of the eccentric is in advance of the centre line of the crank. The amount of lap, plus the lead required, determines the amount of advance.

14. *Describe an eccentric strap and its purpose.*

The eccentric sheaves are embraced by a belt or strap in the form of a casting or forging, which is made in halves and held together by bolts. The sheaves revolve with the axle inside the strap, and transmit the eccentric movement of the sheaves to the eccentric rod attached to the strap. A large amount of friction is generated between the rubbing surfaces, so that it is usual to line the strap with an anti-friction metal. Suitable lubricating arrangements are also formed on the straps.

15. *Describe the eccentric rods.*

The eccentric rods are made from the best hammered iron or steel, forged with suitable ends for attachment to the eccentric straps, and quadrant or expansion links, to communicate the movement of the straps to the link motions. The forward gear rods are usually connected to the top of the links, and the back gear rods to the bottom.

16. *Give a brief description of the Stephenson link motion.*

The Stephenson link motion is an arrangement of valve gear whereby the travel of the valve may be altered to suit the load or gradient, and provides the means for running the engine in a forward or backward direction. It consists of a radial slotted link to which are attached the fore and back gear eccentric rods. The end of the valve spindle is also connected to a sliding block fitted into the radial slot. By raising or lowering the link the position of the block relative to the eccentric rods is altered, so that the motion of the valve may be controlled by either the forward or back gear eccentrics, and the engine moved in the required direction.

17. *Describe a common form of valve gear in which eccentrics are dispensed with, and explain how the necessary movement for the slide valve is obtained.*

In Joy's valve gear, motion for the slide valves is obtained from the connecting rods, and eccentrics are unnecessary. Links and levers transmit the movements of the connecting rods to slipper blocks working in radial guides fitted into a reversing shaft. The valve spindles are connected by rods to the swing links in such a manner that the valve travel can be varied or the engine reversed by partly turning the reversing shaft and thus altering the position of the curved guides.

18. *What is the advantage obtained in varying the valve travel with a link motion or radial valve gear ?*

By lengthening or shortening the valve travel, the point of cut-off can be adjusted to suit the working load in such a manner that economical results are obtained by working the steam expansively.

19. *Valve spindles may be connected directly to the link motion or to a rocker with arms above and below, according to the design of the steamchest. How does the intervention of a rocker affect the position of the eccentrics relative to the cranks ?*

The rocker will reverse the direction of the travel obtained from the eccentrics, and the eccentrics will be a half-turn different upon the axle from the position for direct-driven valve spindles.

20. *Describe a valve spindle and the method of attachment for controlling the movements of the slide valve.*

Valve spindles are made from the best hammered iron or forged steel formed with a buckle or strap for embracing the back of the slide valve. The buckle is made a sliding fit upon the back of the valve, which allows it to follow up the wear upon the valve face. The spindles are maintained steamtight by glands and stuffing-boxes, as described for the piston rods.

21. *Describe briefly the construction and duties of an ordinary locomotive slide valve.*

The ordinary locomotive slide valve is usually made in the form of a hollow phosphor-bronze casting, which is machined and bedded to prevent the leakage of steam across the valve face. It is designed to admit steam to each end of the cylinder alternately when moved over the port faces, to cut off the steam supply as required, and to allow the free release of steam from the cylinder when exhaust takes place.

22. *What is meant by the lead of the valve, and what is its effect on the running of the engine ?*

The lead is the amount by which the port is open to steam at the commencement of the stroke. Its object is to allow the steam to enter the cylinder a little before the end of the preceding stroke, and part of the cushion for reducing the strain upon the crank pins and rods, etc., at the reversal of the stroke.

23. *What is the outside lap of the valve, and how does it affect the admission of steam to the cylinder ?*

The outside lap is the amount by which the steaming edges of the valve overlap the steam ports when in the middle position. Added lap increases the length of the valve, and shortens the period of admission by the valve returning and cutting off the steam supply to the cylinder at an earlier part of the stroke.

24. *Can the point of cut-off be varied without altering the lap of the valve ?*

Link motions or radial valve gears enable the point of cut-off to be varied by altering the travel of the valve.

25. *How does the link motion alter the valve travel ?*

The maximum amount of travel is obtained with the link directly controlled by the forward or back gear eccentrics, in its bottom or top positions. The travel can be varied between these two extremes by moving the link, and the minimum travel is obtained in mid-gear.

26. *How is the point of cut-off or the period of admission affected by altering the travel of the valve ?*

The period of admission is lengthened by the later cut-off obtained when the valve travel is increased. By decreasing the travel by notching up, the valve is returned earlier to the point of cut-off, and the period of admission is shortened.

27. *What is meant by working the steam expansively ?*

Expansive working is obtained by admitting high-pressure steam to the cylinder and cutting off at an early part of the stroke, so that a certain amount of work is performed by expanding the steam to a lower pressure before exhaust takes place.

28. *Explain briefly how the advantages derived from using steam expansively are obtained.*

Steam is saved by abstracting a certain amount of energy after admission to the cylinder has been cut off. By expanding the steam in this manner, exhaust takes place at a much lower pressure than would be the case if steam were admitted during the whole or nearly the whole of the stroke. For example, it may be said that pressure in steam will always represent a certain amount of energy, so that if steam is exhausted at, say, 80 lb. instead of 10 lb. pressure, an amount of energy is wasted. Exhausting at low pressure is an advantage because it reduces the shocks and strains due to the reversal of movement in the reciprocating parts at the end of the stroke.

29. *What is meant by inside lead, and how does it affect expansion or release ?*

Inside lead is the distance by which the edges of the exhaust cavity in the valve are open to the steam ports when in the middle position. With inside lead the exhaust begins earlier and continues longer, and the amount of compression and period of expansion.

30. *Describe inside lap and its effect.*

Inside lap is the opposite to inside lead, and is the amount by which the inside edges of the exhaust cavity cover the exhaust port bars, thus overlapping the steam ports when in the middle position. With inside lap exhaust commences later and ceases earlier, so that a longer period of expansion and a greater amount of compression are obtained.

31. *What is meant by compression or cushioning: how is it controlled, and what is its purpose?*

Compression is obtained by closing the exhaust before the end of the stroke. The remaining steam is confined in the cylinder and compressed by the returning piston. It is controlled by the amount of exhaust lap or cover, and is affected directly by both the inside and the outside lead of the valve. Its purpose is to form a cushion for arresting the momentum of the piston and rods before the reversal of the movement which takes place at the commencement of every stroke.

32. *What is the principal objection advanced against the use of the ordinary D slide valve?*

That considerable valve face friction is generated by the steam pressure on the back of the valve. A large amount of power from the engine is therefore absorbed in moving the valve with a corresponding heavy load on the link motion and eccentric straps.

33. *Mention one or two types of valves which are designed to eliminate valve face friction.*

Balanced slide valves and piston slide valves.

34. *Describe briefly a balanced slide valve.*

A type of balanced valve often used when steam chests are placed above or below the cylinders is machined upon the back to receive four cast-iron strips, which are fitted to enclose the large area immediately behind the exhaust cavity. The cast-iron strips are held against a machined backplate fixed upon the inner side of the steamchest cover. A hole is drilled through the back of the valve, so that any steam leaking past the strips is discharged into the exhaust cavity of the valve.

35. *Describe a piston slide valve.*

A piston slide valve usually consists of two small pistons, fitted to the valve spindle in such a manner that they can be made to uncover the steam ports for each end of the cylinder alternately, as with the ordinary slide valve. The valve chest is cylindrical and the pistons are made steamtight by annular rings, the edges of which control the admission or release to and from the cylinder.

36. *Give one or two advantages and disadvantages attending the use of piston slide valves.*

The valve face friction is reduced considerably by the steam pressure in the valve chest being exerted on opposite sides of the piston, so that the valve is almost in equilibrium. The steam admission can be controlled by the inner edges of the pistons, and the gland packings are subjected to exhaust pressure only. The port area required can be obtained with a shorter travel than with the ordinary slide valve. The principal disadvantages are increased cost of upkeep, as compared with the ordinary slide valve, and the necessity for maintaining the piston rings steamtight.

37. *Explain the difference between a simple expansion and a compound expansion locomotive engine.*

A simple expansion locomotive is one in which the steam is exhausted from the cylinders directly into the atmosphere at or near the end of each stroke. A compound expansion locomotive is one in which the exhaust steam from one or more h.p. cylinders is passed into one or more larger diameter l.p. cylinders before it is exhausted into the atmosphere.

38. *Give some of the advantages derived from the use of compound expansion engines.*

A certain amount of energy, which would otherwise be lost, is obtained from the fuller expansion of the steam and from the lower pressure at which the final exhaust takes place. A greater amount of power is thereby obtained and high boiler pressures may be adopted without excessive mechanical stresses at the beginning of each stroke.

39. *What conditions seriously impair the suitability of compound engines for all classes of railway work?*

The constantly varying conditions of steam pressure, load, and speed.

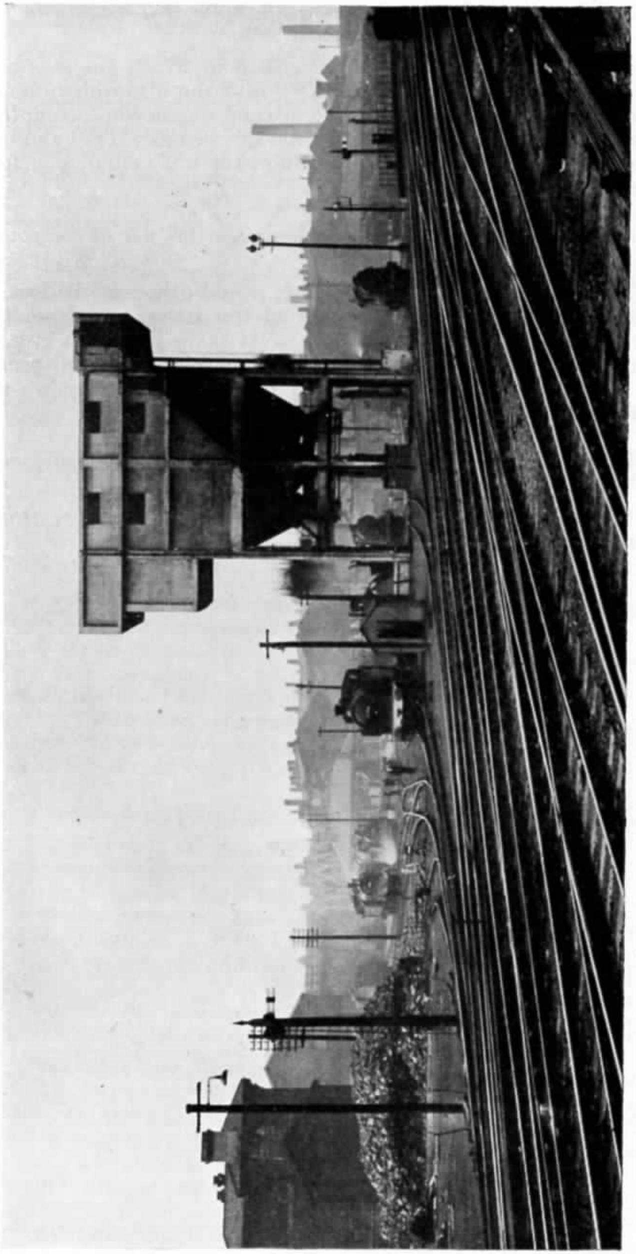


FIG. 266.—LOCOMOTIVE YARD AT LEEDS, L.M.S.R., SHOWING MECHANICAL COALING PLANT.

CHAPTER 21

EXAMINATION ON BRAKES

VACUUM BRAKES

1. *What is meant by vacuum ?*

A vacuum is a void, or, in other words, a space from which atmospheric pressure has been removed.

2. *What is the greatest amount of vacuum obtainable ?*

The removal of the whole of the atmospheric pressure would be a perfect vacuum, so that 14·7 or roughly 15 lb., is the greatest amount theoretically obtainable.

3. *When the gauge indicates a vacuum of, say, 20 in., what does it denote ?*

The pressure of the atmosphere is indicated by a scale showing so many inches of mercury when measured with a barometer. Two inches of the barometer scale are roughly equal to 1 lb. pressure, so that when 20 in. of vacuum is indicated by the gauge, 10 lb. of atmospheric pressure will have been removed from the parts connected thereto.

4. *Why are we insensible to the atmospheric pressure, and how is this pressure made available for working the vacuum brake ?*

Insensibility to atmospheric pressure is due to the balance or equilibrium obtained by the pressure existing on all sides. If, however, this equilibrium can be disturbed by withdrawing the atmosphere from one side of a body, the pressure of the atmosphere exerted against the other side is so much available energy. In the vacuum brake this energy is transmitted to the brake blocks by a piston, which is exposed to a vacuum on one side and atmospheric pressure on the other.

5. *How is the vacuum necessary for the working of the brake created ?*

By an ejector which is fixed on the locomotive so as to be under the control of the driver.

6. *Describe briefly the principle and construction of the ejector.*

The principle of the ejector is much the same as that of the injector ; steam is admitted through properly designed nozzles and discharged at great velocity into a coned barrel. Two ejector cones or nozzles are constructed together in one fitting, the small one placed inside the large one. The action of both is the same —steam is admitted around the cones in such a manner that the speed is sufficient to withdraw the air from the train pipe, cylinders, and air chambers. The small ejector steam valve is worked continuously and is regulated by the driver to maintain the required vacuum. The large ejector steam disc valve is used in conjunction with the small ejector steam valve when required to release the brakes quickly.

7. *How many brake cylinders are used on engine, tender, and passenger train, and how are the pistons contained therein controlled by the ejector ?*

Separate brake cylinders are fitted to the engine, tender, and each vehicle comprising the train. They are connected by a continuous pipe, which has branches to suit each of the cylinders, and is coupled between each vehicle by flexible hose connections. This pipe is known as the train pipe, and as it is connected to the ejector it enables the driver to control the exhaustion or admission of air to the cylinders on each vehicle.

8. *Describe as briefly as possible the construction of a brake cylinder and the manner in which the piston is made to transmit the pressure of the atmosphere to the brake rods.*

The brake cylinder is contained in an airtight chamber. The piston is an easy fit in the bore of the cylinder and is packed with a round rubber ring which rolls between the piston body and cylinder wall, thus forming an airtight frictionless packing. A ball valve is fitted to the bottom of the cylinder and forms the only communication between the top and bottom sides of the piston. When a vacuum is created by the ejector, air is drawn from below the piston directly into the train pipe, and from above the piston by way of the ball valve, thus placing the piston in equilibrium so that it falls by gravity to the lowest position and releases the brake blocks from the wheels. Immediately air is admitted to the train pipe the pressure of the atmosphere not only is exerted against the underside of the piston, but is also instrumental in forcing the ball upon its seat, thus closing the communication and retaining the vacuum in the upper part of the cylinder. In this manner the piston is lifted and the brakes applied with a force proportional to the amount of air admitted.

9. *How is the automatic action of the brake obtained ?*

As previously pointed out, the brake is applied by the admission of air to the train pipe, so that whether purposely admitted by the driver or guard, or by the accidental parting of the train, the action of the air on the pistons in the brake cylinders is the same, and the brakes are automatically applied.

10. *Explain the difference between the normal application of the brake for a station stop and the rapid application for an emergency stop.*

The train is brought to rest for a station stop by the driver admitting a moderate amount of air to the train pipe, and destroying not more than 10 in. of vacuum. When an emergency application of the brake is made the vacuum below the pistons is destroyed completely by a large admission of air, and the

rapidity of application in some cases is increased further by the adoption of patent rapid acting valves which are fitted to each brake cylinder connection. These valves open automatically with the sudden destruction of the vacuum and air is admitted simultaneously on every vehicle, thereby instantly applying the brakes with full force.

11. *What means are used to prevent the leakage of moisture from the ejector into the train pipe ?*

A drip pipe is fitted in front of the ejector, and this should be kept clear and free from dirt. A drip trap is fitted at the lowest part of the train pipe for draining and retaining any moisture that may accumulate. The trap is fitted with a self-acting ball valve, which allows the water to drain when the vacuum has been destroyed. The valve and trap should be examined occasionally and cleaned. A plug is provided on the vacuum reservoir, which should be removed occasionally for draining the accumulated water.

12. *How should the brake blocks on engine and tender be adjusted to obtain the best results ?*

The brake blocks should be adjusted so that the piston in the brake cylinders will not travel more than half the full stroke, thus obtaining a quick application of the brake blocks with a minimum quantity of air.

13. *What is the use of the small auxiliary pipe which connects the ejector to the vacuum chambers on engine and tender ?*

The auxiliary in pipe is communication with the small ejector when the driver's handle is in "full-on" position, thereby constantly maintaining the vacuum above the engine and tender pistons.

14. *Explain the method of procedure for testing the brake when leaving the shed.*

See that the hose is properly on the plug, walk under the engine and tender to oil and examine brake gear, drip valve, and all connections; then mount the footplate and pull the ejector handle into the "full-on" position before opening the small ejector steam valve for testing the vacuum chamber above the brake cylinder pistons.

15. *Why pull the ejector handle into "full-on" position before opening the small ejector steam valve ?*

Because in this position the small ejector will exhaust the air up the auxiliary pipe above the brake cylinder pistons and air will be admitted through the disc handle into the train pipe below. By watching the vacuum gauge finger any leakage of air from the train pipe past the piston packing ring or ball valve will be apparent at once. A certain amount of water is always discharged from the ejector exhaust pipes in sufficient quantities to dirty the boiler top when steam is first admitted. With the ejector handle in "full-on" position it will, however, be found that this water is deposited mostly in the smokebox, and not up the chimney, as when steam is first admitted with the handle in "running position."

16. *Having found the vacuum above the pistons satisfactory, what other test can be applied, and what amount of vacuum should be indicated by both gauge fingers before leaving the shed ?*

Place the ejector disc handle in the "running position," thus releasing the brake and testing by the amount of vacuum obtained in the train pipe and connections. The vacuum chamber and train pipe gauge fingers should now indicate 20 in. of vacuum if the brake is in proper order, and a start should not be made with less than 18 in. vacuum.

17. *If the ejector were sluggish in its action and all joints were found good, what would be the probable cause or causes ?*

The sluggish action of the ejector would point to dirt or other obstruction in the nozzles. The exhaust pipe becoming choked with dirt at the smokebox end also would retard the action of the ejector.

18. *Give some convenient method for removing obstruction from the nozzles.*

Remove and clean large and small ejector nozzles. Before replacing nozzles, screw on the cap and place ejector handle in "full-on" position, thus clearing the steam passages with the rush of steam.

19. *What is one of the most frequent causes of dirt, and so on, in the ejector nozzles ?*

Leaving the steam supply valve open when in the shed, so that dirt is carried down the pipe when washing the boiler out.

20. *If the brake cylinder pistons on the engine stick with the brakes on, what steps should be taken for releasing them ?*

Admit air on the chamber side of the piston by opening release valve on the chamber side of the piston, or by disconnecting the auxiliary hose connection between engine and tender, and forcing the ball contained therein from its seat. Then place the ejector handle in the "off" position, and the vacuum created in the train pipe with the atmospheric pressure above in most cases will be sufficient to release the piston. If unable to get the piston down in this way, knock out the pin connecting the piston rod on the brake gear, or slack the blocks from the wheels by means of the adjusting screws.

21. *What should be done if, after coupling up to a train, it is found impossible to create a vacuum ?*

First examine disc for obstruction between disc and large ejector face. If disc is airtight, uncouple from train to test engine and tender. If nothing is wrong with the latter, examine vehicles for faulty connections or hose not properly on plug.

22. *If in coupling up the train some obstruction, such as a piece of waste, inadvertently should be drawn into the train pipe, what would be the probable effect ?*

The presence of the obstruction in the train pipe would be indicated by a fluttering or jerky movement of the vacuum gauge fingers, and probably by the brakes refusing to act behind the point of obstruction when an application is made.

23. *How would you remove obstruction from train pipe on engine or tender ?*

Create the greatest possible vacuum by opening the large ejector and then suddenly remove hose from plug, allowing a violent rush of air to enter the pipe, which would tend to carry the obstruction toward the union connection below the ejector. The union nut then could be uncoupled for the removal of the obstruction, which, however, may not appear until the operation has been repeated several times.

24. *What should be done if a brake piston on any vehicle gives trouble by sticking or leaking ?*

Isolate the cylinder by inserting a piece of stout paper or tin between the ball valve case and cylinder bottom.

25. *What should be done if the steam supply pipe to ejector on top of the firebox breaks ?*

Close steam supply valve on firebox top ; open release valves by drawing triggers on coaches ; instruct the guard to look after his handbrake, and work the train forward to nearest depot, thus causing as little delay as possible.

26. *If drip valve is lost, how may it be noted and how remedied ?*

When attempting to create a vacuum a hissing sound would be heard below the footplate. Remedy, plug with piece of wood or cork.

27. *If speed has to be reduced to 10 m.p.h. for passing over a junction or dangerous curve when running down an incline, when and how should the brakes be applied ?*

The speed should be reduced sufficiently when approaching the junction or curve for the brake blocks to be released as much as possible from the wheels. In this manner a certain amount of the side strain on the crank axle is relieved, and the wheels, not being held so rigidly as when the brake blocks are hard on, would follow the contour of the road more easily.

28. *What precautions are necessary when entering a terminus ?*

To have the train under full control when approaching, and to use the handbrake when entering the station.

29. *What is invariably the cause of the train pipe heating in the old type of ejectors ?*

Faulty clappet valve in the ejector, which should be repaired or changed.

30. *What parts of the brake gear should be examined for faulty vacuum as denoted by the vacuum chamber gauge pointer ?*

Auxiliary pipe connections to vacuum chambers on engine and tender for leaks. All brake cylinders for faulty or dirty ball valves or leaky piston rings.

31. *Name some faults that would tend to destroy the vacuum in the train pipe.*

Faulty joints. Hose connections improperly on the plug. Faulty drip trap valve. Faulty clappet valves on the rapid acting brake valves. Faulty valves in ejector. Faults in hose connections as by sparks from engines. Faulty piston rod bushes.

32. *How would you detect a faulty cylinder ball valve or defective piston ring ?*

First create a vacuum of, say, 20 in. on both sides of gauge. Then shut the small ejector steam valve and pull the disc handle to the " on " position to destroy the vacuum on the train pipe side of the piston. If the disc handle is placed in the " running position " immediately the vacuum is destroyed, the chamber finger will fall and the train pipe finger rise to an equilibrium, thus proving that air is passing from the chamber to the train pipe side of the piston by way of the faulty ball valve or defective piston ring.

33. *What steps should be periodically taken to ensure the proper working of the ejector ?*

The disc handle should be taken off and the air holes cleaned out before leaving the shed. The disc face should be slightly lubricated and the handle adjusted to work freely when replaced. The ball and drip valves should be taken out and cleaned with a cloth at least once a week.

34. *What precautions should be taken to ensure the proper working of the brakes before starting on a journey ?*

The vacuum to be maintained throughout the journey must be created by the driver after the brake pipes between the engine and train and between each vehicle have been connected properly. Should the driver not be able to create the required vacuum, after satisfying himself that his engine is all right, he must inform the guard and station staff at once, so that the whole of the train may be examined. If the engine has been changed or any vehicles attached or detached, the driver, before proceeding on his journey, must receive from the guard satisfactory information as to the number of vehicles comprising the train, the number, if any, on which the brake is not in operation, and also that the proper amount of vacuum is registered in the guard's van.

35. *What occurs when a passenger makes use of the communication cord or handle ?*

Air is admitted to the train pipe and the vacuum in consequence is reduced by from 7 to 10 in.

36. *What should be done if the communication is made in an inconvenient place such as a tunnel or on an overbridge ?*

The larger ejector should be opened to overcome the loss of vacuum until the train can be brought to a stand at some suitable place for the passengers to leave the train if necessary.

STEAM BRAKE

1. *Describe the action of a steam brake.*

Steam at boiler pressure is admitted behind a piston contained in a cylinder below the footplate. The piston rod is connected to brake levers in such a manner that the pressure exerted by the steam against the piston is transmitted to the brake blocks.

2. *How is the admission and exhaustion of steam to and from the brake cylinder controlled by the driver ?*

By removing the trigger on the steam brake valve the lever controlling the steam piston is released, thereby closing the exhaust passages and admitting steam which, by its pressure, enters the cylinder at a great velocity, and immediately applies the brake. When the trigger is replaced on the lever pin the supply of steam to the cylinder is cut off and the exhaust passages are again opened for exhaustion, thus relieving the pressure on the brake blocks.

3. *How are the steam brakes on engine and tender combined with the vacuum brake so as to be worked in conjunction automatically ?*

When worked in conjunction with the automatic vacuum brake the steam brake valve is fitted with a vacuum or controlling piston, which is exposed on its inner side to the vacuum in the train pipe and to the atmospheric pressure on its outer side. The admission or exhaustion of steam to and from the brake cylinder is controlled automatically by the movements of this controlling piston actuating the steam supply piston according to the increase or decrease of vacuum in the pipe.

4. *How is the steam brake maintained in " running position " by the action of the vacuum in the train pipe ?*

When a vacuum is created in the train pipe the chamber on the inner side of the controlling piston is exhausted also, and the atmosphere, by its pressure, forces the piston inward. This movement is transmitted by a lever to the steam supply piston, thus placing the brakes in " running position " by opening the exhaust port and closing the steam supply to the brake cylinder.

5. *How is the steam brake applied when controlled by the automatic vacuum brake ?*

The vacuum on the inner side of the controlling or vacuum piston is destroyed by the admission of air to the train pipe, and the piston placed in equilibrium. When this takes place the brake valve steam piston is forced from its seat, thus closing the exhaust port and admitting steam to the brake cylinders.

6. *How is the brake force applied by the steam brake made proportional to that of the vacuum brake ?*

The effective areas which are exposed to steam, vacuum, and air on the steam and controlling pistons in the steam brake valve are designed so that the movements of the steam piston for admission and exhaustion of steam to and from the brake cylinders are controlled in accordance with the amount of vacuum acting on the inner side of the controlling piston.

7. *Give a common cause of piston sticking in the steam brake cylinder.*

Neglect of lubrication, causing the walls of cylinder to be dry and rusty.

8. *Give one or more faults which would tend to destroy the efficiency of the steam brake.*

Faulty piston rings in brake cylinders. Faulty steam piston, or seating on brake valve causing a constant blow through, vacuum, or controlling piston dirty or sticking. Faulty intermediate joint between steam brake valve and the auto-ejector.

9. *What signs would denote that the steam piston and seating in the brake valve were leaky or the intermediate steam joint was faulty ?*

The brake would be sluggish in its action, or the brake cylinder piston would show signs of sticking, and a constant blow through the exhaust would take place.

10. *In addition to noting a constant blow through the exhaust, what other method may be adopted sometimes in testing for leaky steam piston on brake valve or faulty intermediate joint ?*

On most engines a three-way cock is fitted with pipes running to brake cylinders on engine and tender, so that either of the brakes may be worked separately in case of accident. Any blow through will be indicated by the appearance of steam when the lubricator on the three-way cock is opened with the brakes in running position.

11. *Give one or more causes which might prevent the release of the brake blocks from the wheels.*

Coil springs on engine and tender not properly adjusted or too weak to overcome weight of brake cylinder piston and brake hangers, and so on. Brake shaft brackets and hangers insufficiently lubricated.

WESTINGHOUSE BRAKE

1. *What motive power is used for working the Westinghouse brake ?*

Air, which is compressed and stored in suitable reservoirs. The pressure of air thus represents so much available energy for the application of the brake.

2. *Why is air so adaptable for brake-power purposes ?*

Air has very elastic qualities, and therefore may be compressed to any required pressure, thus providing a motive force which may be stored and used as occasion requires.

3. *How is the air compressed ?*

By means of a double-acting air pump which is connected to and driven by a steam cylinder. The compressed air is delivered into a main reservoir and the steam for driving the pump is obtained from the locomotive boiler ; the supply valve is under the control of the driver.

4. *How are the brakes applied ?*

The brakes on the different vehicles are connected by a main pipe which runs the full length of the train, and any reduction of the air pressure in this pipe, whether purposely or accidentally produced, will apply the brakes.

5. *How is the admission or the exhaustion of air to or from the main pipe controlled ?*

By means of the driver's brake valve, which is placed in the cab so as to be manipulated easily by the driver. This valve forms the connection between the main air reservoir and main air pipe.

6. *How are the brakes released ?*

By recharging the main pipe to its normal working pressure with air from the main reservoir.

7. *What air pressure should be maintained in the main reservoir, and what is the normal working pressure in the main pipe ?*

The air pressure in the main reservoir should be from 80 to 85 lb. when fitted with the ordinary brake apparatus, and from 90 to 95 lb. for the quick-acting brake. The normal working pressure in the main pipe should be about 70 lb.

8. *How is the difference of pressure in the main air reservoir and main pipe maintained ?*

The pressure in the main pipe is regulated by a small feed valve attached to the driver's brake valve. This valve is controlled by a spring adjusted to give a resistance to 25 lb., so that when the normal pressure in the main pipe is attained the valve closes the communication between the main pipe and main air reservoir. In this manner a pressure of 25 lb. in excess of that in the main pipe is retained in the main reservoir.

9. *Why is the greater pressure in the main reservoir necessary ?*

The excess of pressure in the main reservoir is available for recharging the main pipe and thus quickly releasing the brakes after an application.

10. *How are the brakes on each separate vehicle applied ?*

The locomotive, tender, and each braked vehicle are provided with an auxiliary air reservoir and brake cylinder. The compressed air is supplied through the main pipe from the main reservoir on the engine to each of the auxiliary reservoirs. The air is stored ready for use, and the brakes are applied rapidly on each unit comprising the train when a reduction of pressure occurs in the main pipe.

11. *How are the brake blocks actuated by the brake cylinders ?*

A brake cylinder containing a piston and spring is connected to each auxiliary reservoir. The piston rod is attached to the brake gear in such a manner that the brake blocks are pressed against the wheels when the piston is forced out by the admission of compressed air to the cylinder. The brake blocks are released from the wheels by the spring returning the piston to its normal position when the air is again discharged.

12. *Explain how the admission and the exhaustion of air to and from the cylinder is controlled.*

The air supply to the cylinder is controlled by a valve, known as the triple valve, which in turn is operated by the variations of pressure in the main pipe. When the pressure in the main pipe is reduced, the triple valve automatically admits compressed air from the auxiliary reservoir to the brake cylinder and automatically exhausts the air when the normal pressure in the main pipe is restored.

13. *How is the rapid and simultaneous application of the brakes to all the vehicles obtained in a modern "quick-acting" Westinghouse brake ?*

The quick-acting triple valve, as now made, is designed to accelerate the application of the brakes when an emergency stop is required. In ordinary applications the air is allowed to exhaust at a comparatively low rate of speed from the main pipe. If, however, air is discharged rapidly from the pipe, as in an emergency stop, the sudden reduction of pressure immediately produces the rapid action of the brake by opening on every vehicle a large communication from the main pipe to the brake cylinders in addition to the usual supply of compressed air as in ordinary applications. A considerable proportion of the air in the main pipe therefore is used to increase the available brake force, and this at the same time increases the rapidity with which the train pipe pressure is reduced, thus ensuring simultaneous and almost instantaneous action throughout the train.

14. *How is the application of the brakes by a leakage of air into the brake cylinder prevented, and how does this affect the operation of the brakes ?*

Each brake cylinder is provided with a small groove, which establishes a communication between both sides of the piston when the brake is not applied, so that any slight leakage into the cylinder will pass through the groove to the atmosphere without moving the piston. In ordinary applications of the brake the pressure in the main pipe should therefore be reduced not less than 6 or 8 lb., according to the length of the train, so as to ensure that the pistons in all the brake cylinders clear their respective leakage grooves.

15. *An isolating cock is fitted to the pipe leading from the main reservoir to the driver's brake valve. Explain its purpose.*

In ordinary working, the brake valve isolating cock should be open always. When, however, two engines are coupled to a train it is necessary that the brake should be controlled by the driver of the leading engine, and the second engine therefore must be isolated from the main pipe by closing the brake valve isolating cock until the leading engine is removed.

16. *Give the number of principal positions for the driver's equalising brake valve handle, and state briefly what operation is performed in each respective position.*

There are five principal positions for the driver's brake valve handle. In position 1 a direct communication is established from the main reservoir to the main pipe, thus charging the whole of the brake apparatus with air and releasing the brakes. This direct communication is cut off in position 2, and another passage is opened which leads to the main pipe by way of a small feed valve. By this arrangement, the proper working pressure in the main pipe is maintained, and the excess of pressure in the main reservoir is available for quickly releasing the brakes. The handle therefore should be retained always in this position whilst running. In position 3 all the portways in the valve are closed. Position 4 is for ordinary applications of the brake ; the air is allowed to escape gradually from the main pipe to the atmosphere by way of a passage in the valve. When the brakes are released the handle should be returned to position 1 sufficiently long to release the brakes properly and to recharge the auxiliary reservoirs.

Position 5 is for emergency applications of the brake. When the handle is in this position a large direct communication between the main pipe and the atmosphere is established, thus suddenly reducing the pressure in the main pipe and causing an instant application of the brakes with full force.

17. *Why is it necessary to retain the brake valve handle in position 1 for a short time when releasing the brakes ?*

In applying and releasing the brakes a large amount of air is discharged from the main pipe and auxiliary reservoirs. It is necessary therefore to recharge properly the auxiliary reservoirs by retaining the brake valve handle in position 1 from ten to twenty seconds, according to the length of the train, before returning the handle to position 2.

18. *What would be the effect of placing the brake valve handle in position 1 before applying the brakes or when running unbraked ?*

The main pipe would be placed in direct communication with the main air reservoir, and the excess of pressure required for releasing the brakes would be lost.

19. *What is the effect on the engine and tender brakes when coupled to a train carrying less air pressure ? Explain the cause and method of procedure.*

The brakes on engine and tender would be applied automatically by the reduction of pressure in the main pipe because of equalisation with the lower pressure in the train. If, however, the main reservoir contained the proper excess of pressure when the connection was made, the train would be charged, and the brakes again automatically released when the normal pressure had been attained in the whole of the main pipe and auxiliary reservoirs. The engine brakes may be released also by opening the small release valve which is connected to the engine brake cylinder.

20. *Where should the brake valve handle be placed when the brakes have been applied either by the guard or automatically, as by a rupture of the hose couplings or a separation of the train?*

The valve handle should be placed as for ordinary applications of the brake, thereby aiding in stopping the train and at the same time preventing the escape of air from the main reservoir.

21. *When first coming on duty what precautions should the driver take to see that the brake is in proper working order?*

The brake apparatus on engine and tender should be examined somewhat as follows. See that the brake gear is adjusted and wear of blocks taken up uniformly. Lubricate air pump and work it until 90 lb. is stored in the main reservoir. See that the driver's brake valve operates properly in all positions of the handle and retains an excess of 20 lb. pressure in the main reservoir when the handle is placed in the "position whilst running." Air leaks or any other defect to be repaired before leaving the running shed.

22. *How would you test the brakes before leaving a terminus or any place where the hose couplings have been separated and recoupled?*

See that the hose coupling on the engine or tender is coupled properly to that on the first vehicle, and that the corresponding cocks in the main pipe are open. Apply the brakes on the train for examination and release them when required, to see that the brakes on all the vehicles operate properly.

23. *How should the brake be applied for ordinary stops to prevent a rebound or other inconvenience to passengers?*

To bring the train to a stand without rebounding the brake valve should be opened carefully when the brake is applied, and closed gently when the pressure has been reduced by about 8 lb.

24. *What is the proper speed at which a terminus or a dead end bay in a station should be entered?*

A terminus or dead end bay should be entered at such a speed that the train can be brought to a stand at the proper place by the application of the hand brake only, if necessary.

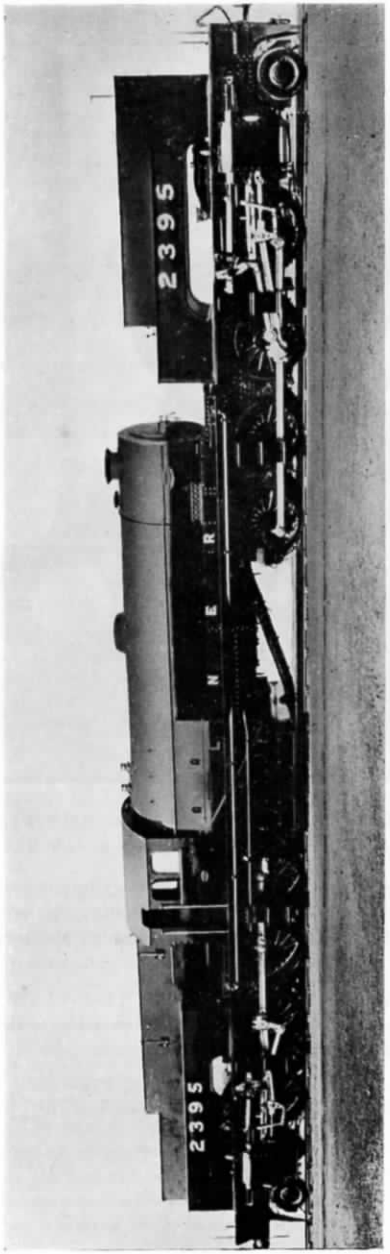


Fig. 267.—Six-Cylinder Garratt Locomotive 2-8-0+0-8-2 Type, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (6), 18½ in. by 26 in. Coupled wheels, 4 ft. 8 in. diameter. Coupled wheelbase, each unit, 17 ft. 10½ in. Total engine wheelbase, 79 ft. 1 in. Boiler pressure, 180 lb. per sq. in. Total heating surface, 3,640 sq. ft. Grate area, 56·4 sq. ft. Weight of engine in working order, 178 tons 0 cwt. 3 qrs. Tractive effort (at 85 per cent. b.p.), 72,940 lb.

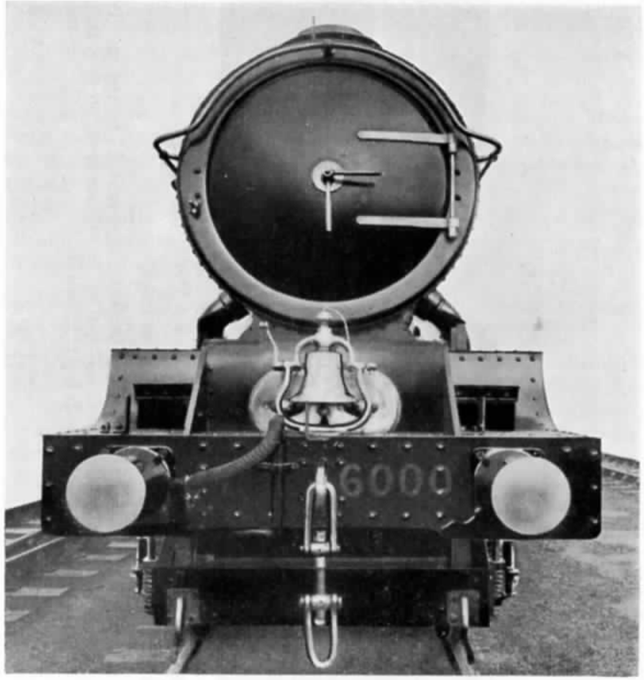


FIG. 268.—FRONT-END VIEW OF FOUR-CYLINDER 4-6-0 TYPE EXPRESS LOCOMOTIVE, NO. 6000, *King George* V, G.W.R.

Engines of this class have four single-expansion cylinders and two sets of valve gearing; the piston valves of the outside cylinders take motion from the spindles of the inside valves through the medium of rocking levers.

The bell was awarded to the engine at the "Fair of the Iron Horse," held at Baltimore, Ohio, in 1927, to celebrate the centenary of the Baltimore & Ohio Railroad.

For general view and dimensions, see p. 223.

CHAPTER 22

EXAMINATION ON BREAKDOWNS

1. *How could you tell whether your engine was right or left hand?*

By placing both crossheads opposite each other at the motion end of the slides. In this position the cranks will point towards the firebox. The uppermost crank, whether it be the right or left, will denote the hand of the engine when looking from the footplate or trailing end.

2. *How would you know if an eccentric had shifted? What might be the cause and remedy?*

A shifted eccentric would be denoted by the engine beats becoming irregular. This irregularity would be most noticeable with the reversing lever in the gear controlled by the faulty eccentric, when separate eccentrics are fitted. The failure is not a common one, since the eccentrics are usually secured by keys sunk into the axle, in addition to $\frac{3}{4}$-in. hexagon-headed steel set screws, which are hollowed on the end to form a cutting edge for sinking into the crankshaft to prevent turning. It may be due to the screws, or cotters when used, working loose, or by insufficient lubrication setting up excessive valve face or motion-work friction, thereby increasing considerably the work of the eccentrics. This heavy strain, together with the reversal of movement at each stroke, might cause the screws or cotters to work slack, which, with the additional wear on the key, would result eventually in failure. If a forward gear eccentric has shifted, place the reversing lever in full forward gear, or in full backward gear for a back gear failure, with the crank on front centre, the brakes hard on and the cylinder drain cocks open. With the regulator slightly open, move the loose eccentric forward, *i.e.*, in advance of the crank, until steam appears at the front drain cock. Secure the eccentric by the screws or cotters, taking care before starting to see that the motion-work pins and slide valve, etc., are perfectly free.

3. *Give one or two causes to which a broken eccentric strap might be due, and explain how temporary repairs may be effected.*

A broken strap may be caused by (1) insufficient or improper lubrication setting up excessive valve face, motion-work, or eccentric sheave friction. (2) Expansion of the sheave and consequent seizure of the eccentric strap due to heat generated by grit picked up when running. (3) Faults in the strap material which were not discernible previously. In a forward gear eccentric, both straps and rods on that side of the engine must be taken down and steam prevented from entering the cylinder by fixing the slide valve in the middle position. In a back gear failure, the forward gear may be left intact and the engine worked forward by taking down the defective gear only, after packing up the quadrant block with a piece of wood inside the slotted link. In either case the connecting rod may be left in position to retain the engine balance. When the slide valve is fixed in the middle position for a forward gear failure the lubricator valve on the defective side should be taken out and the cylinder well flushed with oil before starting away.

4. *What methods would you adopt to secure the slide valve in the middle position with either fibrous or metallic gland packings?*

With fibrous packing the gland may be canted by packing with wood, etc., on one side, and screwing up the nut on the opposite side, thus gripping the valve spindle, or by inserting one or two additional rounds of packing and tightening up the gland beyond the usual working condition. Special clips, to be secured by the gland screws and fitted with a screw for tightening against the spindle, should be carried for metallic packings. If there are no clips to hand the spindle may be secured by taking off the gland or cover and inserting one or two rounds of spun yarn, or by driving wood packings between gland screws and spindle.

5. *State what you know about eccentric rod or bolt failures, giving probable causes and temporary remedies.*

Eccentric rods usually break at the forked ends, which are coupled to the link. The cause may be due to (1) insufficient slide-valve lubrication. (2) Seizure of the link pin. (3) Faulty material. (4) Pieces of broken piston ring passing through the steam port and fouling the valve edge. A broken bolt may sometimes be replaced by a bolt taken from some other part of the engine. Almost invariably, it is necessary to take down the rods as described for the broken eccentric strap.

6. *What would you expect to occur with a bent or broken valve spindle, and how would you act?*

If the spindle were bent the valve lead would be altered and there would be an irregular beat on that side of the engine. With a broken spindle, the valve generally remains at the front end of the steamchest and a constant admission to one end of the cylinder occurs, which stops the engine. In the event of a failure inside the steamchest, a test may be applied as follows: First place the crank on top centre with the brakes hard on and the cylinder drain cocks open. Open the regulator a little, and, by moving the reversing lever forward and backward, it can be seen by means of the drain cocks whether admission to each end of the cylinder changes in accordance with the movements of the lever. In an inside failure, push the broken spindle, after disconnecting its outer end, tight against the internal portion, and secure in position with the gland, thus holding the valve at the front end of the steamchest. The eccentric and connecting rods must be taken down, although the straps may be left on the sheaves if they are clear of the firebox or the underside of the boiler. This can be ascertained by swinging the straps round, taking care to have one of the eccentric sheaves with full throw pointing directly towards the firebox. Then push the piston to the front end of the cylinder and secure by means of the slide-bar clips which are usually carried. If there are no clips to hand, place a piece of fence rail or some such material between the slide bars and secure with spun yarn or cord. In the case of an engine with a rocking-shaft valve motion the connecting rod only need be taken down, and the eccentric rods left intact after disconnecting the valve link or short arm. The piston rod would require to be secured as described already unless the failure was outside the steamchest, in which case both the connecting and eccentric rods may be left intact by working with the valve fixed in the middle position after flushing the cylinder thoroughly with oil and taking out the lubricator valve.

7. *What would you do if the valve spindle cotter was sheared or lost?*

Insert a suitable spanner or chisel and secure with cord. If this is impracticable, secure valve in the middle position and proceed as with broken spindle.

8. *State how a leakage of steam due to the slide valve having become disturbed from its proper working position, or withheld from its face, would be denoted, giving the probable cause and particulars for testing for this.*

If the slide valve was withheld from its face a continuous blow up the chimney would be observed. This might be due to the spindle or buckle having become strained or fractured. To find which side is defective first place the right-hand crank on top or bottom centre with the reversing lever in mid-gear, the cylinder drain cocks open, and the brakes hard on. If steam is discharged through both cylinder drain cocks when the regulator is opened it may be assumed that the valve is off its face. This test may be repeated on the left-hand side by placing the corresponding crank on top or bottom centre with the reversing lever still in mid-gear. A similar leakage of steam would occur if both lap pieces were broken, but the chance of this happening simultaneously at each end of the valve is very remote. In addition to noting the drain cocks, however, the amount of power required to move the reversing lever will also assist in denoting whether a valve is off its face, and which is the defective side. Take the first test, for example, *i.e.*, R.H. crank on top centre, in which position the L.H. crank will be on the back dead centre, assuming the engine to be right hand. If the reversing lever is moved, the L.H. valve will be at its minimum and the R.H. valve at its maximum amount of movement. If, therefore, a certain amount of stiffness not before apparent is noticed when moving the lever, the R.H. valve alignment will have been disturbed, and this stiffness, together with the discharge from the drain cocks, will denote that the fault is on this side of the engine. The amount of leakage will determine whether it will be possible to proceed, although the assistance of another engine is usually necessary with this kind of failure.

9. *How would you act with a seized quadrant or motion pin ?*

In most engines there is insufficient clearance, and considerable time might therefore be lost in attempting to withdraw the pin. If this was found to be the case the parts affected should be taken down, and proceed with one side only, as already described.

10. *Explain the method of procedure and give the proper positions of the cranks on an inside cylinder engine with Stephenson link motion for* (1) *taking down the whole of the valve gear on both sides and* (2) *for taking down one side only.*

First place both cranks on top, *i.e.*, equidistant from top centre, with the reversing lever in full forward gear, thereby bringing the foreward gear eccentric rods immediately over the drag link. In this position the bottom pin for connecting the lifting links to the forked arm of the reversing shaft may be driven out. With the bottom end of the links thus free raise the R.H. foreward gear eccentric rod by means of a pinch bar and secure with a block of wood sufficiently high to enable the pin of the L.H. foreward gear eccentric rod to be removed. The outside links will first be released, after which the pin may be driven completely out. The inside links are held by hand, and the radius link connected to the L.H. back gear eccentric rod is allowed to rest upon the reversing shaft. The wood packing may then be removed from under the right-hand rod, which will then rest upon the drag link. Place the packing under the L.H. foreward gear eccentric rod in order that the pin may be driven out clear of the R.H. rod end as before, and allow the radius link and R.H. back gear rod to rest upon the reversing shaft. By thus disposing of the lifting links the radius links may be disconnected from the bottom or back gear eccentric rods with comparative ease. Proceed by first packing up the R.H. back gear rod with the block, and then drive the pin out of the L.H. back gear rod, thereby releasing the radius links on this side. Again place the wood packing under the L.H. back gear rod to enable the pin of the R.H. block gear rod to be removed, thus releasing completely the four forked ends of the eccentric rods at the motion end. The rods can then be removed from the straps. The back gear is taken down first, since these rods are usually outside with a direct Stephenson link motion. This dismantles completely the whole of the valve motion-work, as required when the engine is to be worked dead. In this case it would also be necessary to take down both connecting rods and to secure the pistons in the cylinders for travelling any considerable distance. If it is necessary only that the rods should be taken down for working with one side, proceed as described with the foreward and back gear rods in the faulty side only, and then couple up the links on the working side to the bottom arm of the reversing shaft. This leaves one side of the motion intact for working home or to the depot.

11. *How would you take the eccentric rods down on an eight-wheeled coupled engine ?*

Eccentric rods on eight-wheeled coupled engines are exceptionally long by reason of the greater distance from the driving wheels

to the cylinders. When a rod breaks it often happens that it will fall low enough to strike the ballast, and be doubled up before the engine can be brought to a stand. In a foreward gear rod, the butt end is detached easily from the strap by taking off the nuts. To uncouple the forked end from the radius link pinch the drag links backward or forward according to their position to clear the suspension links for taking out the eccentric rod pin. In the case of a back gear rod the pin will usually come out in any position, as the point of attachment to the radius links is well below the suspension links. These links may then be uncoupled for removal without detaching the drag links. Place the full throw of the eccentric towards the firebox or stretcher plate, whichever is nearest, and swing the straps round on the sheaves to see that they clear. Should the straps foul or any doubt exist as to clearance, they must be taken down to prevent further damage when the engine is moved.

12. *How would you deal with a broken slipper block on Joy's valve gear ?*

Slipper blocks for Joy's valve gear are bored through the centre for attachment to the swing links, and usually break across this, the weakest part, in which case the bottom portion is usually lost. This, however, does not prevent the engine from being worked carefully to its destination, since the upper portion is retained in position by the slipper block slides, and will therefore perform the duty of the whole block temporarily. In the event of a slipper block breaking in such a manner that it is impossible to work forward, the slide valve on the faulty side must be fixed in the middle position with the cylinder drain cocks open, the brakes hard on, and the connecting rod on bottom centre for taking down the valve gear. First uncouple the swing links from the stirrup link, and then raise the swing links and slipper blocks as high as possible with a pinch bar so that they may be secured by means of a rope to the boiler handrail or the framing. The bottom of the swing links should then be moved toward the motion plate and the reversing lever moved to find the most suitable position for taking out the valve-rod pin. After detaching the valve rod, the swing links and slipper blocks may be lowered steadily down the slipper block slides and liberated. The connecting rod and remaining links may be left in position for working with one side to the depot. Care must be taken to lubricate the cylinder thoroughly on the faulty side.

13. *How would you deal with a broken swing link or a broken anchor link on a Joy's valve gear ?*

A broken swing link would have to be taken down as described for a broken slipper block. The method of dealing with a broken anchor link would be somewhat different, since the movements of the stirrup link and swing links are controlled by it, and the whole of the valve gear on the faulty side would have to be taken down. After fixing the valve in the middle position, take down the swing links and that portion of the anchor link connected to them. Disconnect the stirrup link which has thus been left hanging on to the connecting rod and proceed to the depot as described already when working with one side only.

14. *Give the probable causes of, and state how you would proceed with, a broken reversing rod.*

A broken reversing rod may be due to (1) excessive valve face friction. (2) Valve spindle gland too tight or valve spindle galling. (3) Faulty material. When this failure occurs the links by their weight will fall into forward gear and the engine may therefore still be worked in a forward direction. When it is required to reverse, the links will have to be raised by means of a pinch bar or other lever. To retain them in the proper running position loosen the caps on the reversing shaft bearings and insert underneath a piece of tin, leather, wood, etc., to grip the shaft when the caps are screwed up tightly.

15. *What would denote that the reversing screw thrust gland had seized? Give the probable cause and remedy.*

The seizing or galling of the reversing screw thrust gland is usually accompanied by a gradually increasing stiffness when reversing, and would probably be due to dirty or choked up oil holes preventing the proper lubrication of thrust collars. To remedy the defect, remove the nuts from the gland, which may then be forced out by turning the screw. Relieve the catch plate by taking off the handle, thereby releasing the bolts, and the gland will then leave the screw. Thoroughly clean all parts, smooth over with a file where rough, and lubricate before replacing.

16. *How would you act with a broken or uncoupled regulator?*

If the regulator became uncoupled or broken so as to be out of control with the valve open, the steam admission to the cylinders would have to be regulated by means of the reversing lever. In stopping the engine the steam could be shut off from the cylinders almost entirely by placing the lever in mid-gear, which, together with a judicious use of the brakes, would give the necessary control. It would, however, be necessary to wire forward for another engine to be in readiness at the nearest convenient place, since the regulator might be closed at any moment by the jolting of the engine. The steam pressure should be reduced for working forward or home light. Should the failure occur with the regulator closed there would be no alternative but to obtain an assisting engine, and in this case care should be taken not to reverse the motion in the opposite running direction, otherwise an alteration to the steam pressure on each side of the regulator might cause it to open.

17. *Describe how you would test your engine for faulty valves, pistons, or rings, broken front or back valve lap pieces, or a broken valve cavity.*

First place crank of engine on top centre with the brakes hard on and the cylinder drain cocks open. If the piston and rings are in good condition steam will issue from the back drain cock only, when the lever is placed in full forward gear and the regulator opened. If either the piston or the rings are faulty, steam will be discharged at both the drain cocks. The test may be repeated by placing the lever in full backward gear, to steam to the front end of the cylinder, and through the front drain cock only if the piston and rings are in proper working order, When testing for broken valve lap pieces the lever should be placed in mid-gear, thus shutting off steam from the cylinder entirely if the valve is in good condition. With the valve in this position a broken front or back lap piece will be denoted by an issue of steam from the corresponding drain cock. A broken valve cavity will discharge steam up the blast pipe in all positions of the reversing lever. The left-hand engine may also be tested by placing the crank on top centre and repeating the foregoing. These tests could also be carried out with cranks on bottom centres, in which case steam would be admitted to the opposite ends of cylinders and would issue from the drain cocks accordingly.

18. *State how a broken port bridge would be observed, how it would be located, and the method of dealing with this.*

A broken port bridge would be observed by the occurrence of one strong blow to every three beats of the valves or to one revolution of the driving wheels. This strong blow is caused by the steam following the line of least resistance, and passing directly through the broken port bridge and up the blast-pipe immediately the faulty port is open to steam. To locate the fault move the engine slowly forward, with the reversing lever in forward gear, assuming the engine to be right hand. If the blow occurs during the time that the R.H. crank is passing through the top front quarter, *i.e.*, between top and front centres, the left-hand back port bridge is defective. In a similar manner the broken port bridge may be located if the blow occurs with cranks in the following positions :—

R.H. crank passing through bottom back quarter, L.H. front port bridge broken.

L.H. crank passing through top front quarter, R.H. front port bridge broken.

L.H. crank passing through bottom back quarter, R.H. back port bridge broken.

If the amount of steam passing through the broken port renders it impossible to go forward, the slide valve must be fixed in its central position and the connecting rod may be left intact, if the nearest depot is near at hand. Care must be taken to lubricate the useless cylinder. Another method is to fix the valve at the end of the steamchest, to cover the faulty port, and secure the piston at the same end of the cylinder after taking down the connecting rod. In this manner the cylinder is converted into an ordinary steamchest, and the engine may then be worked to its destination or depot with one side only.

19. *Explain probable causes of broken air valve and how it may be repaired temporarily.*

Excessive lift or faulty castings are the most common causes of air-valve failure. The lift should therefore never exceed $\frac{3}{8}$ in. In case of failure place a piece of timber to make up the thickness on top of valve, and insert a piece of iron between the timber and the valve lift regulating screw. Tighten down securely by means of the screw, and although the valve will be rendered useless the engine may be worked to its destination. It is good practice to carry a round disc of iron of suitable size for cases of emergency.

20. *Give the probable cause of a broken piston head. State how it may be observed, and remedied temporarily.*

A broken piston head may be due to priming. In this case, the water carried over with the steam from the boiler is trapped between the piston head and cylinder cover, and the latter is therefore often damaged at the same time. Pieces of broken piston ring, by becoming jammed against the cylinder walls or between covers and piston, or by fouling, as when protruding through the ports, may also be sufficient to damage the piston head seriously. When this failure occurs, a dangerous knock, which is transmitted through the cylinder and motion-work, is usually heard. If the knocking is insufficient to attract attention, the fractured piston head will be denoted by two heavy blows up the blast-pipe at every revolution of the driving wheels. The blows will commence with the admission of steam, and cease with the point of cut-off at each end of the cylinder alternately. Having ascertained by means of the drain cocks which is the faulty side, uncouple the engine by taking down the connecting rod and securing the various parts as previously described. If, however, the whole of the piston is broken from the rod and the back cover has remained intact, the pieces may be removed and the rods retained in position, provided the engine is within reasonable distance of a depot. Should any part of the head remain on the rod or any doubt exist, the engine must be uncoupled. In all cases steam must be shut off from the cylinder by fixing the valve in the middle position before the engine is moved.

21. *Give probable causes to which a damaged piston rod or sheared crosshead cotter might be due, and explain method of procedure with this kind of failure.*

A damaged piston rod or sheared crosshead cotter may be due (1) to obstruction in the cylinder; (2) to priming; (3) to insufficient rod lubrication, especially when running without steam; (4) seized slide blocks; (5) faulty material. A bent piston rod is usually accompanied by excessive heating due to increased friction at the gland, and the condition of the rod will therefore determine whether it is possible to work slowly forward by well lubricating the rod until the main line can be left at a siding, loop, or depot where the defective side could be taken down. If the rod is badly bent or broken, or the crosshead cotter sheared, the connecting rod must be uncoupled and the slide valve fixed in the middle position. The eccentric rods must also be taken down unless a rocking-shaft valve motion is employed, in which case they may be left up as previously explained. The front cylinder cover is often damaged when a piston rod breaks or a crosshead cotter shears, so that the method of securing the piston in position will always depend upon the circumstances. If, for instance, the rod is badly bent or broken outside the cylinder it may be secured by means of the gland.

22. *Explain the probable causes of a broken or damaged crosshead, giving particulars as to small end adjustment, and how you would proceed in this case of failure.*

In addition to the causes enumerated for a broken piston or rod, the crosshead may also be damaged by excessive knock at the small end. Unless it is located carefully drivers may be misled and book " big end knocking," when it is the little end that is at fault. The connecting rod adjustment should therefore be tested from time to time, with the crank on top centre, the cylinder drain cocks open, and the brakes hard on. By opening the regulator a little and allowing the fireman to work the reversing lever backward and forward, thus admitting steam to each end of the cylinder alternately, excessive movement in either the small or big end will be at once apparent. The slide bars are usually damaged when a crosshead breaks, and it would be necessary to take down the connecting rod, secure the piston rod, and fix the slide valve in the middle position for working with one engine only.

23. *Give causes of a broken piston rod gland, and state how it may be remedied temporarily.*

Check nuts improperly locked or working loose are the most common causes of a broken piston rod gland. When unrestrained by check nuts the gland will travel with the piston rod on the outward stroke and be broken on its return by fouling the gland stud ends. If not entirely broken, the gland may be fixed in position with a piece of rope or spun yarn securely passed round the gland and the slide bar supports. If it is not possible to secure the gland, it will be necessary to take down the whole of the faulty side and proceed with one side only.

24. *State the causes of a broken solid small end or strap, and how you would proceed to take down faulty connecting rod of an inside cylinder engine.*

A broken small end may be due to any of the causes mentioned in the three foregoing answers, and would necessitate taking down the defective side to work with one engine only, as described. As pit accommodation would not be available, the engine should first be pinched until the crank on the faulty side is straight out towards the cylinders for taking down the connecting rod. In this position there is ample space above the ballast for slacking back the big end bolts, which are usually very securely tightened. After slacking the bolts, pinch the engine forward until the crank is midway between the front and bottom centres for the removal of the set screws, bolts, and cotters. This releases the big end strap, which, with the cross brass, will now slide off the rod end. The butt end brass may be freed by raising the rod, which may then be drawn or pinched towards the firebox, and the crank journal used for support. This will bring the piston against the back cylinder cover with the small end bolts behind the motion plate, in which position they are easily removed, thus liberating the rod. If, however, the small end is solid, the rod need not be drawn out so far, as it may be released by taking out the gudgeon pin after removing the nut by which it is secured.

25. *How would you deal with a broken small end strap or gudgeon pin when Joy's valve gear is used?*

Fix slide valve on faulty side in middle position, take down whole of valve gear as described for broken anchor link, remove connecting rod and secure piston in cylinder for working to depot with one side only.

26. *Give causes of bent or broken connecting rod, and state how you would proceed with this kind of failure.*

A damaged connecting rod may be due to any of the causes mentioned for piston head, rod, and crosshead failures, or to the big end brasses seizing the crank journal by expansion when excessively hot. If only slightly bent it may be possible to run forward to destination at a reduced speed. Special attention to lubrication of big and small ends would be necessary, however, as these would be liable to run hot, because of the rod alignment being disturbed. If badly bent the rod must be taken down, but if broken the position of fracture will determine the method of procedure. The fracture, for example, usually occurs at the weakest part of the rod, *i.e.*, near the small end, so that in many instances a saving of time may be effected by leaving this portion attached to the crosshead and taking down the big end only. In an engine with open slide bars, the big end cotter may be used against the spectacle plate for securing crosshead in position. The fixing of the slide valve in middle position with cylinder drain cocks open always should be the first duty in taking down the motion, thus avoiding any risk of accident that otherwise might occur by a faulty regulator valve allowing a leakage of steam into the cylinder, and thereby moving the piston when disconnecting the various engine parts.

27. *Give causes for broken big end strap or bolts, and state how temporary repairs may be effected.*

A big end strap or bolt may be damaged by excessive knock because of the brasses having ground away when running hot, or the various causes previously mentioned for bent rod and small end failures. In the event of both bolts breaking without damaging the strap a bolt may be taken from the other rod and the engine worked lightly to destination. With a broken strap the faulty side must be taken down for working home with one engine only. Care should be taken when working with one side to stop with running crank away from dead centres, otherwise the engine will have to be moved by means of a pinch bar or jack for a proper admission of steam to the cylinders before a start can be made.

28. *How would you proceed to take down a connecting rod on an eight-wheel coupled outside cylinder engine?*

First place the engine with the faulty rod on the front bottom angle, *i.e.*, half-way between front and bottom centres, as this is the most suitable position for taking out the brasses. After the big end brasses have been removed the rod may be allowed to rest upon the crank-pin for taking out the gudgeon pin. In most engines of this type it will be found impossible to get behind

the rod at the small end to remove the gudgeon pin; special arrangements are provided for this purpose, and the centre of the pin is drilled and tapped for the reception of a screw. Each engine usually is supplied with a wrought-iron or steel bracket somewhat in the form of a cup with a suitable screw fitted through the centre. This bracket or cup, when used, rests on the cross-head clear of the gudgeon pin, which is withdrawn gradually as the screw is tightened up. After removing the rod, the temporary bush, which should be carried always on the engine, must be placed upon the crank-pin journal, and held secure by the crank-pin washer, thus retaining the side rods in position for working home with the opposite side.

29. *Give causes and state how you would deal with a bent or broken side rod on four, six, and eight wheel coupled engines.*

Excessive slipping of the wheels, with faulty sanding, may be given as the most common cause of bent or broken side rod, although the failure may arise also from faulty material. In the case of a four-wheel coupled, both rods will require taking down, and the engine then may be worked as a single-wheeler. With six or eight wheel coupled engines the side rods are jointed to give the necessary flexibility, and usually it will be found that the eye of the rod is the weakest part, more especially when it has become worn by the coupling pin. These coupling joints therefore should be examined carefully from time to time for the prevention of failure. On six-wheel coupled engines this joint is placed almost invariably immediately beyond the driving crank-pin at the trailing end, so that should the leading rod become defective, it will be necessary to take down the whole of the rods. If, however, a trailing rod is damaged, the leading rods may be left intact and the engine run as a four-wheel coupled. In all cases of coupling-rod failure it is necessary to remove the corresponding rod on the opposite side for retaining the engine balance, and to prevent dangerous twisting strains that would be set up with one side coupled only. Eight-wheel coupled engines are constructed usually with outside cylinders, in which case the connecting rods also require taking down for removing the whole of the rods, as they are connected to the driving crank-pins on the outer side of the side rods. In this type of engine the flexibility usually is obtained by constructing the side rods in three portions, and the method of detachment in case of failure becomes somewhat more complicated than with the ordinary four or six wheel coupled engines. In the case of a leading or trailing side-rod failure, the centre rods may be left intact and the engine placed in a suitable position for taking out the coupling pins through the spokes of the wheels, thus liberating the faulty rod, always taking care to remove the corresponding rod on the opposite side. If, however, the centre rod should be defective, it will necessitate taking down the complete set of rods. Before replacing the connecting rods, the space previously taken up by the side rods on the driving crank-pins will require filling up again with packing, or temporary wood or metal bushes which should be carried for this purpose on this class of engine. These bushes will retain the big ends of the connecting rods in their proper position on the crank-pin journals when working home or to destination. The hauling power of the engine will be reduced according to the number of wheels uncoupled, and this, with the amount of load behind, will determine whether the whole or only a portion of the train can be taken forward.

30. *State how you would proceed with a broken crank-pin, and give probable causes of failure.*

The various strains which tend to damage the side rods are passed also through the crank-pins, and the causes of failure therefore are similar in both cases. Sharp curves on the road, excessive slipping, crank-pin heating up, and faulty material, whether singly or combined, are the most common cause of crank-pin failure. The side rods will require taking down in accordance with the position of the damaged pin, and the engine worked with a reduced number of coupled wheels as described in the preceding question and answer.

31. *If an axlebox became fast in the horn plates, what might be the cause, how would it be observed, and how remedied?*

A hot journal, which may arise from insufficient lubrication, or grit picked up when running, may cause an axlebox to expand and thus seize in the horn plates. This is perhaps the most common cause, although it may arise also from the box being too good a fit when delivered from the repair shop, which, with insufficient lubrication, might cause it to become fast. When this occurs, excessive and dangerous vibration is at once observed. If the horn plates are fitted with a wedge, the box may be released by slacking back the adjusting bolt. If, however, the horns are fitted with solid plates, the box should be cooled first with water to see if it can be freed by the contraction that will take place. Should this contraction be insufficient for releasing the box, the sliding faces will require flushing with oil or paraffin, and the engine run over a fishplate or hard piece of wood to start the box working again. If the box cannot be freed in this manner the engine must be worked to the nearest siding or depot, and the assistance of another engine obtained. A fast box is a far more dangerous failure than a journal merely running hot, so that the engine must be run as slowly as possible and the journal well lubricated with a liberal supply of oil, or a mixture of oil and plumbago.

32. *State how you would deal with a broken leading, driving, or trailing spring, and explain method of procedure when not provided with a lifting jack.*

The method of procedure with a broken spring will depend always on the nature of the failure. Underhung springs and many others of the laminated type, for instance, are so situated that the additional weight due to a defective spring, such as broken top plate or back, will be distributed over the other bearings, and it will be possible therefore to work the engine forward carefully at a reduced speed. Providing it is not a leading spring failure, it is sometimes even possible to work cautiously forward to a siding or depot after a spring has broken through the whole of the plates, and which in consequence has been lost

on the road. In the event of complete failure due to a broken leading spring it would be necessary to relieve the weight of the engine by first running the driving wheels on to hardwood wedges or fishplates, etc., afterwards placing reversing lever in mid-gear, cylinder drain cocks open, and brakes hard on. Suitable packings should then be placed between the top of the axlebox and horn block at the faulty end. After the engine has been run off the wedges it will be found that sufficient weight is borne directly on the bearing near the faulty spring for working home in safety. This method would require reversing for a broken driving spring, taking care first to pack between the trailing axleboxes and horn blocks to provide a solid base when lifting the leading end on to the wedges. Many engines are fitted with spiral springs, more especially in connection with the driving bearing. In this type of spring it is rare for more than one or two coils to break on any one journey, and the centre spring link therefore would be found sufficient in most cases to retain the spring in position for working home. In case of total collapse, the method of procedure would be the same as described for laminated springs.

33. *If by any means the engine leaves the road, what steps should be taken after its being replaced on the rails to ascertain that the axles and wheels are in proper working condition?*

The wheels always should be carefully gauged after the engine has been placed on the rails. A staff or gauge should be obtained and the wheels measured at four equal quarters between the rims. Should the wheels vary more than one-eighth of an inch between the rims at any of the quarters, the axles must be overhauled thoroughly before proceeding.

34. *Give probable cause of broken axle, and state how you would proceed with this kind of failure.*

A broken axle is often due to faulty tyres, which, because of having run an excessive mileage without returning, have worn out of true, and therefore vary in diameter at different points of the circumference, thereby setting up heavy alternating strains when running. The breakage may be due also to incipient fracture or faults in the material, which although not previously discernible, may have developed gradually as the mileage increased until finally failure occurs. Much depends on the nature of the fracture as to the methods of procedure. Modern crank axles, for instance, often have the webs hooped, and strong bolts, as already described, are fitted carefully through the centre of the crank journals. If, therefore, the fracture occurred in any part of this journal, the bolt might be found in a sufficiently good condition to allow the engine to be worked to the nearest siding or depot. With the tools usually at the disposal of the driver, the packing up of axleboxes and removal of driving spring centre pins, and so on, is much easier said than done, so that it is advisable in all cases of axle failure to wire for the breakdown van at the earliest opportunity. If, for example, a leading or trailing axle broke, it would not be possible to move the engine until a trolley had been obtained for relieving the weight from the faulty axle by giving support to that end of the engine. Assuming that the crank axle had broken in such a manner that it would be dangerous to proceed, the driver, after wiring for the breakdown van, should be making such preparations as his tools allow for the removal of the engine. The side rods should be taken down first and the leading and trailing axleboxes afterwards packed solid with timber between the top of the boxes and underside of framing. The front end of the engine then should be raised by means of the lifting jack, thus relieving the weight from the driving spring centre pins for their removal. In the absence of a lifting jack, the leading wheels may be run on to packings or sprags of sufficient thickness, in which position it will be possible to knock out the driving spring centre pins, after which the engine may be moved for lowering the leading wheels on to the rails. The driving wheels may then be run on to the packings, thus forcing the driving axleboxes to the top of the horns, in which position wood packings should be tightly fixed between the bottom of the boxes and horn stays, thereby retaining the driving wheels clear above the rails after the wheel packings have been removed. In this manner the engine will rest upon the leading and trailing axles only, and therefore be ready for removal when assisting engine arrives.

35. *Give probable causes and state how you would deal with a broken engine or tender tyre.*

A broken tyre may be due to (1) excessive allowance for shrinkage when the tyre is placed first upon the wheel centre; (2) alternate heating and cooling due to friction of brake blocks; (3) tyre out of true due to excessive mileage without returning; (4) faulty material. The method of dealing with this kind of failure will be determined by the nature of the fracture, and if, after careful examination, it is found possible to go forward, the engine should be worked slowly to the nearest siding or depot. In many cases, however, the tyre will open out considerably, and it will be dangerous, therefore, to attempt to run the engine forward. The breakdown van should be wired for, and the driver should proceed to pack up the boxes, etc., for lifting the faulty tyre clear of the rails, as described for broken axle.

36. *Explain the methods of procedure in endeavouring to avoid trouble from hot axlebox journals. Mention some of the probable causes of hot driving and tender axles, and the means to be adopted to reduce the tendency to overheating.*

Hot axlebox journals sometimes may be avoided by a proper inspection of the axleboxes before starting on a journey. As a result of a casual inspection, it often has been assumed that the boxes were filled properly with oil, whereas a closer inspection would have shown that water from boiler washing out, or water flushing from tanks, or injector overflows, and so on, had entered the box and displaced the lubricant, the latter floating on the top of the water. In such a case, the contact of the lubricant with the journal is prevented, and overheating is almost inevitable. Insufficient allowance for longitudinal expansion of the bearing, indicated by the absence of end-play when the bearing is cold, or grit picked up when running, also may be the cause of hot

axlebox journals. In the event of a journal running persistently hot, and if oiled from the top, the trimming should be examined to make sure that oil can pass freely to the journal. Providing the design of the spring rigging or adjusting arrangements of the axlebox will permit, the load on the axle sometimes may be reduced slightly by a readjustment of the axlebox or the spring supports. (For seized axlebox, see also answer to question 31.)

37. *Give the probable causes of (a) hot connecting-rod big end; (b) overheated side-rod journals; (c) eccentric straps running hot.*

(*a*) A hot connecting-rod big end may be caused by (1) insufficient lubrication; (2) insufficient end-play or excessive tightness of brasses; or (3) grit picked up when running. When cold, it should be possible to produce a small amount of side movement of the big end on the crank-pin journal, by using a small pinch bar. Excessive tightness of brasses, or knock due to excessive wear, sometimes may be responsible for overheating. To test whether the brasses are too tight or too slack, place the crank on top or bottom centre, with cylinder drain cocks open, and brakes hard on. By opening the regulator a little, and allowing the fireman to work the reversing lever backward and forward, to admit steam to each end of the cylinder alternately, too little or too much movement in either the small or the big end immediately will be apparent. If overheating is because of grit picked up when running, the journal should be flushed with oil from time to time, for which purpose it may be necessary to alter the trimming, to permit the passage of an additional quantity of the lubricant. The closing of brasses to take up excessive wear, or to prevent undue knocking, should be done by degrees; otherwise there will be a liability to overtightening and consequent dangerous overheating.

(*b*) Overheated side-rod journals may arise from causes similar to those enumerated for connecting-rod big end, but as the ends are usually of the solid bush type, the adjustment cannot be altered. The engineman, however, can make sure that the lubricating passages are clear, and give extra oil from time to time.

(*c*) Overheating of eccentric straps may be caused by (1) insufficient or improper lubrication setting up excessive slide-valve face friction, motion-work friction, or eccentric sheave friction; (2) expansion of sheave and consequent seizure of eccentric strap, because of heat generated by grit picked up when running; and (3) knocking of strap on sheave because of excessive wear. The closing of straps to take up wear, or to prevent knocking, should be done gradually, as mentioned for faulty connecting-rod big end.

APPENDIX 1

OIL-BURNING LOCOMOTIVES AND THEIR FIRING

As the result of the serious fuel situation which developed after the 1939-1945 war, the Minister of Transport announced, in August, 1946, that he had authorised the main-line railway companies to proceed as quickly as possible with the conversion of more than 1,200 locomotives from coal to oil burning, to secure a saving in consumption of approximately 1,000,000 tons of coal a year. For more than a year before that date, the G.W.R. had conducted valuable research work in the use of oil fuel for locomotives, and was already operating a number of oil-fired engines for both passenger and goods trains, with successful results. The following description of the equipment and method of operation has been prepared from information supplied by Mr F. W. Hawksworth, Chief Mechanical Engineer, G.W.R.

The equipment is designed for use with black residual fuel oil, weighing about $9\frac{1}{2}$ lb. per gallon. The oil does not flow freely enough through the valves and pipes at ordinary atmospheric temperatures, and preheating is necessary to give it the required fluidity. To obtain efficient combustion, it is necessary to supply the fuel to the firebox in a finely divided state, and this is accomplished most readily by a steam jet. At the same time, to sustain combustion, air in correct proportion must be supplied, and the products of combustion must be ejected from the smokebox after they have given up a satisfactory proportion of their heat to the boiler. These conditions must be maintained within the practical limits of the rate of combustion, and in circumstances which include the process of raising steam as well as normal working in steam. The rate of combustion must be capable of being adjusted quickly to suit variations in working conditions, and for this reason the controls must be effective, as simple as possible, and conveniently situated. The general layout of the equipment is shown diagrammatically in Fig. 268A.

For the proper combustion of the oil it is necessary to arrange for :—

1. The supply of oil to the burner (24) from the tank on the tender through an oil fuel valve (18), actuated by an oil control (12) in the cab.
2. The supply of steam to the burner (24) to atomise the oil and inject it in this state into the firebox. In the cab a burner steam pressure gauge (22) is required for indicating the pressure of the supply, and a burner steam valve (16) is provided for its control.
3. The supply of air necessary to sustain the required rate of combustion. When the regulator is open this can be induced in the usual manner by the action of the exhaust

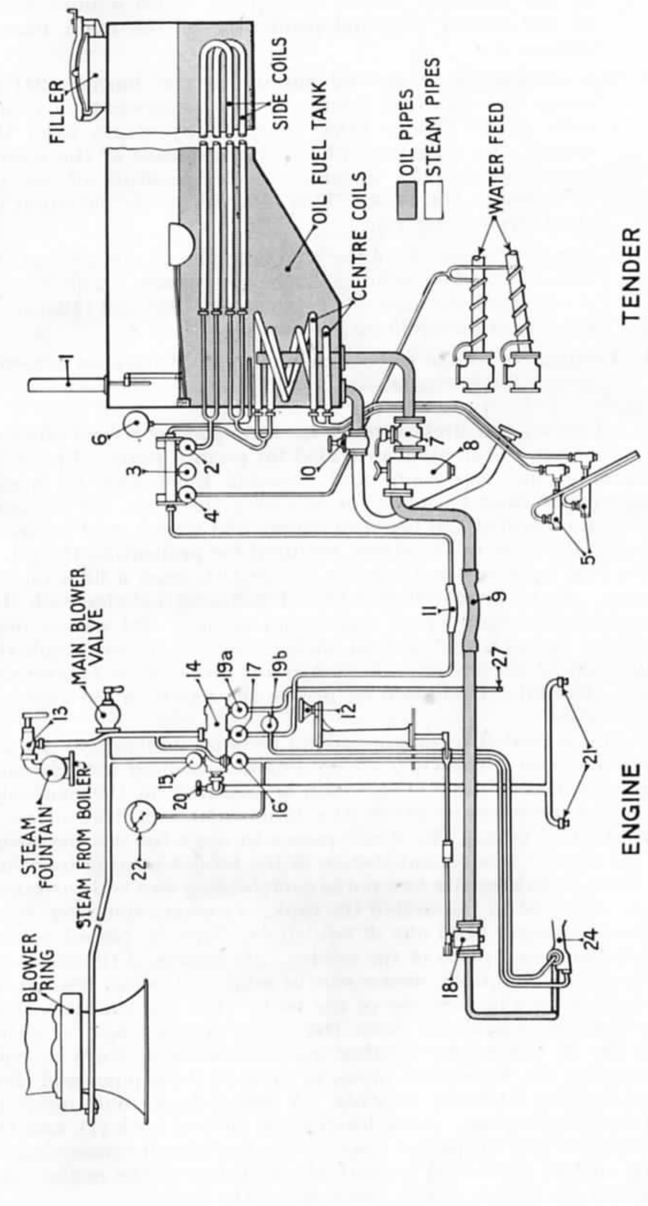


FIG. 268A.—DIAGRAM OF OIL FUEL EQUIPMENT ON ENGINE AND TENDER, G.W.R.

steam issuing from the blast pipe, and can be regulated by dampers, but provision must be made for supplying the air when the regulator is closed. This is obtained by the auxiliary blower valve (15), which admits steam to the blower ring independently of the main blower valve.

4. The preheating of the oil supply to the burner (24) to attain the required fluidity. This is effected by steam coils in the tender tank, supplied by steam from the engine, the regulation of which, by means of the tender heater valve (17), governs the temperature of the oil as it leaves the tank. This temperature is indicated on the thermometer (6).
5. A supply of steam from the engine to the oil chamber of the burner (24) for cleaning it when necessary. This supply is arranged through the two valves (19*a*) and (19*b*) from the steam manifold on the engine.
6. A supply of steam to the engine manifold from an external source for raising steam.

In addition, the firebox must be arranged to secure efficient combustion, and protection provided for certain parts. Provision for lighting up, inspection, and cleaning must also be made. Arrangements must be made for servicing the tank, for the conveyance of oil and steam between engine and tender, and for using efficiently the heat in the steam required for preheating the oil.

The fuel tank on the tender is serviced through a filler on the tank top. An oil level indicator (1) is fitted, and a sludge cock (10) is provided for draining off water and sludge. Oil passes from the tender through the oil feed cock (7) and thence through the oil filter (8) to the flexible oil connection (9) between engine and tender. The filter is cleaned by giving the handle a few turns in each direction.

The oil is heated by steam coils to increase its fluidity. Steam for this purpose is drawn from the engine manifold (14) through the tender heater valve (17), which is mounted on the manifold. This valve therefore controls the temperature of the oil as it leaves the fuel tank. The steam passes through the flexible steam pipe (11) to the tender and thence to the tender heating manifold (3). Here it divides into two paths each leading to a coil surrounding the oil outlet in the well of the tank. Condensation from these coils is discharged from one of two steam traps (5) placed behind the left hand step plate of the tender. By means of the valve (2) on the tender manifold, steam can be admitted, when desired, to two further coils in the sides of the tank. The condensation from these coils is discharged from the other steam trap. Another valve (4) on the tender heating manifold admits steam to coils surrounding the water feed pipes, to prevent these pipes and their valves freezing in frosty weather. A naked flame must never be used for this purpose. After leaving the oil feed cock (7), and the oil feed filter (8), oil passes through the flexible oil connection (9) to the oil fuel valve (18) beneath the footplate of the engine, and thence to the burner (24) in the front of the firebox.

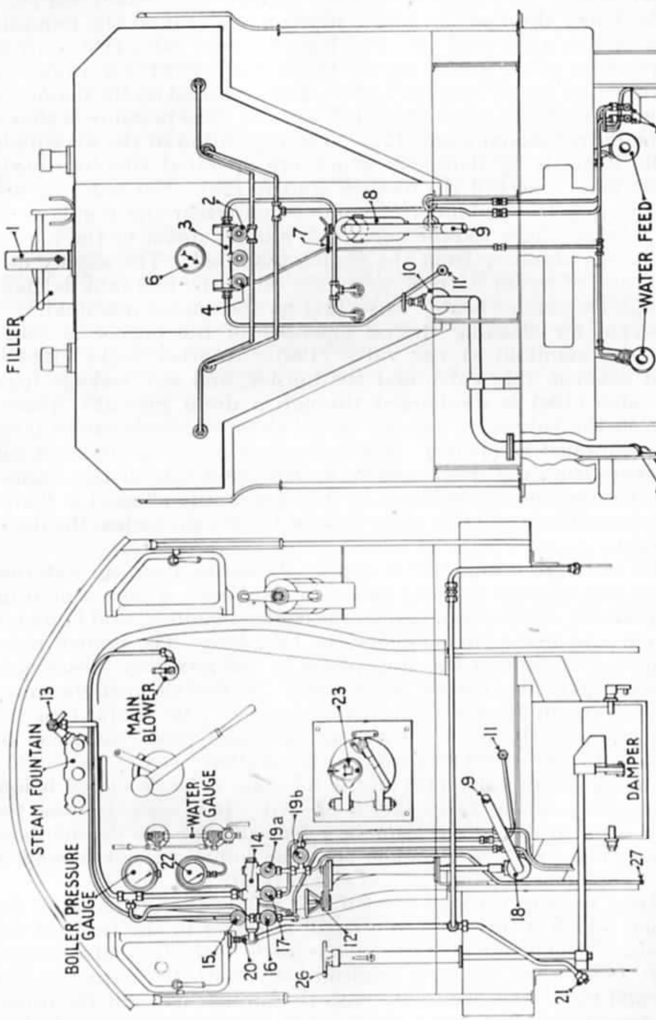


FIG. 268B.—FITTINGS ON CAB AND TENDER OF OIL-BURNING LOCOMOTIVE, G.W.R.

Fig. 268B shows the fittings on the cab and tender. The oil fuel control (12) actuates the oil fuel valve (18) beneath the footplate. This control consists of a hand wheel and graduated quadrant fitted with a hinged stop, to mark the setting (at about 20 deg.) for the " stand by " flame, which can be brought into or thrown out of operation as desired. Steam is normally supplied by the boiler through the boiler steam valve (13) on the fountain to the engine manifold (14). The burner steam valve (16) controls the pressure of the steam supply to the burner (24) for atomising and injecting the oil into the firebox, and is carried on the manifold, but is not in direct communication with it. The pressure is shown on the burner steam gauge (22). The regulation of the air supply to the flame is by dampers, which are operated simultaneously by the hand wheel of the damper control (26). For inducing air, and ejecting the products of combustion when the regulator is shut, the auxiliary blower valve (15) admits steam to the blower ring in the chimney from the engine manifold. The supply and regulation of steam for preheating the oil in the fuel tank is made through the tender heater valve (17) on the engine manifold.

Steam for cleaning the oil chamber of the burner is taken from the manifold at the valve (19*a*). Another valve (19*b*) is fitted between this valve and the burner, and any leakage from the valve (19*a*) is discharged through a drain pipe (27) placed between the valves. To clean the oil chamber, both valves (19*a*) and (19*b*) must be opened. While they are in this position, steam will issue from the drain under the left-hand side of the engine. Since the presence of moisture in the oil seriously affects the flame, the valves (19*a*) and (19*b*) must be kept tightly shut when the flame is alight.

To make provision for a supply of steam from an external source, when steam is being raised in the boiler, a pipe runs from the auxiliary steam valve (20) on the engine manifold, and branches to each side of the engine below the footplate. The branch pipes terminate in front of the step plates in the auxiliary steam connections (21), fitted with blank caps. A flexible metallic hose, carrying steam from an external source, can be coupled to the connection on the most convenient side, and then steam can be supplied to the manifold through the auxiliary steam valve (20). The boiler steam valve (13) on the fountain must be closed before the auxiliary steam valve (20) is opened. It is essential that the blank caps on the connections be replaced when the flexible hose is removed, and care be taken that the joints are not damaged, as the caps must be maintained steam tight.

After passing through the oil fuel valve, the oil flows to the burner, which is mounted in a small chamber in the front of the firebox. The bottom of the firebox is made in the form of a trough, about 18 in. wide, running longitudinally, with the burner at one end, and the " flash wall," beneath the firehole door, at the other. The trough, which forms a flame path, is carried on a steel plate floor, and is lined on the bottom and sides with special firebricks; the foundation ring is covered by the side walls. Air is admitted through ducts in the floor from the firepan below, and is regulated by dampers operated simultaneously by the hand wheel of the damper control (26) in the cab. The flame issues from the sides

of the trough, and is drawn upwards and over the brick arch by the draught induced by the smokebox vacuum. The plates surrounding the firebox door joint are protected by metal shields. The special hinged door is also protected on the inside by a shield. An opening is provided in the door for lighting the burner, cleaning away any deposit which might form, and for inspecting the flame. This opening is covered by a swivelling plate in which a piece of heat-resisting glass (23) is mounted. The main firehole door must not be opened when the flame is alight.

The function of the burner is to atomise the oil by means of a steam jet, and inject the oil in this state into the firebox. It consists of an upper chamber, to which oil flows from the fuel valve (18), and a lower chamber containing steam, the pressure of which is controlled by the burner steam valve on the engine manifold, and indicated on the burner steam pressure gauge. The two chambers terminate in orifices, one above the other. Under the influence of gravity and draught, oil flows from the upper orifice on to the ribbon of steam, which issues at high velocity from the lower orifice, and catches up and atomises the oil, and injects it into the firebox. The lower orifice is wider than the upper orifice, and is only ·03 in. deep.

The following procedure should be adopted for lighting up and raising steam :—

(*a*) Ensure that the boiler steam valve (13) and all other valves of the equipment are closed.

(*b*) Couple the 24-ft. flexible steam pipe to one of the auxiliary steam connections (21) and to the external steam supply, which may be obtained from the boiler washing steam mains or from the injector or train-heating pipe of a nearby engine in steam.

(*c*) Open the auxiliary steam valve (20) to admit auxiliary steam to the engine manifold.

(*d*) Open the tender heater valve (17) on the engine manifold, and, in cold weather, open the valve (2) on the tender-heating manifold to admit steam to the side coils. The heating process should be allowed to continue until a temperature of about 130 deg. is registered on the thermometer (6), when the valve (17) should be adjusted to prevent a further rise in temperature. In no case should the temperature exceed 160 deg. The flame can be lit when the temperature is only 110 deg., but a higher temperature is recommended because, owing to the demands afterwards made on the auxiliary steam supply by the burner steam and the auxiliary blower, the steam feed to the heating coils may be reduced sufficiently to cause a drop in the temperature of the oil.

(*e*) Open the dampers by the damper control (26) until the indicator shows about one quarter open.

(*f*) If the brickwork in the firebox is new and " green," it may be necessary to light a small wood fire on the floor of the firebox, so that the burner will not go out and drip oil into the firepan. Under normal conditions, the burner may be lit by using oily waste, as described in (*j*) below.

(*g*) Open the oil feed cock (7) on the tender, and give the handle of the filter (8) a few turns in each direction.

(*h*) Partly open the auxiliary blower valve (15). This is essential.

(*i*) Open the burner cleaner valves (19*a*) and (19*b*) for a few seconds to clear the oil chamber and warm the burner, and then close both valves tightly. These valves must be kept closed when the burner is in operation.

(*j*) See that the firehole door is securely closed, and, if a wood fire has not been used, insert some burning oily waste through the inspection door with the rod provided. Hang the waste a foot or so in front of the burner, but slightly above and to one side of the line of the jet. This enables the burner orifices to be observed by the light of the burning waste and avoids extinguishing the waste when the burner steam is turned on.

(*k*) Open the burner steam valve (16) until a pressure not less than 10 lb. per sq. in. is registered on the burner steam pressure gauge (22). Allow several seconds to elapse before the next operation, to clear the burner steam jet of water.

(*l*) Test the pressure of the auxiliary steam supply by opening the burner steam valve (16) until about 20 lb. per sq. in. can be obtained and held with the auxiliary blower (15) and tender heater valve (17) sufficiently open. Do not proceed unless this is possible, otherwise oil will spill into the firepan and on the floor of the firebox. If satisfactory, adjust the burner steam valve (16) again to 10 lb. per sq. in. on the burner steam pressure gauge. It is most important that the pressure of the boiler supplying the auxiliary steam should be maintained from this point onward.

(*m*) Slowly open the oil fuel control (12), at the same time observing the oil outlet from the burner through the inspection door (23). When oil is seen to arrive at the burner oil orifice, the jet should ignite almost immediately, and the oil control (12) should then be eased back gradually until the flame tends to go out, when it should be opened slightly until a steady flame is obtained.

Do not flood the firepan by opening the oil control too far before the jet ignites. An accumulation of oil in the pan is liable to ignite there later on, and an accumulation on the floor of the firebox will form a hard deposit when the firebricks become very hot. The fuel valve is open slightly at about 20 deg. on the quadrant of the oil control, *i.e.*, at the setting of the "stand-by" flame marked by the hinged stop, and this should be taken as a guide.

(*n*) Adjust the blower steam, burner steam, oil flow, and dampers to maintain a low flame to avoid damaging the tubes, stays, and superheater elements by raising steam too rapidly. The time taken to raise steam must not be appreciably less than for a coal-fired engine in the same circumstances.

The burner steam pressure may be allowed to increase gradually to about 18 to 19 lb. per sq. in., when the change-over to boiler steam can be effected.

(*o*) When the boiler pressure has reached 70 to 80 lb. per sq. in., the auxiliary steam supply may be shut off. To do this, first partly open the boiler steam valve (13) on the fountain, and immediately shut the auxiliary steam valve (20). Then open the valve (13) fully, and adjust the burner steam pressure and auxiliary blower, if necessary. The changeover should take place perfectly smoothly. Should the flame go out and fail to ignite from the hot bricks immediately, turn off the oil supply, and turn on the main blower fully for several seconds, to get rid of the combustible gases. Then relight with oily waste as previously described. If this procedure is not adopted, there is a risk of the accumulated gases exploding in the firebox with enough violence to cause injury. It cannot be emphasised too strongly that the auxiliary blower valve (15) must be open to create sufficient draught when relighting the burner after shutting down temporarily.

In an oil-fired engine, the fuel is consumed almost at the instant of its injection into the firebox, and no time lag is permissible in adjusting the fuel supply to the steam demand. The exhaustion of the steam admitted to the cylinders provides sufficient air to support the rate of combustion demanded, but, to attain that rate, oil in sufficient quantity must be fed into the firebox, up to the limit imposed by the rate of air supply. This part of the cycle is not automatic in the oil-fired engine. It depends entirely on the fireman following up the steam demand by the adjustment of the oil feed, and in this respect he has to be particularly careful, especially during periods when the engine is working hard. Lapses on the part of the fireman result in a fall in boiler pressure which may be very difficult to overcome. A tendency for the boiler pressure to fall must be checked immediately by increasing the oil feed, and it must be noted that the boiler pressure must not be allowed to fall much below the maximum working pressure. The water level must be maintained within close limits, if necessary, by using the injectors little and often. The auxiliary blower may be used to assist the fireman in maintaining this condition, but it must never be used any more than is necessary while the regulator is open. In an emergency, the main blower is available, but it must never be used when the regulator is shut. The normal measures for recovery, adopted with coal-fired engines, are not possible to the same extent, and must be avoided. Engines must approach a stop in a condition suitable for restarting.

When the regulator is closed, the air supply produced by the exhaust at the blast pipe ceases. The auxiliary blower must then be in operation to supply sufficient air to maintain combustion, and the oil feed must be reduced in accordance with the reduced air supply, as an excess of oil produces black smoke.

Close co-operation between driver and fireman is essential. So far as possible, the driver must warn his fireman of any change he is about to make in the engine working. This applies equally to increases and decreases in steam demand, and particularly to the sudden closing of the regulator. The fireman must maintain correct combustion conditions, and adjust these in accordance with the steam demand, which will vary with the speed and the setting of the regulator and reversing gear.

Alterations in steam demand usually may be anticipated by following the movements of the driver and by watching the road. Correct combustion conditions can be judged by the colour of the exhaust, which should be brown at the chimney, and the colour of the flame as viewed through the inspection door. The flame then should be of a distinctly yellow hue, with traces of orange round its edges. It should be smooth and voluminous, and the oil should burn with a steady muffled sound. Black smoke should be absent.

When the regulator is closed, the first movement should be to open the auxiliary blower valve; indeed, it is an advantage to open this valve before the regulator is closed. The oil control must then be brought back towards its stop, the burner steam pressure reduced accordingly, and the dampers set to a small opening. The oil feed should not be reduced too rapidly after the regulator is closed. If this is done before all the steam is exhausted from the cylinders, excess air is drawn into the firebox, and this results in the formation of obnoxious light blue smoke. Damage may be done to the boiler and superheater when an excess of air is admitted.

With a properly designed flame trough in the firebox, it is not possible, at other times, to admit air much in excess of the proper requirements, but it will be found that a slight adjustment of the dampers produces the best combustion conditions. The dampers should always be set at a small opening when a low oil feed is being used, and must always be closed when the oil is shut down.

Every setting of the oil control requires a corresponding burner steam pressure. Since the size of the steam orifice of the burner is fixed, the greater steam flow necessary to atomise a greater oil flow can be obtained only by increasing the steam pressure. For the same reason, a reduction in oil feed must be accompanied by a reduction in steam pressure. This must be borne in mind when standing by, especially in a station. If the pressure is too high, the low flame will be clear, noisy, and pulsating, even if the dampers are properly adjusted. The noise is irritating, and can be avoided by reducing the burner steam to a pressure of not less than 10 lb. per sq. in. Both the oil flow and the burner steam pressure must vary with the steam demand. There is no fixed " running position " either of the oil control or of the needle of the burner steam gauge.

If the burner steam pressure is too low, the oil flow from the burner does not become divided finely. Comparatively large drops then fall either on the hot brickwork, where they rapidly build up a hard deposit, or through the air ducts into the firepan, where an accumulation might ignite subsequently. A sign that

the burner steam pressure is too low for the oil flow is given by the persistent blackening of the glass in the inspection door of the firehole. If this door is opened, drops of unburned oil will be ejected. On the other hand, if the burner steam pressure is too high for the oil feed and draught available, the firehole door may become overheated, and the protection shields burned.

The partial choking of the steam orifice of the burner will result in failure to steam. A sign of this taking place is a high mound of deposit building up on the firebox floor in line with the obstruction. Trouble from this source arises usually from a dirty boiler, but it can be eliminated by proper inspection and cleaning of the burner at every washout.

Both the smokebox door and the firebox door must be kept closed while the flame is alight, and the burner steam pressure must not be allowed to fall below 10 lb. per sq. in. while the burner is in operation. It should be noted that the auxiliary blower must always be in operation when the regulator is closed.

The term " standing by " covers the periods when the engine is at rest under steam, and these may be on a running line, in a siding, or at the shed. When the engine is standing on a running line, the flame must not be extinguished, except for temporary examination of the burner, because it is essential for the locomotive to be ready to move at a moment's notice. The controls must therefore be set to give as low a flame as possible consistent with the maintenance of boiler pressure.

When it is necessary for an engine to stand by in a siding or in a shed for an appreciable time, with sufficient head of steam to enable it to move off at short notice, steam may be maintained by intermittent firing with the oil burner. This must be done with care, and the boiler pressure must not be allowed to fall so low that the burner cannot be relighted with boiler steam.

If the flame is extinguished momentarily for inspection, usually it can be relighted from the hot brickwork. If the flame does not ignite immediately, the oil supply must be turned off, and the main blower turned on fully for several seconds, to get rid of the combustible gases. The burner should then be relighted with oily waste. If this procedure is not adopted, there is a risk of the accumulated gases exploding in the firebox with enough violence to cause harm. It cannot be emphasised too strongly that the auxiliary blower valve must be open to create sufficient draught when relighting the burner after shutting down temporarily.

APPENDIX 2

THE LOCOMOTIVE BOOSTER

The capacity of a locomotive is limited by the load it can start, and once the load is in motion it can easily be handled at speed. It has long been recognised that some form of auxiliary power available for use at the critical moment of starting and also when ascending heavy grades, would increase the capacity, *i.e.*, the tractive effort, of the locomotive. It was the need of such auxiliary power that led to the development of the locomotive booster, which provides an additional draw-bar pull not only at the critical moment of starting, but for many other emergency demands.

The booster is self-contained, and has a flexible mounting in the form of a three-point suspension. It is designed for applying power to the trailing or tender wheels *in the forward running direction only*, and is operated by superheated steam from one or both steamchests of the locomotive, or direct from the live-steam side of the superheater header.

Briefly, the control system functions as follows :—

With the idling valve in the running position, when the latch is raised to cut in the booster, air from the brake valve or the main reservoir line, or steam when the steam control is fitted, passes through the latch valve and simultaneously to the clutch cylinder (which carries the idler gear into the meshing position) and to the preliminary throttle valve. After the preliminary throttle valve has opened, a small amount of steam passes to the booster engine for turning it over slowly to mesh the gears and to apply a slight torque to the trailer axle. When the gears are fully in mesh, air or steam, as the case may be, passes through the clutch cylinder to the throttle operating cylinder which opens the booster throttle. After the locomotive throttle has been opened and sufficient steam pressure has built up in the booster steam inlet pipe, it passes to the delay action valve and past the adjustable needle valve to the cylinder cock operating cylinders, which allow the cylinder cocks to close. When the latch is knocked down to cut out the booster, the air supply from the brake valve or the main reservoir line, or steam from the boiler, is cut off at the latch valve and the power in the entire control system is released to the atmosphere through ports in the latch valve and clutch cylinder, allowing all control parts to return to their release positions with the gears out of mesh.

The booster latch is secured to the reversing lever of the locomotive, the method of fixing varying with the type of reversing gear. The latch valve is secured to a bracket at the forward gear end of the reversing gear, in such a position that when the latch is lifted it engages with the spring cage—Fig. 269 gives a typical latch arrangement for a screw reversing gear. When the screw gear indicator block is moved back to a point where the booster latch will not engage with the spring cage of the latch

valve the latch drops down, automatically releasing the steam in the control, and disengages the booster. The point of disengagement of the latch or latch lever for the long cut-off engine is about 66 per cent. of the locomotive cut-off ; and for the limited cut-off engine about 55 per cent. cut-off ; that is 66 and 55 per cent. of the locomotive piston stroke. The latch may be disengaged from the spring cage of the latch valve at any time, by knocking down the latch.

It is always advantageous to idle the booster before cutting in. This is evident when the locomotive has been standing in the engine shed, or when starting the train from the terminal or station stops, but it may not be considered as important at other

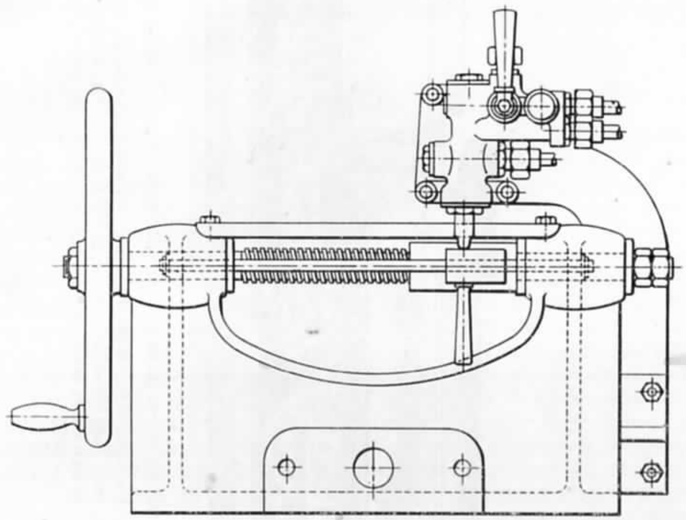


Fig. 269.—Typical Booster Control Latch Arrangement as used with Screw Reversing Gear.

points on the run, such as when approaching a grade. It is nevertheless particularly advantageous at this time, since the quick response with full booster power is wanted when it is cut in. This is obtained if the booster has been idling while approaching the grade, as the cylinders and pipes will have been warmed and the steam from the preliminary throttle valve will be sufficient to turn the booster over fast enough to allow the gears to mesh properly at the running speed of the locomotive when the booster is cut in.

The average increase in the tractive power of the locomotive when the booster is fitted is 20 per cent., with a maximum of perhaps 30 per cent. An example from actual practice may be cited. The tractive effort of the main cylinders in the case of the L.N.E.R. 2-8-2 type heavy freight engine with tender, class P. 1, calculated at 85 per cent. of the boiler pressure is 38,500 lb,

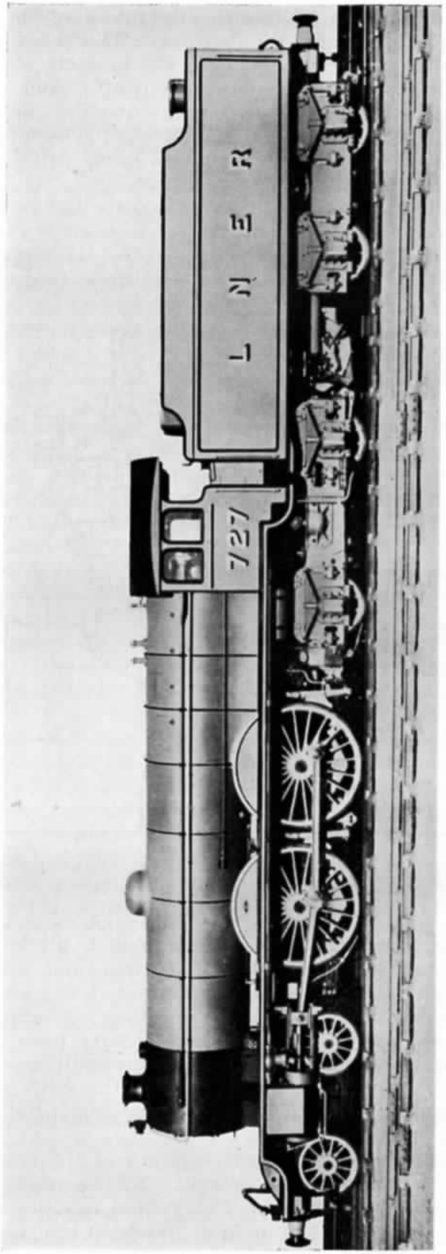


FIG. 270.—L.N.E.R. 4-4-2 LOCOMOTIVE FITTED WITH ARTICULATED BOOSTER-DRIVEN TRUCK BETWEEN ENGINE AND TENDER

Cylinders (3), 16½ in. by 26 in. Coupled wheels, 6 ft. 10 in. diameter. Coupled wheelbase, 7 ft. 7 in. Total engine wheelbase, 30 ft. 2¼ in. Boiler pressure, 200 lb. per sq. in. Total heating surface, 2,317·6 sq. ft. Grate area, 30 sq. ft. Weight of engine and tender in working order, 135 tons 8 cwt. Tractive effort (at 85 per cent. b.p.), 22,012 lb. (or with booster, 27,012 lb.).

With the booster in action this is increased to 47,000 lb. Fig. 270 illustrates a locomotive of the 4-4-2 type, L.N.E.R. (N.E. Section), rebuilt and fitted with a bogie placed behind the coupled wheels under the cab. This bogie is fitted with a booster engine having a gear ratio of 1 : 1, which enables the booster to operate usefully at a speed of 30 m.p.h. It is steam controlled and can be "cut in" at any speed up to that mentioned.

APPENDIX 3

GOODALL ARTICULATED DRAWGEAR

Of the many problems claiming the attention of locomotive designers, not the least important is that of providing an efficient coupling between the engine and its tender. What is aimed at is increased steadiness in riding and freedom from unnecessary resistance, but these cannot be achieved unless there is first of all unyielding firmness in the connecting joints and freedom from undue restriction to natural movements of the engine and tender. To meet these and other requirements, the Goodall articulated drawgear (illustrated in Fig. 271) has been designed and fitted to a very large number of locomotives operating in various countries. It provides a machine-finished and accurately articulated connection between the engine and tender, ensuring absolute stability under all conditions. It is practically frictionless in operation, and experience has shown that it exercises complete control over the lateral movements arising on curves. In this gear, connection is made by means of a substantial bar fitted at each end with a spherical joint, and the whole fitting is so constructed as to combine the engine and tender as one articulated vehicle with a common inertia, allowing every natural movement in either unit to be made with ease and smoothness.

There is no gearing of any sort between the buffer beams where the most destructive action takes place. All the working parts can readily be lubricated from the footplate, either with grease or oil, and the coupling can be run for many thousands of miles without adjustment of any kind. When, after long intervals, adjustment becomes necessary, it can easily be made by means of a liner forming part of the gear.

The distance between the centres of articulation is absolute under all conditions, and there can therefore be no slackness at any time between the engine and tender. In the Goodall drawgear any retarding force arising from a check to the engine speed must pass through the axis of the bar, direct from one point of articulation to the other, putting the bar in momentary compression. As the ends of the bar can only move radially and with a relatively long swing, and as the bar cannot be relieved completely of compression until it resumes its alignment, sudden slips from side to side are impossible, such movements must be gradual and easy. Lateral movements are, therefore, smoothly and naturally controlled without the use of springs or other friction devices. Since there can be no slackness at any time in the joints, shocks and disturbances arising in either vehicle are absorbed in the whole mass, and steady riding is assured.

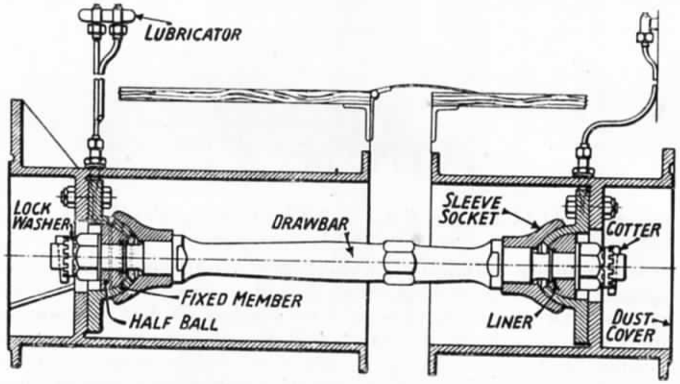


FIG. 271.—DETAILS OF GOODALL ARTICULATED DRAWGEAR FOR LOCOMOTIVES (BOLTED PATTERN).

The gear is made in standard sizes suitable for locomotives ranging from the smallest to the largest and most powerful types. Two methods of securing the drawgear to the locomotive and tender dragboxes are employed. One is known as the bolted type, and the other the wedge type. The first is secured by bolts to a suitable facing on each dragbox, and in the second, the gear is secured to the dragbox by wedges, which permit the whole section to be removed complete when the wedges are withdrawn. The wedges are held in position by bridge pieces which also serve as a ready means of withdrawal. The illustration shows the bolted type.

APPENDIX 4

LOCOMOTIVE CABS AND FITTINGS

An air of Spartan simplicity characterised the locomotive footplate and its fittings in the earliest days of railways. No attempt whatever was made to provide even the most elementary protection from the weather for engine crews; and indeed the history of the locomotive cab rather supports the view that if any such attempt had been made it would have been viewed with suspicion and even hostility rather than given the welcome that might be considered natural. In those days toughness was one of the prerequisites of enginemen, and was, from the company's viewpoint, probably a more valuable quality than finesse in the art of running a locomotive and train.

As footplate fittings gradually increased in number, and in the quality of workmanship embodied in them—and hence in their total intrinsic value—it became desirable, however, to provide general protection of the footplate. With the change from coke to coal as fuel, engine-driving became more and more a skilled art, and it was realised that better results could be expected if a man were not being distracted by, say, sleet or rain, particularly with the general increase in speeds of main-line trains. Added to this, as already mentioned, was the increased service to be expected from the equipment on the footplate as a result of screening it from the worst effects of the weather.

In 1860, when coke was being superseded by coal as fuel, and when devices such as injectors and water pick-up gear were beginning to appear, the first really notable cabs, with roof and side sheets, made their appearance in this country on some 4-4-0 engines designed by William Bouch for the Stockton & Darlington Railway. These cabs were rather reminiscent of contemporary American practice, and made an impressive contrast with the meagre spectacle plate that was the only protection available on other British engines of that time. In the different climatic and other conditions of North America, cabs had been introduced in the U.S.A. in the forties, and by the fifties had become general. In Great Britain their use spread slowly, and as late as 1873 there were engines without any form of protection. Mostly, however, a bent weatherboard was adopted during the sixties, and gradually was provided with sides to form a small cab. In 1886 the modern form of side-window cab was introduced on the North Eastern Railway. In recent years the principal improvements in the cab itself have been the provision of cushioned seats, the fitting of plate glass side shields to protect the look-out, and automatic wipers for the cab windows. Lighting remains inadequate, excepting on comparatively few modern engines.

From the enginemen's point of view, one of the most important things about a locomotive is the design of the cab and the arrangement of the fittings. In modern practice the cab is usually commodious, with the controls arranged so as to be easily accessible to the driver's hand. Improvements affecting the work of the fireman have also been introduced.

The illustrations on this and succeeding pages, together with the accompanying text, will serve to bear out this statement.

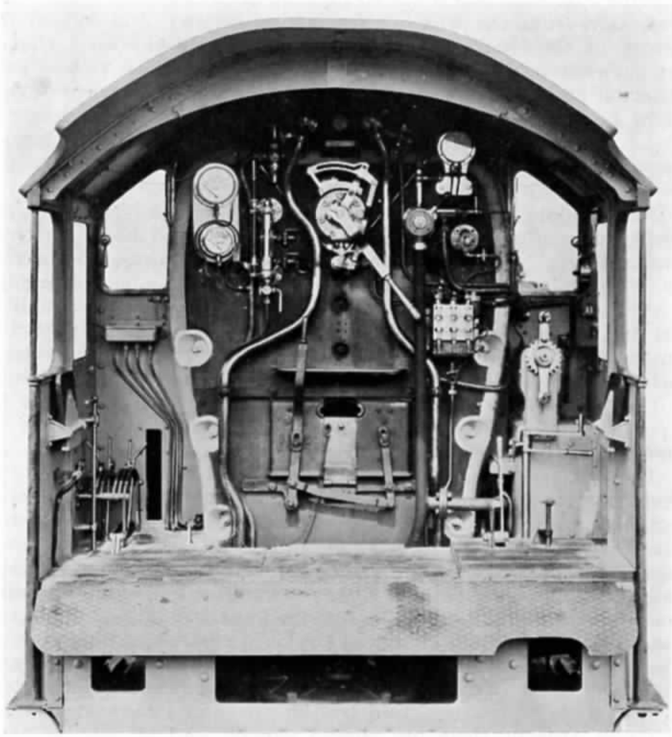


FIG. 272.—VIEW OF FOOTPLATE AND FITTINGS: G.W.R. "KING" CLASS LOCOMOTIVE.

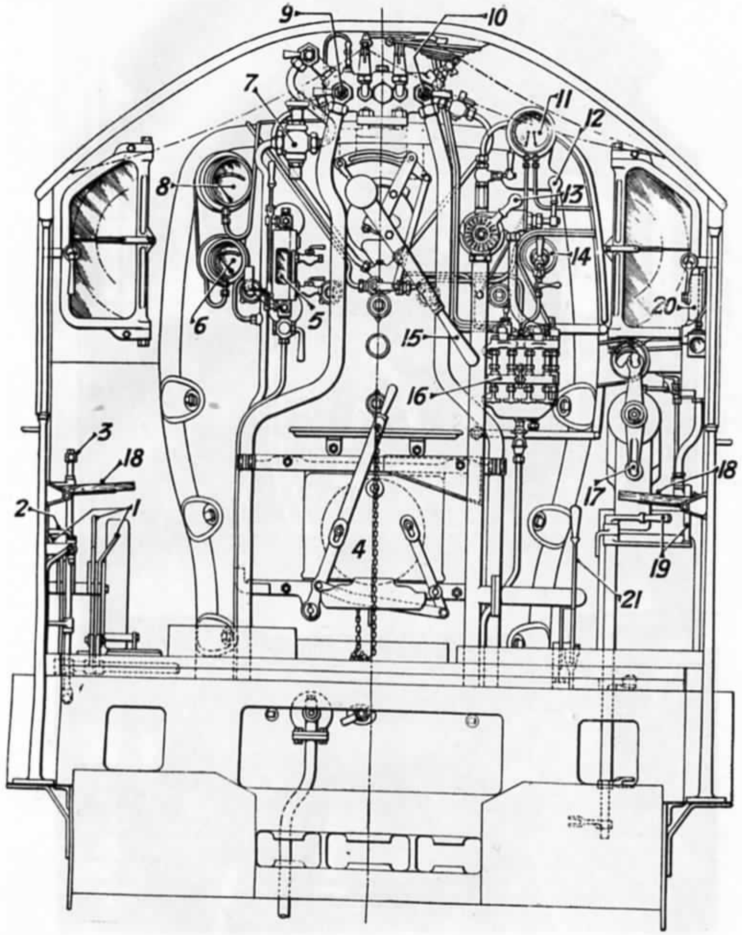


FIG. 273.—ARRANGEMENT OF FOOTPLATE FITTINGS: G.W.R. "KING" CLASS LOCOMOTIVE.

1. Damper controls.
2. Coal-watering cock.
3. Exhaust injector control.
4. Firehole doors.
5. Water gauge.
6. Steam-heating pressure gauge.
7. Steam-heating valve.
8. Boiler steam-pressure gauge.
9. Exhaust injector live steam valve.
10. Right-hand injector live steam valve.
11. Vacuum gauge.
12. Ejector steam valve.
13. Ejector air valve.
14. Blower valve.
15. Regulator handle.
16. Lubricator.
17. Reversing handle.
18. Tip-up seat.
19. Sanding-gear levers.
20. Audible signalling apparatus.
21. Cylinder cock lever.

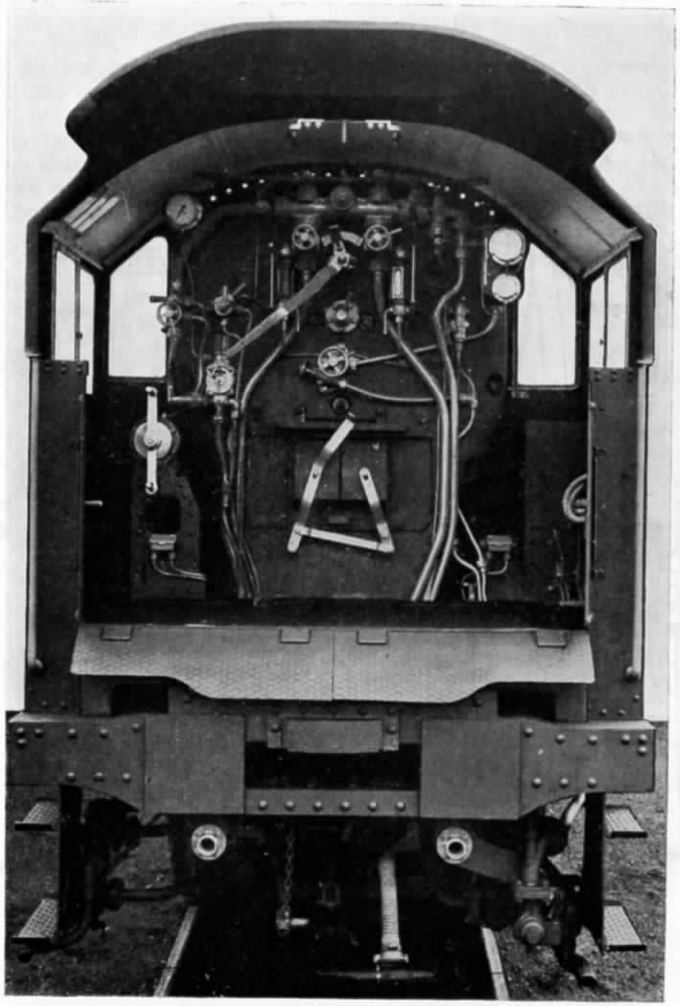


Fig. 274.—View of Footplate Fittings: L.M.S.R. "5 X" Class Locomotive.

1. Regulator handle.
2. Main steam valve for steam supply stand.
3. Live steam valve to exhaust steam injector.
4. Live steam pipe to injector.
5. Exhaust steam injector.
6. Auxiliary steam pipe from steamchest to injector.
7. Exhaust steam pipe to injector.
8. Water-feed pipe to injector.
9. Delivery pipe from injector to boiler.
10. Overflow pipe from injector.
11. Water-control gear for injector.
12. Steam valve to live steam injector.
13. Live steam pipe to injector.
14. Live steam injector.
15. Water-feed pipe to injector.
16. Delivery pipe from injector to boiler.
17. Overflow pipe from injector.
18. Water-control gear for injector.
19. Stop valve to ejector steam valves.
20. Small ejector steam valve.
21. Large ejector steam valve.
22. Combined large and small ejector.
23. Vacuum gauge.
24. Driver's brake valve.
25. Train pipe.
26. Steam brake pipe.
27. Steam brake cylinder lubricator.

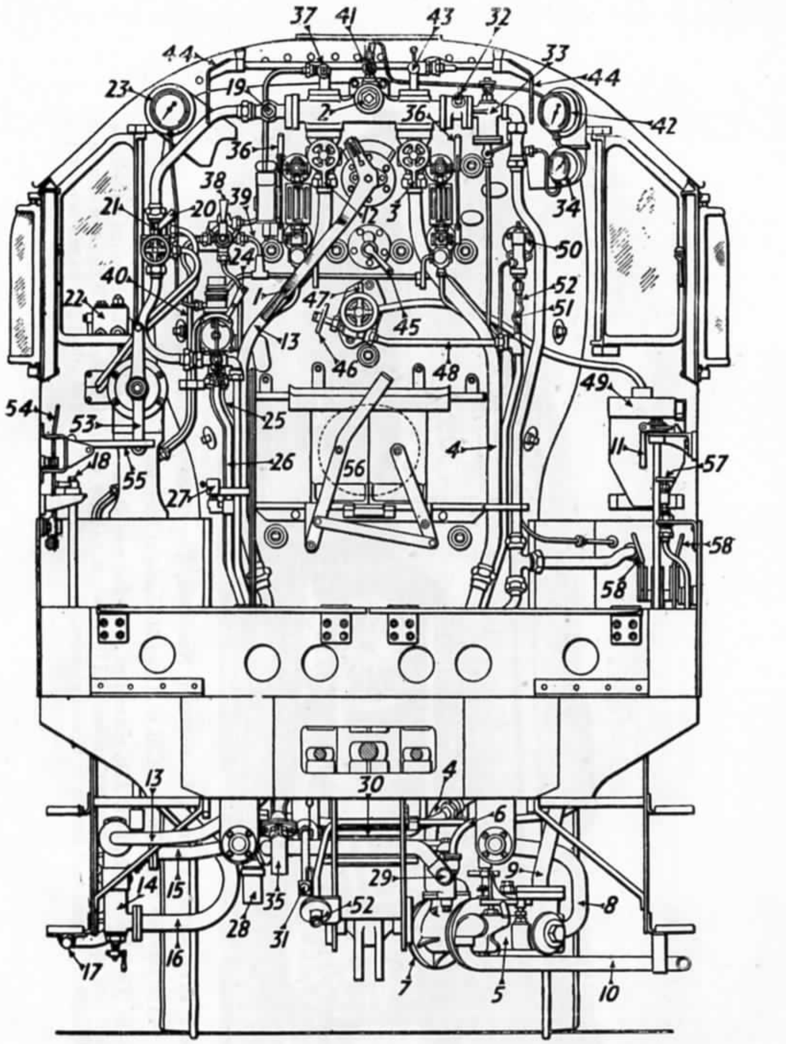


Fig. 275.—Arrangement of Footplate Fittings: L.M.S.R. "5 X" Class Locomotive.

28. Drip valve for train pipe.
29. Train pipe connection to tender.
30. Steam pipe to engine brake cylinder.
31. Steam brake pipe connection to tender.
32. Stop valve to carriage-warming reducing valve.
33. Carriage-warming reducing valve.
34. Carriage-warming pressure gauge.
35. Carriage-warming hose-pipe connection to tender.
36. Water-gauge cocks.
37. Stop valve to sanding valve.
38. Steam sanding valve.
39. Sand pipe to trailing wheels.
40. Sand pipe to leading and driving wheels.
41. Steam valve for boiler-pressure gauge.
42. Boiler-pressure gauge.
43. Whistle valve.
44. Whistle handles.
45. Blower valve.
46. Steam valve for sand gun.
47. Sand gun hand-operating wheel.
48. Steam pipe from steamchest to sand gun.
49. Sand hopper for sand gun.
50. Continuous blow-down valve.
51. Steam pipe from steamchest to blow-down.
52. Blow-down pipe to tender.
53. Reversing screw handle.
54. Cylinder drain cock handle.
55. Driver's seat.
56. Firehole door.
57. Coal-watering cock.
58. Ashpan handles.

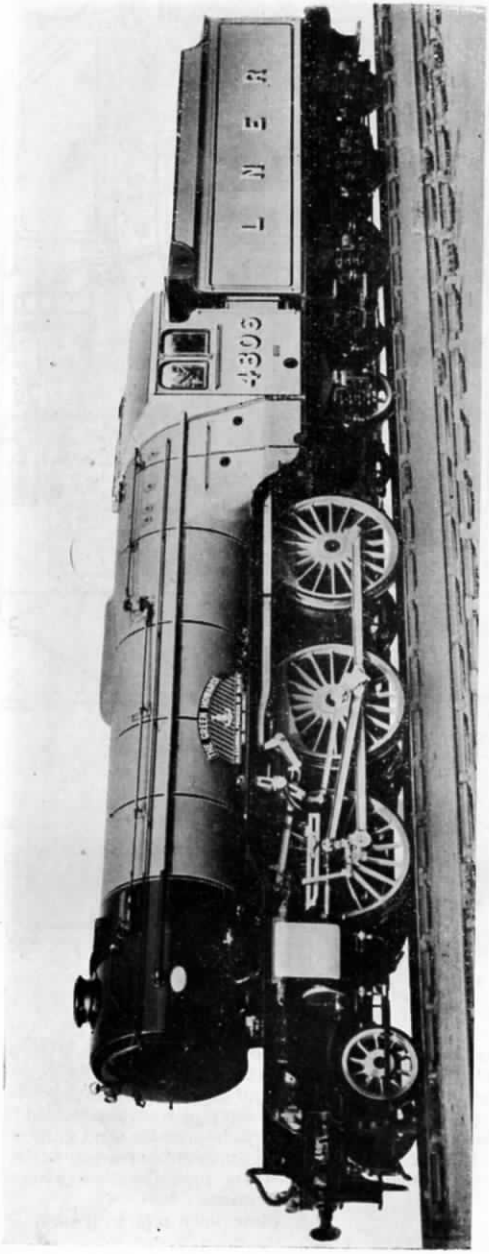


FIG. 276.—2-6-2 TYPE MIXED-TRAFFIC LOCOMOTIVE No. 4806, *The Green Howard*, L.N.E.R.

The late Sir Nigel Gresley, C.B.E., Chief Mechanical Engineer.

Cylinders (3), 18¼ in. by 26 in. Coupled wheels, 6 ft. 2 in. diameter. Coupled wheelbase, 15 ft. 6 in. Total engine wheelbase, 33 ft. 8 in. Boiler pressure, 220 lb. per sq. in. Total heating surface, 3,110·74 sq. ft. Grate area, 41·25 sq. ft. Weight of engine in working order, 93 tons 2 cwt. Weight of engine and tender in working order, 144 tons 2 cwt. Tractive effort (at 85 per cent. b.p.), 33,730 lb.

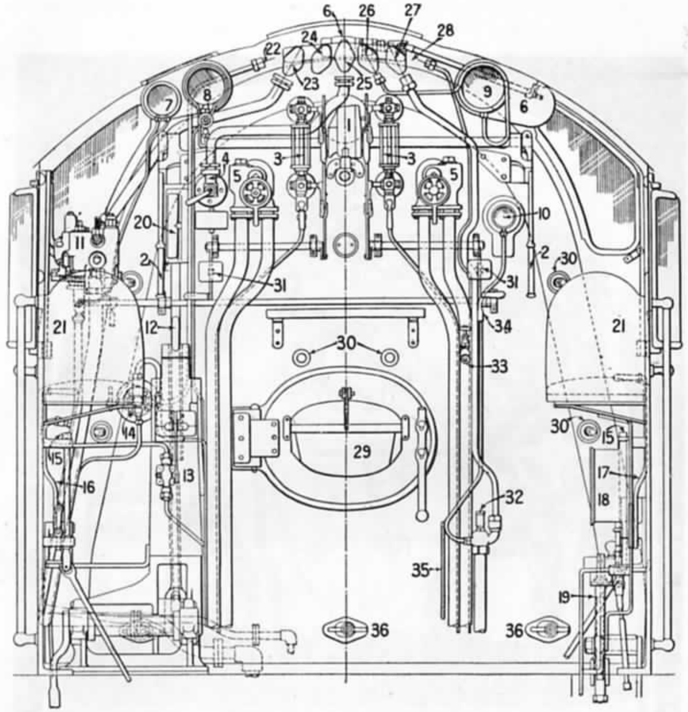


FIG. 277.—ARRANGEMENT OF FOOTPLATE FITTINGS: L.N.E.R. "A 4" CLASS LOCOMOTIVE.

1. Regulator stuffing-box.
2. Regulator handles.
3. Water gauges.
4. Blower valve.
5. Combined steam and delivery valves.
6. Stop valve for steam stand.
7. Duplex vacuum gauge.
8. Steamchest pressure gauge.
9. Boiler-pressure gauge.
10. Carriage-heating pressure gauge.
11. Vacuum ejector.
12. Reversing screw handle.
13. Reversing gear clutch lock.
14. Steam sand valve.
15. Water control for injectors.
16. Sand-gear lever.
17. Cylinder: cock lever.
18. Speed recorder.
19. Drop-gate screw.
20. Cut-off indicator.
21. Enginemen's seats.
22. Steam sand supply valve.
23. Ejector steam stop valve.
24. Blank.
25. Blower stop valve.
26. Pressure-gauge stop valve.
27. Carriage-heating stop valve.
28. Mechanical lubricator warming valve.
29. Firebox door.
30. Washout plugs.
31. Remote control for water-gauge cocks.
32. Carriage-heating safety valve.
33. Coal-watering cock.
34. Whistle control.
35. Damper rod.
36. Handholes.

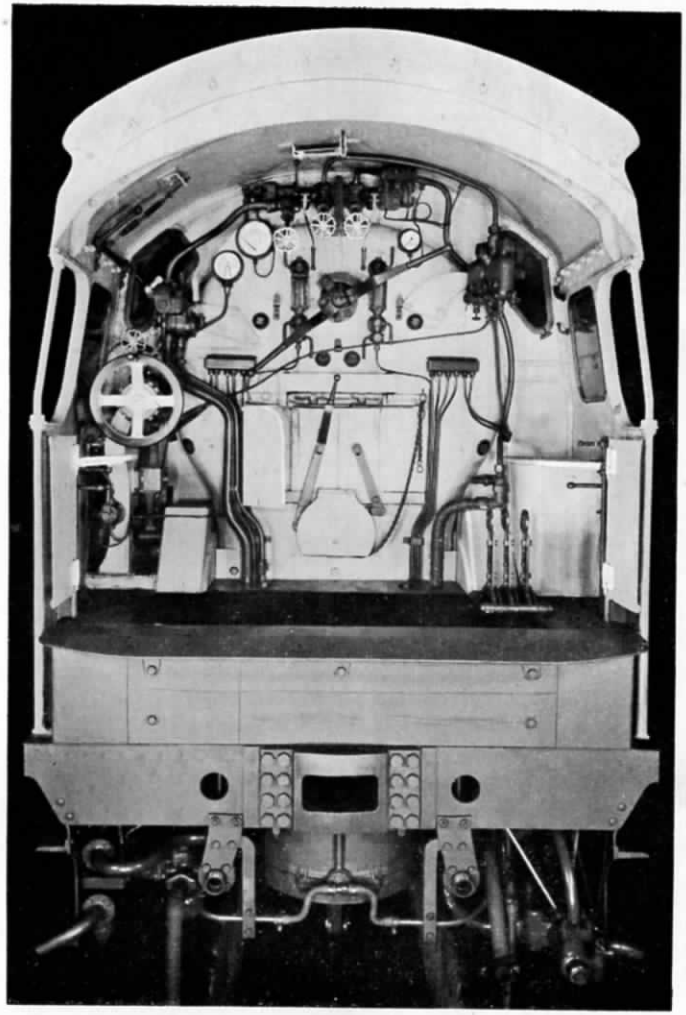


Fig. 278.—View of Footplate Fittings: Southern Railway "Schools" Class Locomotive.

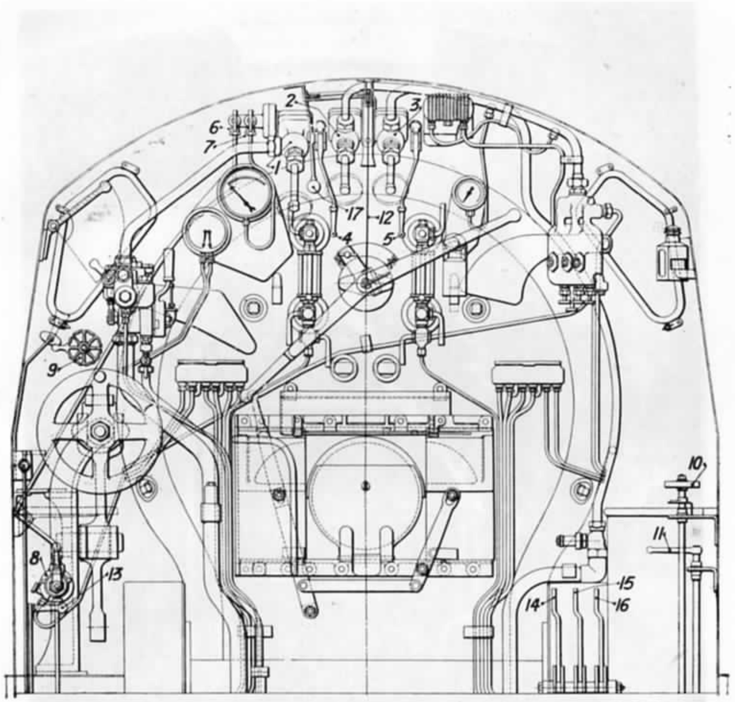


Fig. 279.—Arrangement of Footplate Fittings: Southern Railway "Schools" Class Locomotive.

1. Vacuum ejector steam valve.
2. Sight-feed lubricator steam valve.
3. Train-heating steam valve.
4. Live steam injector valve lever.
5. Exhaust injector steam valve lever.
6. Steam to clutch valve.
7. Steam to pressure gauge.
8. Reversing shaft clutch valve.
9. Blower valve handwheel.
10. Water regulator, exhaust injector.
11. Feed-cock spindle.
12. Whistle wire.
13. Cylinder drain cocks lever.
14. Ashpan front damper lever.
15. Sanding valves lever.
16. Ashpan back damper lever.
17. Whistle lever.

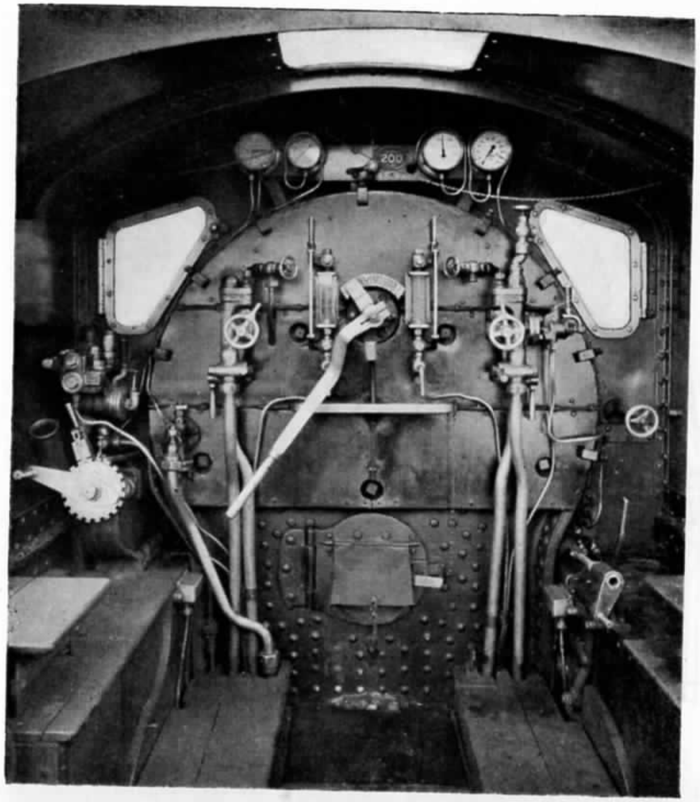


FIG. 280.—VIEW OF FOOTPLATE FITTINGS: GREAT NORTHERN RAILWAY (IRELAND).

(Three-Cylinder Compound Locomotive.)

1. Regulator handle.
2. Water-gauge glasses.
3. Combination injectors.
4. Steam sanding cock.
5. Steam-heating cock.
6. Steam-heating reducing valve.
7. Coal-watering cock.
8. Tube-cleaning cock.
9. "Dreadnought" vacuum ejector.
10. Vacuum ejector steam-cock handle.
11. Vacuum gauge.
12. Steam-heating gauge.
13. Boiler-pressure gauge.

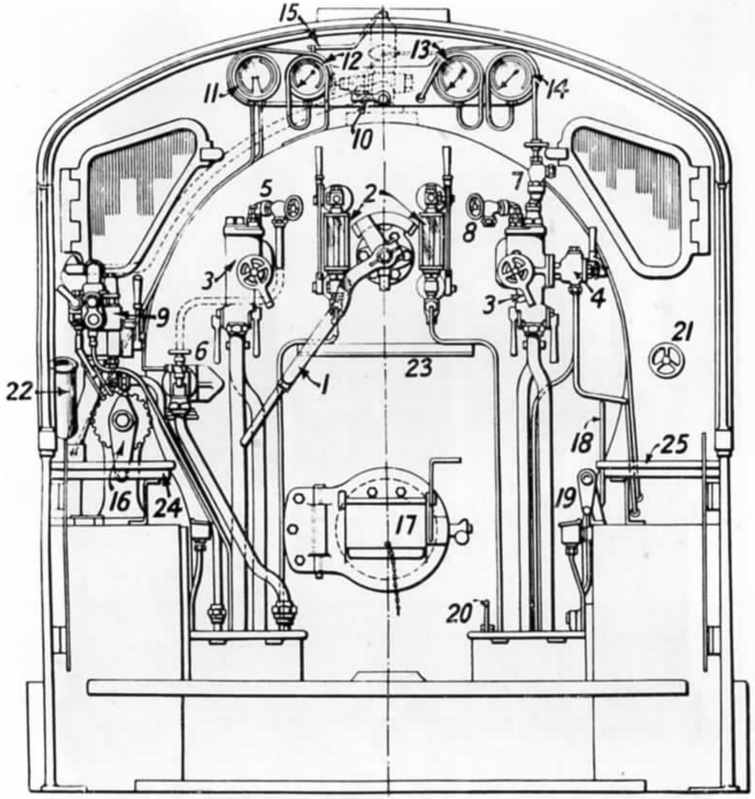


FIG. 281.—ARRANGEMENT OF FOOTPLATE FITTINGS: GREAT NORTHERN RAILWAY (IRELAND).

(Three-Cylinder Compound Locomotive.)

14. Receiver gauge.
15. Whistle lever.
16. Reversing handle.
17. Firedoor.
18. Cylinder drain-cock lever.
19. Front damper lever.
20. Back damper lever.
21. Blower wheel.
22. Staff holder.
23. Kettle tray.
24. Driver's seat.
25. Fireman's seat.

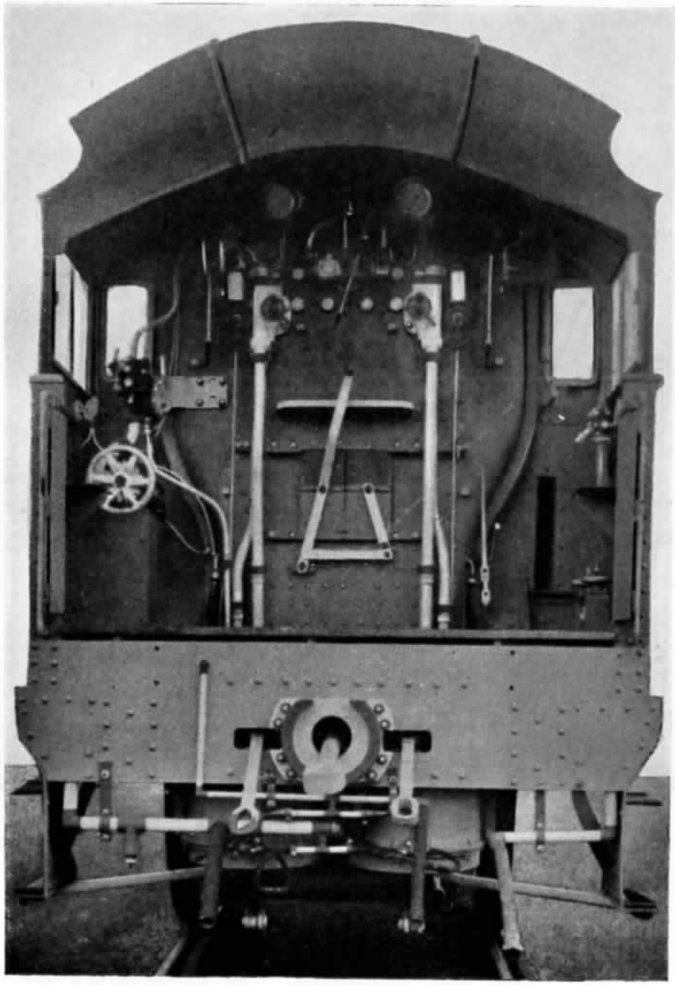


FIG. 282.—VIEW OF FOOTPLATE FITTINGS:
4-4-0 TYPE LOCOMOTIVE, CORAS IOMPAIR EIREANN.

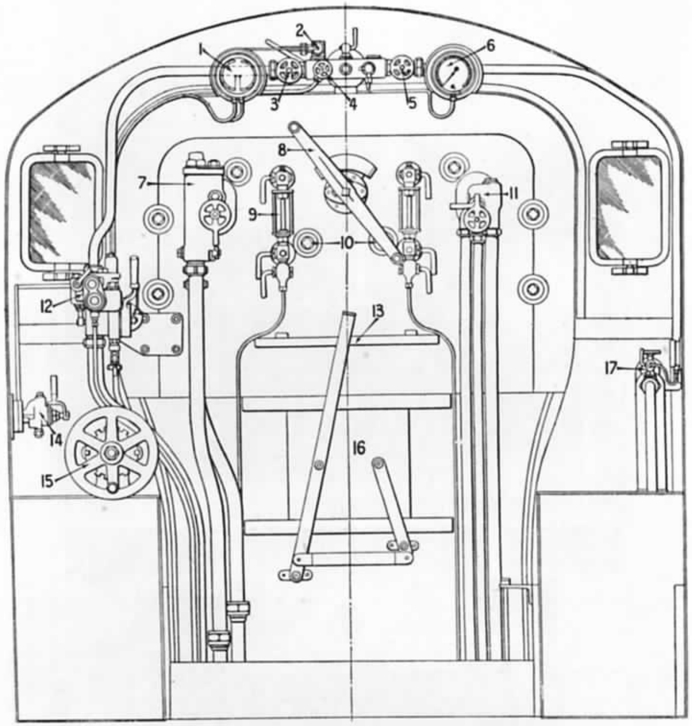


FIG. 283.—ARRANGEMENT OF FOOTPLATE FITTINGS:
4-4-0 TYPE LOCOMOTIVE, CORAS IOMPAIR EIREANN.

1. Vacuum gauge.
2. Whistle valve.
3. Brake ejector valve.
4. Sanding valve.
5. Steam-heating valve.
6. Pressure gauge.
7. Live steam injector.
8. Regulator.
9. Water gauge.
10. Washing-out plugs.
11. Exhaust steam injector.
12. Brake application.
13. Shelf.
14. Steam sanding valve.
15. Reversing wheel.
16. Firedoors.
17. Steam-heating reducing valve.

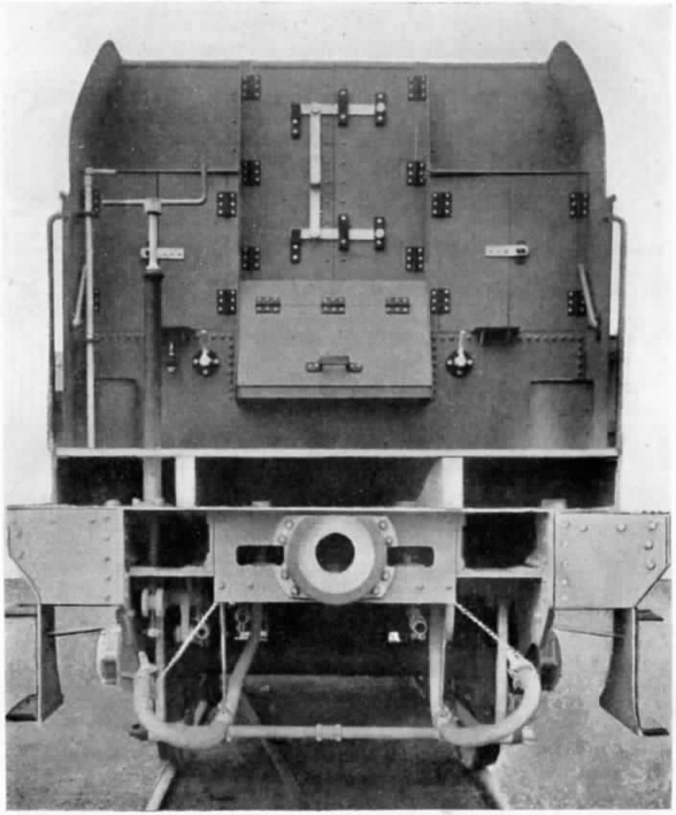


Fig. 284.—View of Tender Fittings: 4-4-0 Type Locomotive, Coras Iompair Eireann.

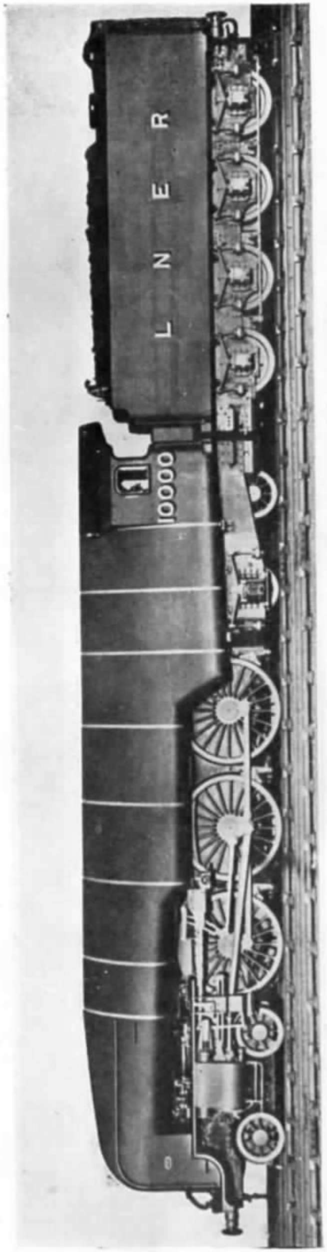


Fig. 285.—L.N.E.R. Engine No. 10000 as originally built in 1929. Four-Cylinder Compound; Water-Tube Boiler, 450 lb. Pressure.

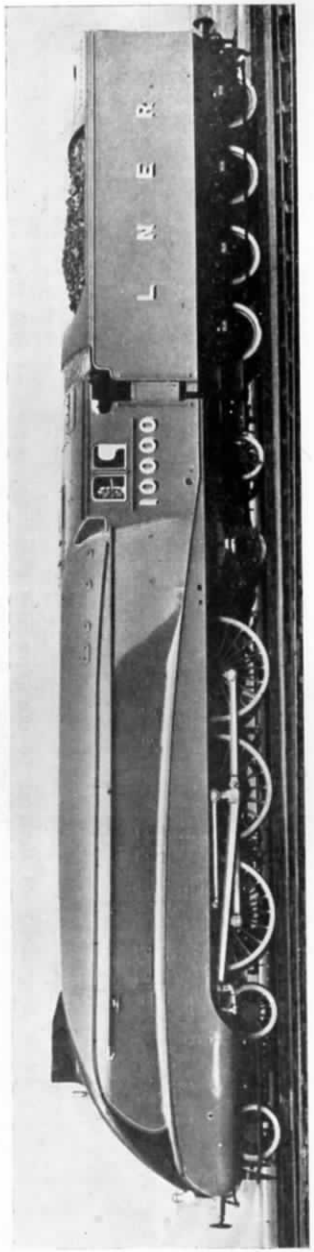


Fig. 286.—The same Engine rebuilt in 1937. Three-Cylinder Simple; 250 lb. Pressure. *For dimensions of locomotive before and after conversion, see p. 120.*

APPENDIX 5

REPRESENTATIVE LOCOMOTIVE DIAGRAMS

It is frequently of interest to compare the chief dimensions of one type of locomotive with those of another. Several of the illustrations in this book include details of the designs of locomotives, and some additional information is furnished by the outline drawings on the following pages. Despite considerable progress towards standardisation in recent years, the number of locomotive types on British railways remains considerable, and no more than a representative selection has been possible. The diagrams have been chosen from the comprehensive collection illustrated in *British Locomotive Types*, published by the Railway Publishing Co. Ltd., 33 Tothill Street, London, S.W.1, price 8s. 3d., including postage.

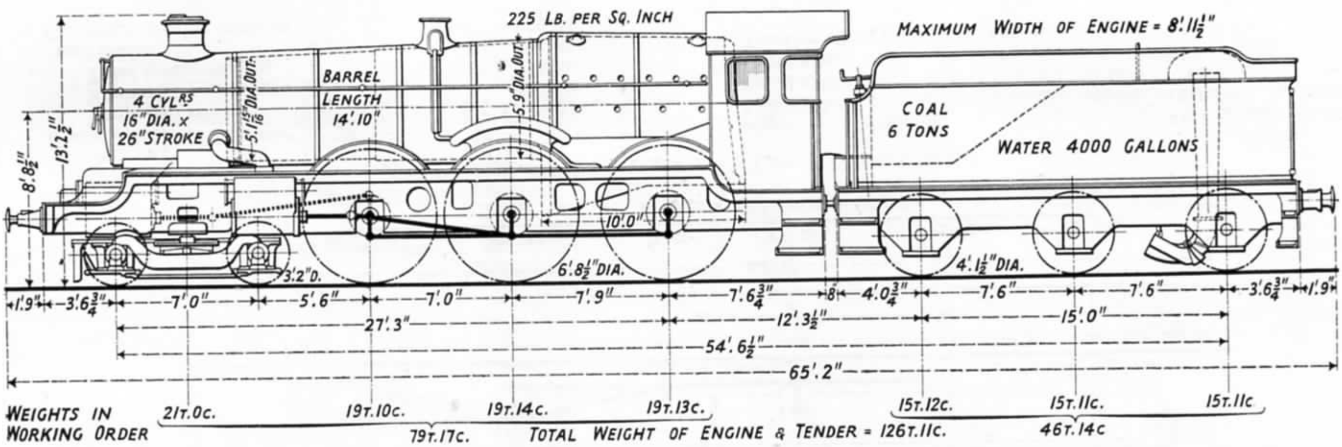


Fig. 287.—"Castle" Class 4-6-0 Locomotive, G.W.R.

Heating Surface, Tubes—	
Large and small	1,854·31 sq. ft.
Firebox	163·76 ,,
Total (evaporative)	2,018·07 ,,
Superheater	262·62 ,,
Combined heating surfaces	2,280·69 ,,

Superheater tubes (triple elements)		84–1 in. dia. outside.
Large tubes	14–5⅛ in. dia. outside	15 ft. 2 15/16 in. between tubeplates.
Small tubes	197–2 in. dia. outside	
Grate area		29·36 sq. ft.
Tractive effort (at 85 per cent. b.p.)		31,625 lb.

Recent change not shown on drawing: height to top of chimney decreased by 3 in.

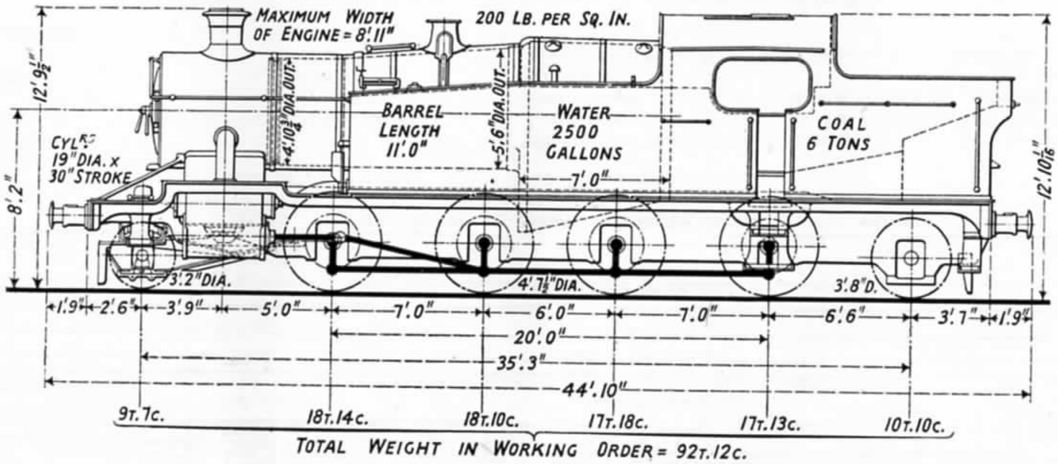


Fig. 288.—" 7200 " Class 2-8-2 Tank Engine, G.W.R.

Heating Surface, Tubes—		
Large and small	1,349·64	sq. ft.
Firebox	128·72	,,
Total (evaporative)	1,478·36	,,
Superheater	191·88	,,
Combined heating surfaces	1,670·24	,,

Superheater elements		84–1 in. dia. outside.
Large tubes	14–5⅛ in. dia. outside	11 ft. 4 7/16 in. between tubeplates.
Small tubes	235–1⅝ in. dia. outside	
Grate area		20·56 sq. ft.
Tractive effort (at 85 per cent. b.p.)		33,170 lb.

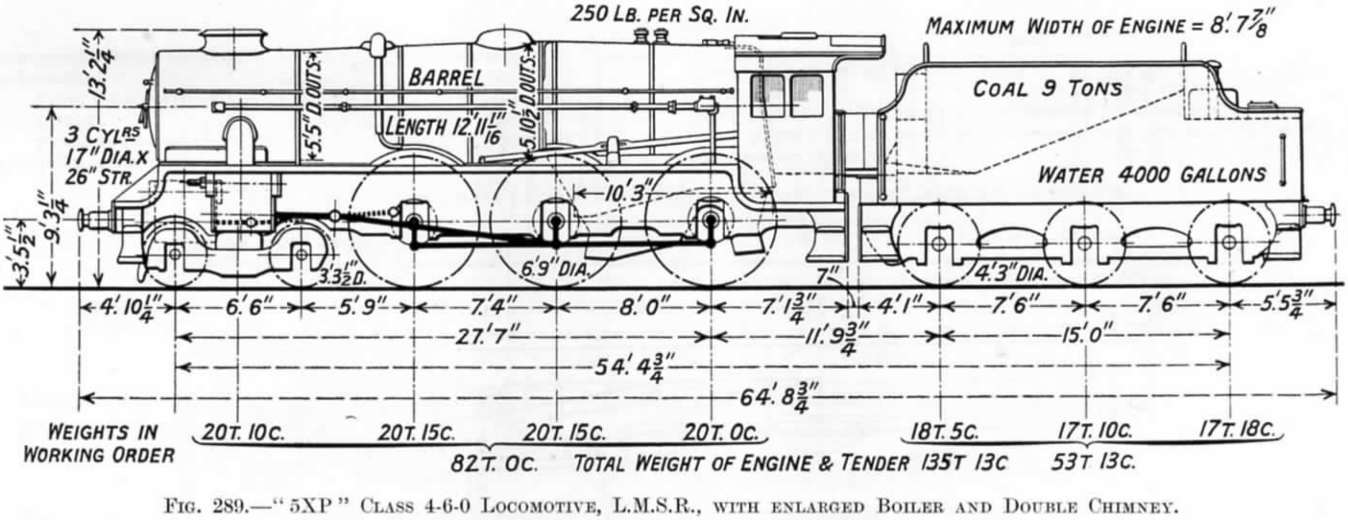


Fig. 289.—" 5XP " Class 4-6-0 Locomotive, L.M.S.R., with enlarged Boiler and Double Chimney.

Heating Surface, Tubes—		
Large and small	1,667	sq. ft.
Firebox	195	,,
Total (evaporative)	1,862	,,
Superheater	348	,,
Combined heating surfaces	2,210	,,

Superheater elements		28–1¼ in. dia. outside.
Large tubes	28–5⅛ in. dia. outside	13 ft. between tube-plates.
Small tubes	198–1¾ in. dia. outside	
Grate area		31·25 sq. ft.
Tractive effort (at 85 per cent. b.p.)		29,590 lb.

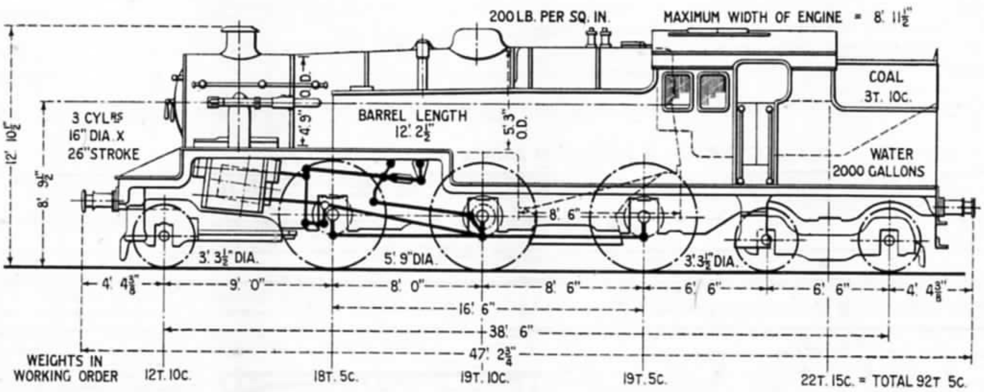


Fig. 290.—"4P" Class Three-Cylinder 2-6-4 Tank Engine, L.M.S.R., with Taper Boiler.

Heating Surface, Tubes—	
Large and small	1,126 sq. ft.
Firebox	139 „
Total (evaporative)	1,265 „
Superheater	198 „
Combined heating surfaces	1,463 „

Superheater elements		18–1¼ in. dia. outside.
Large tubes	18–5⅛ in. dia. outside	12 ft. 3 in. between tubeplates.
Small tubes	148–1¾ in. dia. outside	
Grate area		26·7 sq. ft.
Tractive effort (at 85 per cent. b.p.)		24,600 lb.

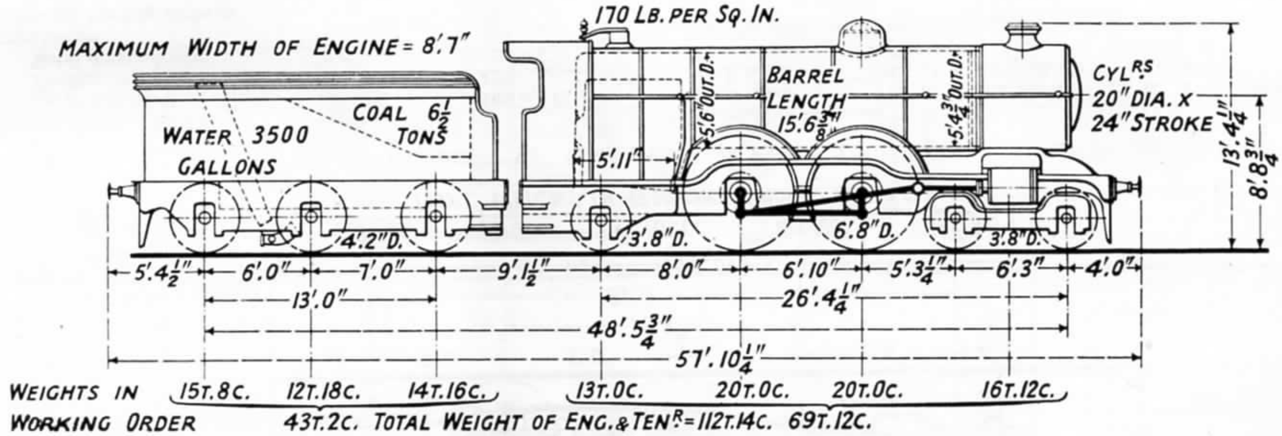


Fig. 291.—"C1" Class 4-4-2 Locomotive, L.N.E.R.

Heating Surface, Tubes—	
Large and small	1,824 sq. ft.
Firebox	141 „
Total (evaporative)	1,965 „
Superheater	568 „
Combined heating surfaces	2,533 „

Superheater elements		32–1½ in. dia. outside.
Large tubes	32–5¼ in. dia. outside	15 ft. 11¾ in. between tubeplates.
Small tubes	133–2 in. dia. outside	
Grate area		31 sq. ft.
Tractive effort (at 85 per cent. b.p.)		17,340 lb

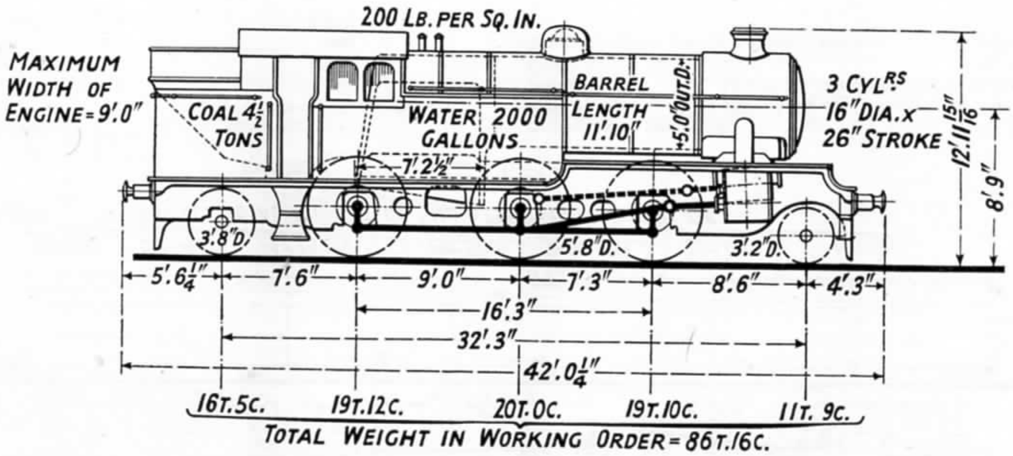


FIG. 292.—" V3 " CLASS 2-6-2 TANK ENGINE, L.N.E.R.

Heating Surface, Tubes—	
Large and small	1,198 sq. ft.
Firebox	127 ,,
Total (evaporative)	1,325 ,,
Superheater	284 ,,
Combined heating surfaces	1,609 ,,

Superheater elements		22–1½ in. dia. outside.
Large tubes	22–5¼ in. dia. outside	12 ft. 2 in. between tubeplates.
Small tubes	149–1¾ in. dia. outside	
Grate area		22·08 sq. ft.
Tractive effort (at 85 per cent. b.p.)		24·960 lb.

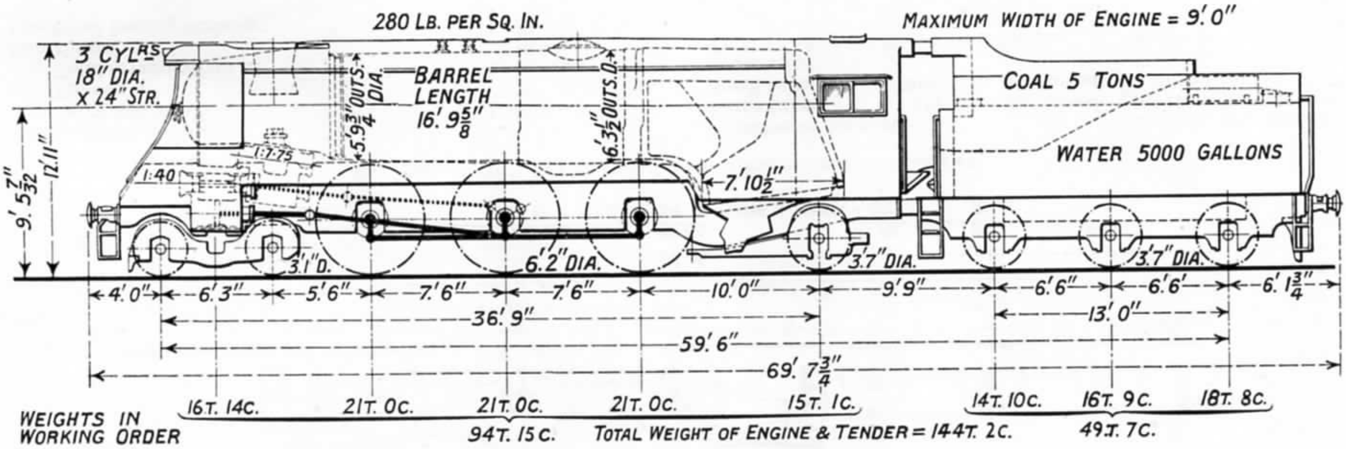


FIG. 293.—" MERCHANT NAVY " CLASS 4-6-2 LOCOMOTIVE, SOUTHERN RAILWAY.

Heating Surface, Tubes—	
Large and small	2,175·9 sq. ft.
Firebox	275·0 ,,
Total (evaporative)	2,450·9 ,,
Superheater	822·0 ,,
Combined heating surfaces	3,272·9 ,,

Superheater elements		40–1½ in. dia. outside.
Large tubes	40–5¼ in. dia. outside	17 ft. between tube-plates.
Small tubes	124–2¼ in. dia. outside	
Grate area		48·50 sq. ft.
Tractive effort (at 85 per cent. b.p.)		37·500 lb.

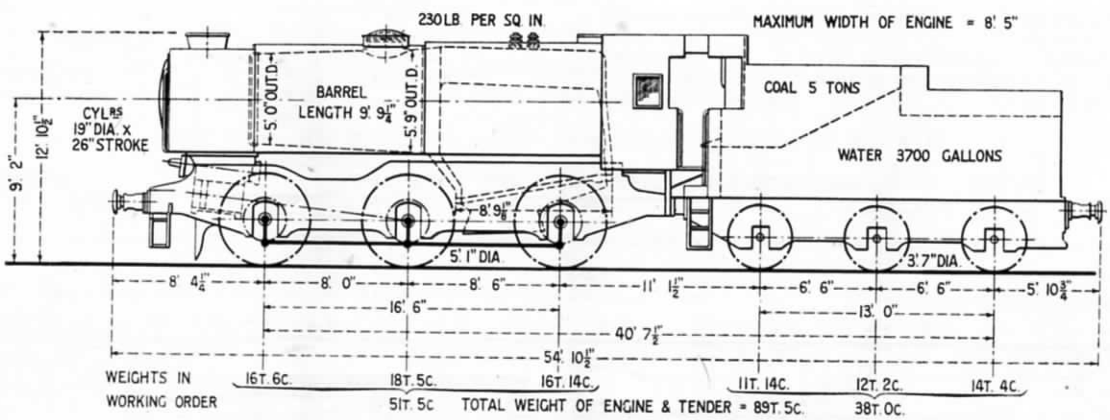


Fig. 294.—"Q1" Class 0-6-0 Locomotive, Southern Railway.

Heating Surface, Tubes—	
Large and small	1,302 sq. ft.
Firebox	170 ,,
Total (evaporative)	1,472 ,,
Superheater	218 ,,
Combined heating surfaces	1,690 ,,

Superheater elements		21–1⅜ in. dia. outside.
Large tubes	21–5¼ in. dia. outside	10 ft. 6 in. between tubeplates.
Small tubes	209–1¾ in. dia. outside	
Grate area		27 sq. ft.
Tractive effort (at 85 per cent. b.p.)		30,000 lb.

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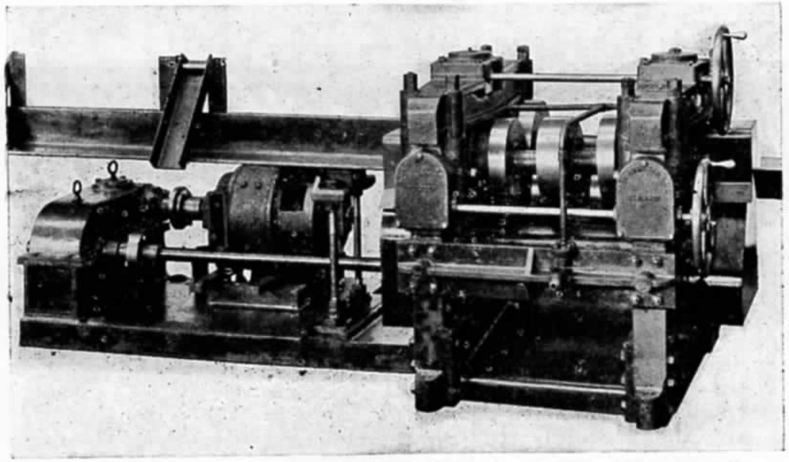

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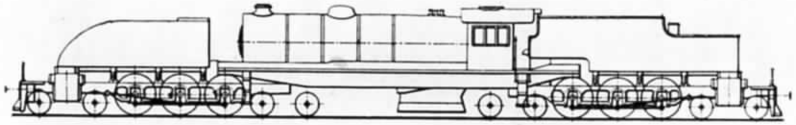

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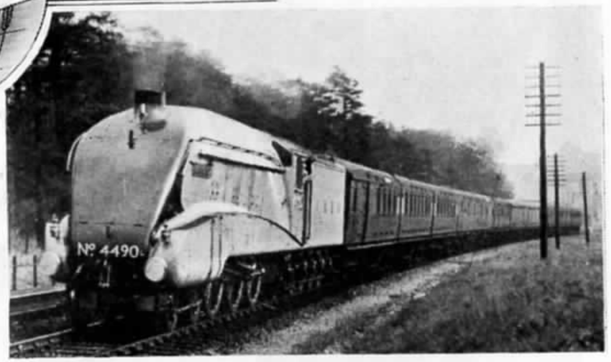

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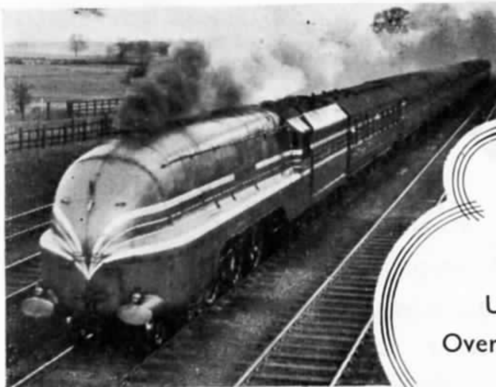

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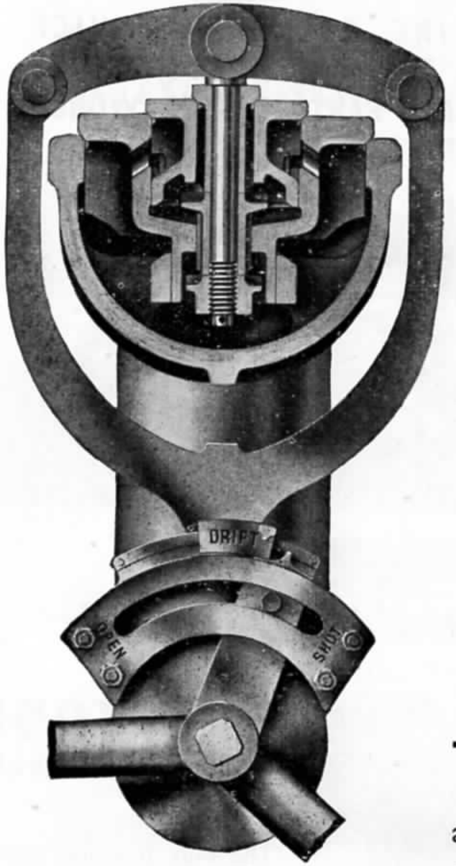
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