SECTION 5

# VALVES AND PISTONS

The steam locomotive is the means of converting the heat energy contained in the fuel into useful work by driving the pistons, the reciprocating motion of these being converted into the rotary motion of the driving wheels by the piston rod, connecting rod and cranks.

When the regulator valve is opened, steam generated in the boiler passes through the internal steam pipe (and superheater when fitted), through the external steam pipe to the steam chest, where the supply of steam to the cylinders is regulated by the action of the valves, In the cylinders the steam expands and does useful work on the piston before escaping into the atmosphere.

The locomotive valve of any kind must, in conjunction with the valve gear, so control the valve that the following events take place in succession in the cylinder:—

(*a*) A period of admission of live steam up to a point of cut-off.
(*b*) A period of expansion up to a point of release.
(*c*) A period of release for the used steam.
(*d*) A period of compression after the valve has closed.
(*e*) A brief period of pre-admission of live steam before the piston commences its working stroke (see Fig. 32).

In the events just indicated the valve has three distinct duties to perform:—

(*a*) closes both steam ports when in its central position;
(*b*) admits steam to one end of the cylinder only at one time;
(*c*) opens to exhaust at one end of the cylinder at least as soon as it opens to admit steam at the other.

Figs. 33 and 33A show sections through steam chests in which slide and piston valves operate. The face on which the valve slides has three ports, the end ports "A" lead one to each end of the cylinder, the larger centre port "C" leads to the exhaust passage. In the position shown in the bottom figure, steam from the steam chest is passing the edge of the valve into the left-hand steam port, exerting a pressure, driving the piston to the right. On the other side of the piston steam is escaping by way of the right-hand steam port, through the cavity in the slide valve to the exhaust passage.

The relative positions of the valve and piston (ordinary "D" slide valve and inside admission piston valve) for one revolution of the wheel are shown in Fig. 34.

It will be noted that the slide or piston valve controlling the



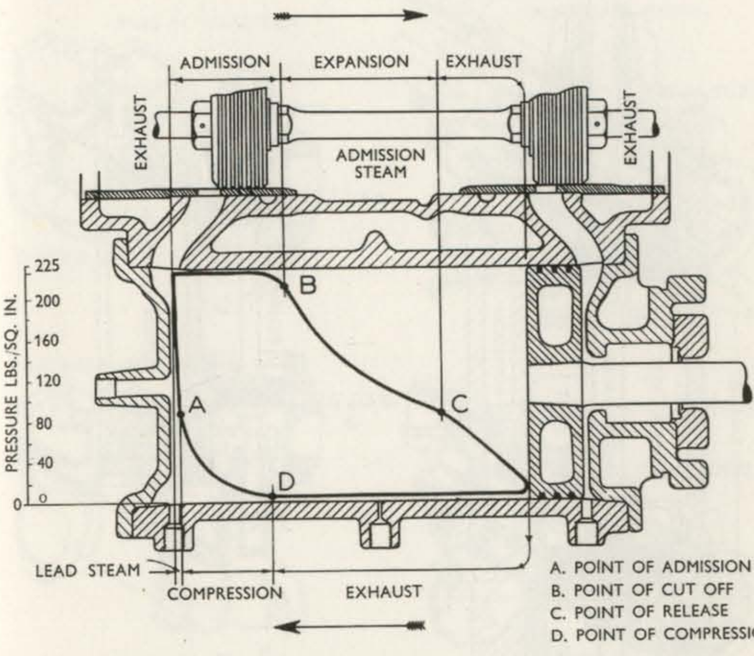



**Fig. 32 DIAGRAM SHOWING THE DISTRIBUTION OF STEAM ON ONE SIDE OF THE PISTON FOR A DOUBLE STROKE**

admission and exhaustion of steam to and from the cylinders has its face of such breadth that when the valve is in mid position it completely closes both steam ports. Two more important items have to be considered now—the "lap" and "lead" of the valve. "Lap" is the amount by which the valve overlaps each steam port at the middle position of each valve. There are actually two kinds of lap: "steam lap" is the amount by which the valve overlaps the port on the live steam side; similarly, the "exhaust lap" is the amount by which the valve overlaps the port on the exhaust side. "Exhaust lap" is generally given to slow-running locomotives, i.e. those designed for shunting duties, the effect being to delay the exhaust and derive the maximum work from the expanding steam in the cylinder.

"Negative exhaust lap", or as commonly termed "exhaust clearance" (Fig. 33), is the amount the port is open to exhaust when

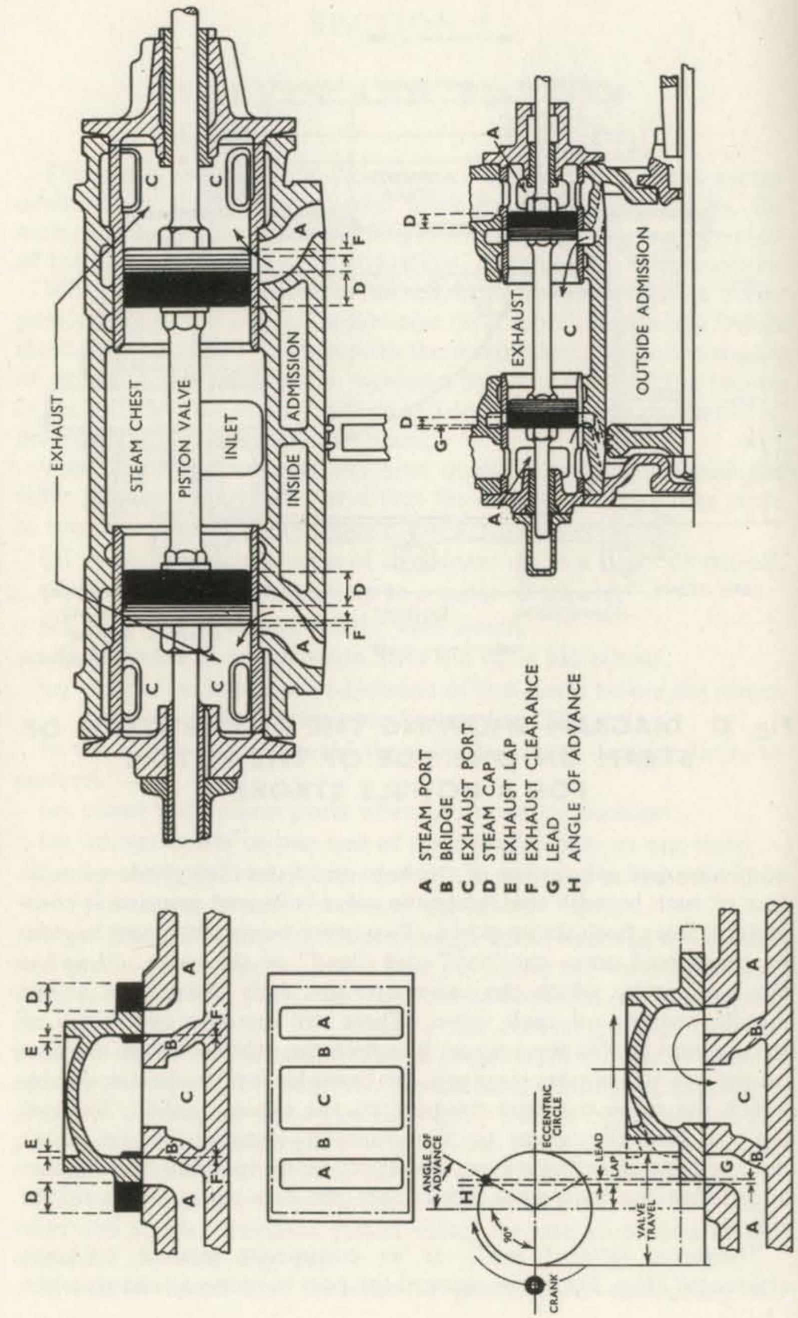
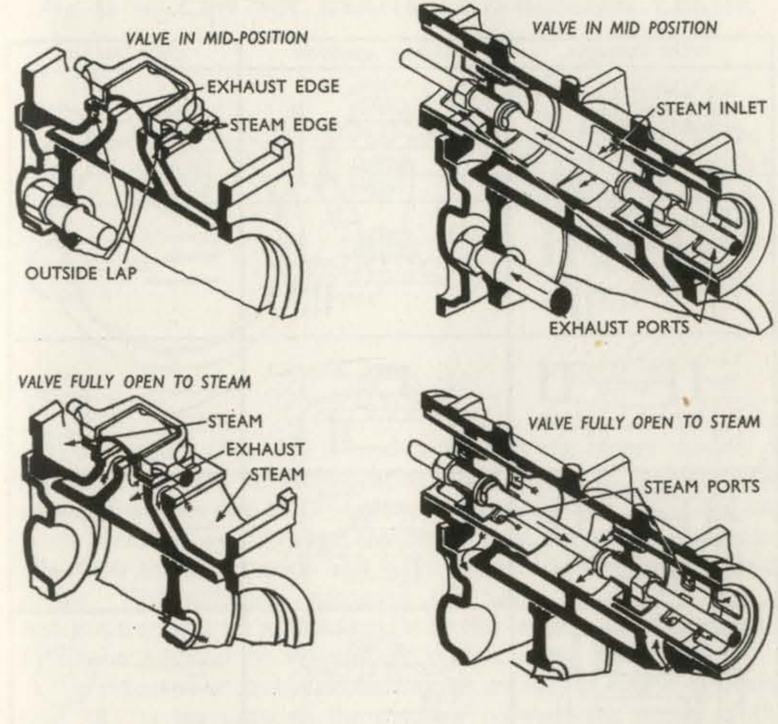



Fig. 33 SECTION SLIDE AND PISTON VALVE








**SLIDE VALVE AND STEAM CHEST**

**PISTON VALVE AND STEAM CHEST**

**Fig. 33a**

the valve is in mid-position, and this is used on many fast-running locomotives to give a free exhaust. The amount seldom exceeds $\frac{1}{16}$ in. when exhaust clearance is given; the cylinder on both sides of the piston is open to exhaust at the same time when the valve is passing through the mid-position, which is only momentary when running.

The "lead" of the valve is the amount by which the steam port is open when the piston is static at front or back dead centre. Pre-admission of steam fills the clearance space between the cylinder and piston and ensures maximum cylinder pressure at the commencement of the stroke. "Lead" is particularly necessary on locomotives designed for high speeds, under which conditions the valve events are taking place in rapid succession.

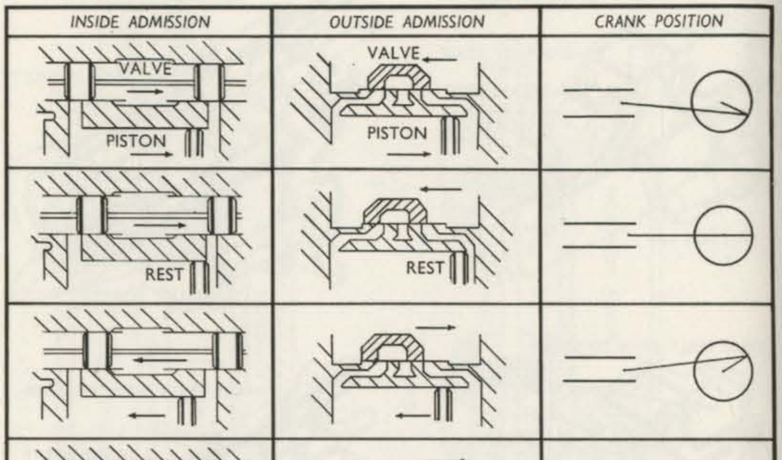
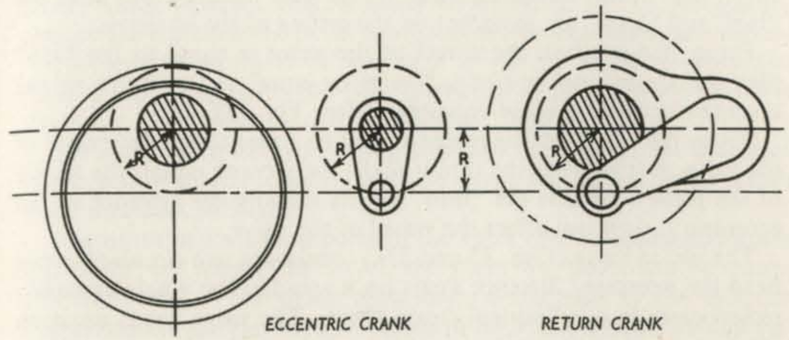



**Fig. 34 VALVE EVENTS FOR ONE REVOLUTION OF WHEEL**



**Fig. 35 ECCENTRIC CRANK AND RETURN CRANK**




The eccentric (Fig. 35) is used to convert the rotary motion of the crank axle into the reciprocating motion required to operate the valve. If we imagine a "D"-type slide valve without "lap" and not given "lead" it would, when the piston is at the end of its stroke, just cover the steam ports and be in the central position, i.e. mid-stroke. The eccentric operating the valve would also be in mid-position and set at 90° (a right-angle) in advance of the crank. From this position the valve would commence to open.

The eccentric is equivalent to a small crank, the length of whose arm "R" is the same as the distance between the centre of the eccentric sheave and centre of shaft. The length of "R" is called the eccentricity of the eccentric, and the valve travel is equal to twice the eccentricity. The return crank gives an equivalent movement to that of the eccentric and describes a circle of radius equal to distance "R" between the centre of the shaft or axle and the centre of the return crank pin.

If "steam lap" is added to the valve it would overlap the port by the amount of "lap" and if the eccentric were set as described above, steam would not be admitted to the cylinder until the piston had travelled some distance from dead centre and the engine would not work properly. To overcome this difficulty and to admit steam through the steam port to behind the piston immediately it moves from dead centre, the valve must be set ahead of the crank by 90° plus the "steam lap" (see Fig. 33). It is necessary also, as we have previously stated, to provide "lead" and this is done by moving the eccentric still further in advance of the crank; the eccentric has therefore been moved through a total of 90° plus "lap", plus "lead", the angle in excess of the right-angle being known as the "angle of advance".

It should be remembered that only the "lap" is apparent on the valve, the "lead" being a portion of the port opening, but both the "lap" and "lead" are apparent on the setting of the eccentric.

From mid-position the travel of the valve is equal to the "lap" plus the steam port opening, this being equal to the throw of the eccentric or the radius of eccentricity (see Fig. 35).

Twice the throw of the eccentric will be equal to the full travel of the valve, just as twice the throw of the main crank equals the stroke of the piston. Whilst the "lead" affects the angular advance of the eccentric it does not affect the travel of the valve.

The piston valve (Figs. 33 and 33A) consists of two circular pistons fixed the necessary distance apart on a spindle; the whole assembly reciprocates in a cylindrical steam chest. The valve heads are each fitted with rings to maintain a steam-tight fit in the steam chest. Piston valves can be adapted for inside or outside admission of steam to the cylinders. With inside-admission piston valves the live steam is contained between the two heads and is admitted to the steam ports at the inner edges of the valve heads, being exhausted at the outer edges into separate exhaust passages which combine to communicate with the blast pipe.

With outside-admission piston valves the steam is contained outside the valve heads with a common exhaust chamber between the heads, steam entering the ports at the outer edges of the valve heads and being exhausted at the inner edges.

With this arrangement the valve spindle glands are subjected to high-pressure steam at high temperature in the case of superheated locomotives and for this reason modern locomotives are almost invariably of the inside-admission type. Exceptions are the former S.R. Merchant Navy and West Country classes which have outside-admission valves, but which employ steam chest rocking shafts in place of valve spindle glands, as shown in Fig. 50. The modified former S.R. "Pacific's" have normal Walschaert valve gear, but whilst the inside cylinder has inside admission the outside ones have outside admission.

With inside-admission piston valves the travel of the valve is opposite that of the slide valve and outside steam admission piston valve; thus, to admit steam to the front port the valve must be moved forward to allow steam to pass the inside edge of the front valve head, i.e. in a direction opposite to that of the cylinder piston. The setting of the eccentrics in each case is shown in Fig. 35A.

When using a direct-acting link motion with inside-admission piston valves the eccentric requires to be set an additional 180° in advance of the crank to that used for outside admission, which position is actually following the crank by 90° minus "lead".



Inside-admission piston valves actuated by means of a rocking shaft, which reverses the direction of travel of the valve motion, require the eccentrics to be set as with direct motion with slide valves.

The maximum travel of the slide or piston valve is twice the "steam lap" plus twice the port openings. The minimum travel is twice the "lap" plus twice the mid-gear "lead".

The chief points affecting steam flows are valve travel, the diameter of the piston valves, together with the shape and layout of the steam chest and port passages.

The width of the steam ports in the valve liner is dependent upon the travel: the longer the travel, the wider the ports can be made. The extension of the steam chest beyond the ends of the cylinder barrel enables the piston valve heads to be widely spaced so that the

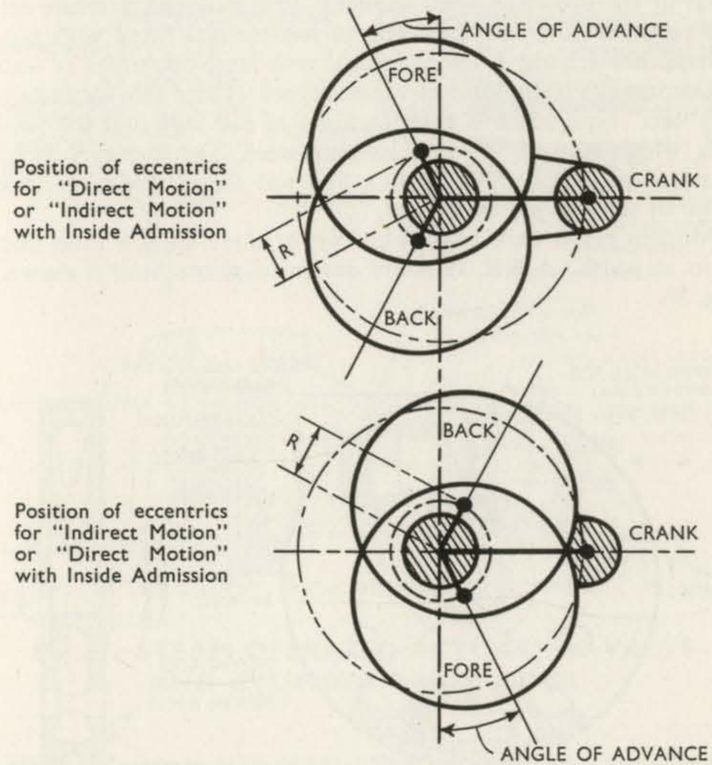



**Fig. 35a POSITION OF ECCENTRICS**

steam ports can be located directly at the ends of the cylinder bore, allowing direct passages between the valve ports and the cylinder.

The term "long travel" is actually a "long lap" valve, the increased steam lap being greater in proportion than the increase in valve travel. The chief advantage derived from long-lap valves is greater exhaust freedom and earlier cut-off working, the valve moving a greater distance for a given angular movement of the crank. The initial movement of the valve is accelerated, being the valve events of admission, expansion, exhaustion and compression more sharply defined. The port opening to steam is increased and both the exhaust and compression delayed, at the same time the greater port opening to exhaust provides a free exhaust at high speed and a decrease in back pressure.

The slide valve has an advantage over the piston valve in that it will lift off the port face to release water which may have accumulated in the cylinders when standing, and although pressure relief valves are fitted to the cylinders of locomotives fitted with piston valves, they are not designed to deal with large quantities of water.

Locomotive pistons are of various types. There are, for instance, the "box" type which is manufactured of cast iron and the "dish" type which is made of cast iron or steel. On former L.N.E.R. standard locomotives, the piston and rod are in one piece, being made of steel forged or welded.

Modern pistons are fitted with two or three narrow rings about $\frac{5}{16}$ in. in width. A B.R. standard design of piston head is shown in Fig. 36.

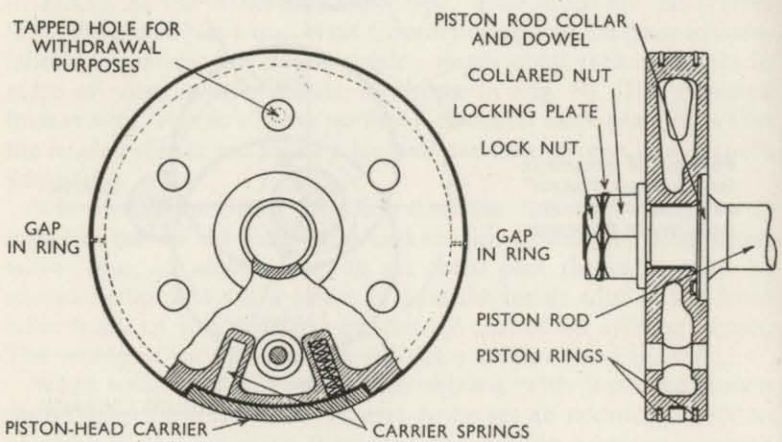



**Fig. 36 PISTON HEAD**



Cylinder drain cocks are fitted to drain away any accumulation of water from the cylinders and steam chest. Three drain cocks are fitted to each cylinder casting, one at each end of the cylinders and one connected to the steam chest. Cylinder cocks should always be open when the locomotive is standing or at any time when there is an indication of water in the cylinders. Steam-operated cylinder cocks are fitted to some of the B.R. standard locomotives (see Fig. 37).

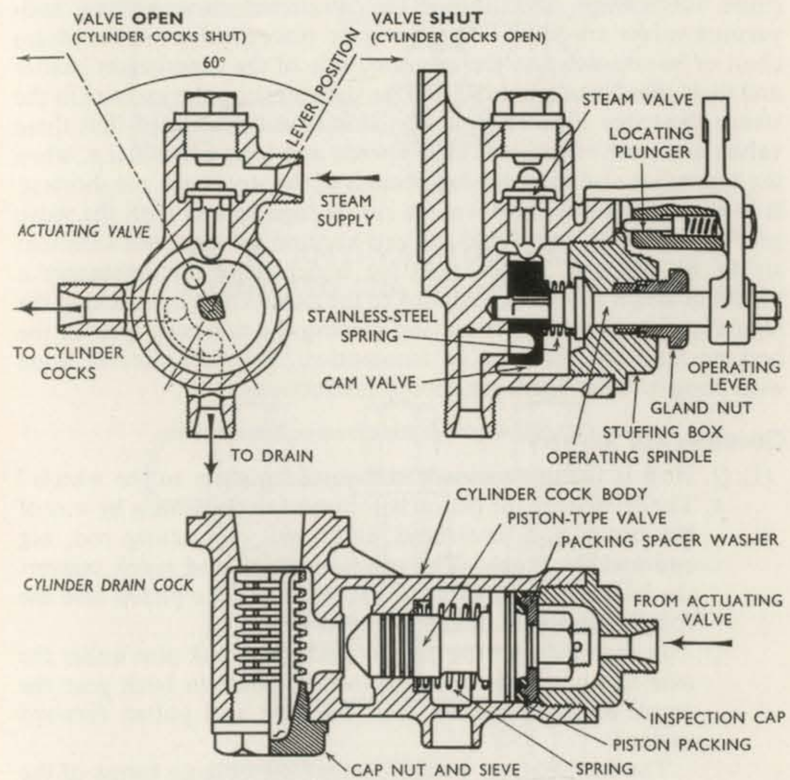



**Fig. 37 STEAM-OPERATED ACTUATING VALVE AND CYLINDER DRAIN COCK**

Most locomotives with piston valves are fitted with one or more anti-vacuum valves which automatically admit air to minimise the partial vacuum created in the cylinders and steam chests when coasting with the regulator closed. Under these conditions the valves and pistons in the cylinders act like pumps, tending to induce air from the steam chest, which action rapidly creates a partial vacuum inside the steam chest, the amount being further increased by the cylinders during what would be the normal "expansion" portion of the stroke, with the result that when the valve opens to exhaust, smokebox gases and possibly ashes may be drawn down the blast pipe to destroy the vacuum. Additionally, during the compression portion of the stroke very high temperatures are reached which cause lubrication difficulties. To counteract these effects anti-vacuum valves are fitted. These may be placed either on the steam chest or be connected to the saturated side of the superheater header and their effect is to admit air and partially destroy the vacuum in the steam chest (see Figs. 38 and 39). It will be appreciated that these valves are more effective at slow speeds and long cut-offs, i.e. when the expansion and compression periods of the stroke are the shortest. It is not satisfactory, however, to run at high speeds with the valve gear in full travel, nor would the anti-vacuum valves admit sufficient air to be effective. When coasting under these circumstances a breath of steam should be supplied to the steam chest by cracking the regulator, i.e. slightly opening and placing the reversing gear in the best position for the type of locomotive. For locomotives fitted with poppet valves there are special instructions.

**Questions and Answers**

(1) *Q*. How is the drive conveyed from the pistons to the wheels?

*A*. The drive from the piston is conveyed to the wheels by way of the piston rod, crosshead, little end, connecting rod, big end and the crank. The connecting rod and crank convert the backward and forward movement of the piston into the rotary movement of the axle and wheel.

In forward gear the pistons push the crank pins under the axle and pull them forward over it, while in back gear the crank pins are pushed over the axle and pulled forward under it.

The slide bars or guides prevent the oblique thrust of the connecting rod from bending the piston rod. For example, if the crank is on the top quarter and the piston being propelled forward as in fore gear, the resistance of the crank causes an upward thrust in the connecting rod which is transmitted to the slide bars. The thrust of the piston rod crosshead being against the top slide bar when running forwards and against the bottom bar when running backwards, with regulator open.



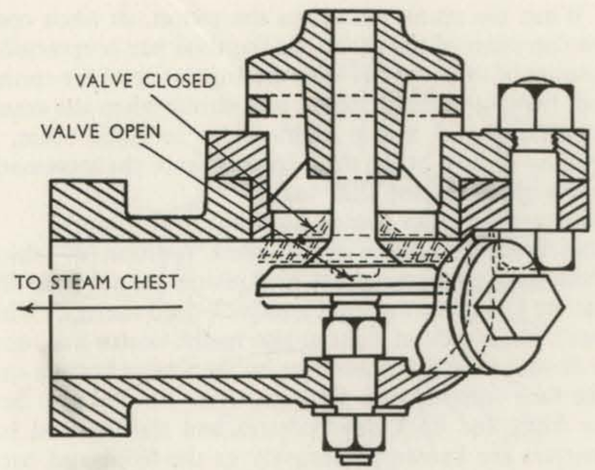



**Fig. 38 ANTI-VACUUM VALVE MOUNTED ON STEAM CHEST**

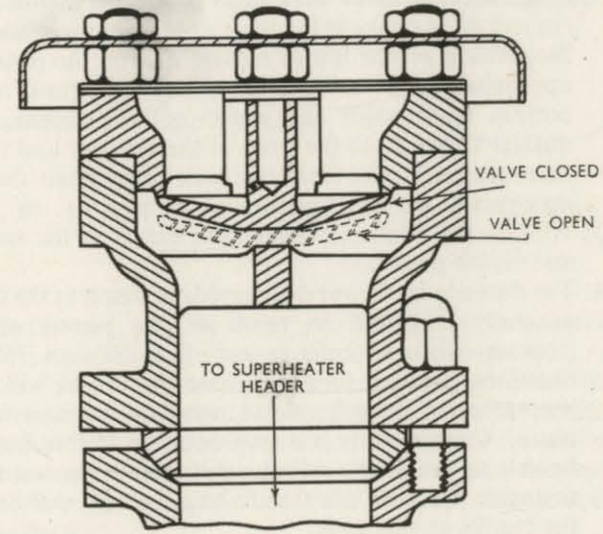



**Fig. 39 ANTI-VACUUM VALVE MOUNTED ON SUPERHEATER HEADER**

When the crank pin drives the piston, as when coasting, the direction of the thrust on the slide bar is reversed. The amount of thrust varies with the angularity of the connecting rod, being greatest at about half stroke when the crank and connecting rod are at right-angles to each other, being reduced to zero at the dead centre, hence the increased wear in the middle of the slide bars.

(2) *Q*. What are the eight named positions of the crank?

*A*. The forward and backward crank position in which the crank pin, connecting rod and piston are all in a straight line are known as the front and back dead centres. When the crank pin stands at right-angles to the centre line, upwards or downwards, it is said to be on the top or bottom quarter. The four intermediate settings which lie mid-way between the front and back dead centres and the top and bottom quarters are known respectively as the front and back top angles and the front and back bottom angles (see Fig. 40).

(3) *Q*. Does the position of the crank supply any clue to the position of the piston in the cylinder?

*A*. Yes. By reference to the eight crank positions described in the previous question it is quite easy to visualise the position of the piston within the cylinder. For instance, when the crank is on front or back dead centre the piston will be at the end of its stroke at the front or back of the cylinder, when the crank is on the top or bottom quarter the piston will be approximately at mid-stroke. With the crank on top or bottom front angle the piston will be rather less than quarter stroke from the front of the cylinder and rather less than quarter stroke from the back cover when the crank is on either of the two angles.

(4) *Q*. What is the relation between the events in the steam cycle and piston position?

*A*. The duration of the various periods of steam in the cylinder is generally measured in terms of the piston stroke, for instance, when we refer to cut-off at 50% or 75%. It is, therefore, possible to state where the piston will be when the events of cut-off, release, compression and admission occur. Consequently it is only one step further from this to be able to couple the cylinder events with the crank settings to enable the valve position to be judged from the setting of the cranks or side rods.

(5) *Q*. The steam action in the cylinder has been explained in relation to the piston movement. Can you explain it in relation to the crank positions?



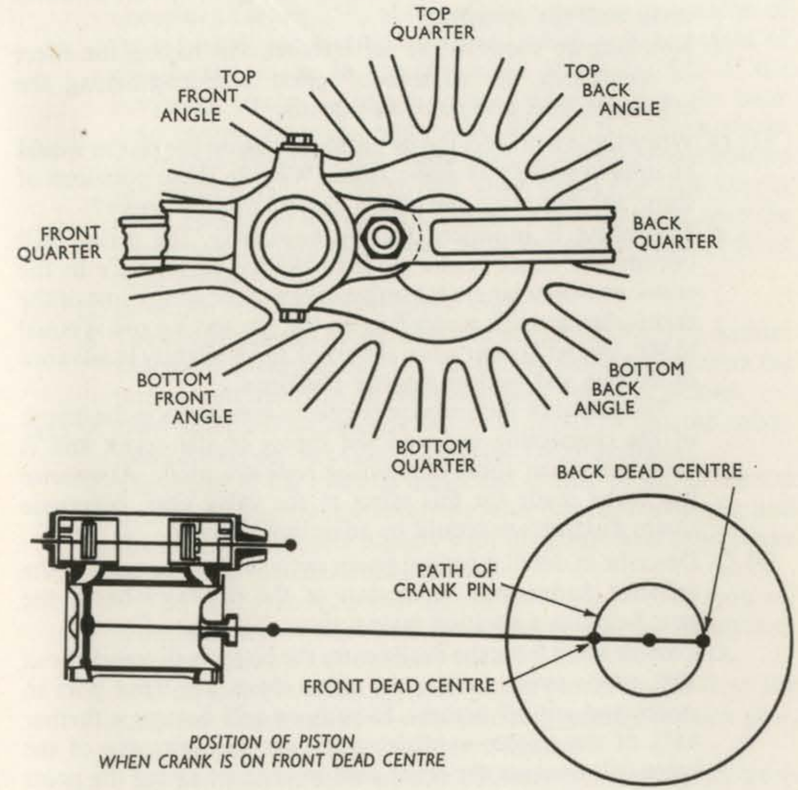



**Fig. 40 LEAST-EFFORT POSITION OF CRANK**

*A*. In forward gear the front side of the piston is exposed to live steam during admission and expansion periods and the rear side is exhausting as the crank moves under the axle from front dead centre to back dead centre. After the crank passes back dead centre position the back of the piston takes admission steam followed by expansion and the front side of the piston enters upon the exhaust and compression periods.

In back gear steam acts in front of the piston as the crank passes over the axle and behind the piston as the crank moves forward under the axle.

(6) *Q*. What is the effect of notching up the gear upon the steam cycle with the cylinder?

*A*. Notching up shortens the valve travel, this having the effect of shortening the admission period and lengthening the expansion and compression periods.

(7) *Q*. When the crank is on top or bottom position the piston would be approximately at mid-stroke. Why do these positions of the crank not place the piston exactly at mid-stroke?

*A*. This effect is produced by the angularity, the piston will occupy the exact centre of the cylinder barrel only in the crank positions where the angle between the centre line of the crank pins and the centre line on the connecting rod is equal to 90°, this will occur when the crank pin is slightly in advance of the top and bottom quarter positions.

The extent of this angularity effect depends upon the length of the connecting rod and the throw of the crank and is increased when short connecting rods are used. Allowance has to be made for this effect in the valve gear, otherwise steam distribution would be adversely affected.

(8) *Q*. Describe in detail a typical steam cycle in the front end of the cylinder during one revolution of the driving wheels, the gear being in a position giving about 30% cut-off.

*A*. Commencing from the dead centre the piston will travel about 30% of its stroke before the valve closes the front port to steam and cut-off occurs. Expansion will occupy a further 45% of the stroke, at which point the exhaust edge of the valve will uncover the front port to exhaust giving the point of release, the piston then completes the remaining 25% of the backward stroke with the front port open to exhaust. The piston will now make about 70% of the return stroke before the exhaust edge of the valve again closes the front port starting the period of compression. This will occupy about 25% of the return stroke, at which point the steam edge of the valve clears the front port, once more opening it to lead. This is the period of pre-admission which occupies the remaining 5% of the return stroke until the piston reaches the front dead-centre position in readiness for the commencement of the next cycle (see Fig. 32).

(9) *Q*. What is occurring in the back of the cylinder during the same period?

*A*. Starting from the front dead centre the valve already has the back port open to exhaust, which continues until the piston has covered 70% of the backward stroke, when the valve closes the back port and compression commences. This occupies a further 25% of the stroke, when the steam edge of the valve will uncover the back port to lead and the period of pre-admission sets in to occupy the remaining 5% of the backward stroke. The piston now returns from the back dead centre and will cover about 30% of the return stroke before cut-off occurs at the back port. Expansion then follows for another 45% of the stroke, after which the back port is again opened to exhaust and release occurs, lasting over the remaining 25% of the stroke until the piston reaches front dead centre.

(10) *Q*. How can you tell which crank leads?

*A*. The engine should be set with one big end on the top quarter and if the other big end is then on the front dead centre the latter crank leads, if on the back dead centre it follows.

(11) *Q*. How should a locomotive be set in order to test the valves and pistons on one side? Describe the procedure.

*A*. The crank of the cylinder under test should be set on the top or bottom quarter, the reversing lever placed in mid-gear and the regulator opened slightly with the steam and hand brake on and the cylinder cocks closed.

The test is made by moving the reversing lever as required from forward to backward gear and noting the indications given at chimney or cylinder cocks.

If on going into full forward gear a blow is heard from the chimney which ceases in mid-gear and restarts in back gear, leakage past the piston will be indicated.

A continuous blow up the chimney obtained in all positions of the reversing lever would indicate that the valve under test was blowing through, but on two-cylinder locomotives this effect would also be produced by a defective piston on the opposite side, and therefore if this indication is obtained, reset the engine and test the other cylinder in order to prove the opposite piston before coming to any decision.

(12) *Q*. What indication would be given by this test if the valves and pistons were in good order?

*A*. In this case no blow will be heard from the chimney in any position of the gear, but a single and well-defined beat will be heard as the gear is reversed from forward to back gear and vice versa.

(13) *Q*. How would you test for a broken valve lap on a slide valve engine or admission steam rings on a piston valve engine?

*A*. This may be found with big end on bottom quarter setting as described above, but the cylinder cocks should be left open.

If on moving the reversing gear a short distance towards forward gear steam blows from the front cock, or from the back cock when the reversing gear is moved a short distance toward back gear, this indicates that a portion is broken off the front or back valve lap respectively. In the case of a piston valve a broken ring or damaged steam edge of the valve would be indicated. In the case of badly damaged laps, a blow from either of the cocks may be obtained with the lever in mid-gear according to which lap is affected. The front laps may also be tested with cranks set on the front angles and the back laps with cranks set on the back angles if desired.

(14) *Q.* Describe the principle of the angles tests using front angles setting.

*A.* In this position two crossheads will be level in the slide bars next to the front end, and with the reversing gear in mid-position both front ports will be just covered by the steam edges of the valves, whilst the two back ports will be open to exhaust. In forward gear the R.H. valve will uncover the front port to steam and will maintain the back port to exhaust. The L.H. valve will open the front port to exhaust and will close the back port. In backward gear the R.H. valve opens the front port to steam and the back port to exhaust.

(15) *Q.* If your engine was suspected of having a cracked valve cavity or defective piston valve rings, causing a bad blow through to exhaust, could you ascertain which valve was at fault?

*A.* Yes. This could be ascertained by employing the mid-stroke tests with crank on top or bottom quarter, but it would be advisable to test both sides. In this test the cylinder cocks should be used and when the defective side is tested steam will be found to issue from both front and back cylinder cocks when the gear is in forward and backward gear. In forward gear a heavy blow will be obtained from the front cock and a light blow from the back, whilst in back gear the back cock will blow heavily and the front one lightly. On former G.W.R. locomotives fitted with piston valves the test required is slightly different as the valves are fitted with only two rings on each head, i.e. one steam and one exhaust. In this case the suspected side should be placed with big end on the bottom, cylinder cocks open, brake hard on, reversing lever in mid-gear. With the regulator open, steam from the front cylinder cock indicates that the front steam ring is defective. No steam from either cylinder cock indicates that steam rings on both heads are good.



Close cylinder cocks and put reversing lever into full forward gear, open regulator to fill front end of cylinder with steam and then shut. Bring back reversing gear nearly to mid-gear and retain in this position for a few seconds. In this position the exhaust ring is on the exhaust side of the port, thus keeping the steam in the cylinder. If steam is blowing through to exhaust in this position no beat will be heard up the chimney when the reversing lever is moved into back gear; the front exhaust ring is defective. If, however, a good beat is heard when the reversing lever is placed into back gear the front exhausting ring is good. By placing the lever into back gear and then following the same procedure the back exhaust ring may be tested.

*Note:* A blow up the chimney in both fore and back gear would indicate a defective piston.

(16) *Q.* How can the valves and pistons be tested on a three-cylinder simple engine?

*A.* Each cylinder should be tested separately by the mid-stroke method with crank on top or bottom quarter. Another method is to test each piston separately with its crank on front or back dead centre. By this method a defective piston will be disclosed by a continuous blow up the chimney in all positions of the lever when the regulator is opened, because one port will be open to lead and the other to exhaust. If the piston is sound there will, of course, be no blow of any kind. Whichever method is used, all three pistons must be tested in turn and the results noted before any decision is formed as to where the defect lies, because it is possible to be misled from a single test if defects exist in one or both of the other two cylinders.

(17) *Q.* How can a four-cylinder simple engine be tested for valves and pistons?

*A.* In this case also the mid-stroke setting should be used, but it has to be realised that the adjacent inside and outside cylinder will be tested simultaneously due to the fact that their respective cranks are fixed on opposite centres.

SECTION 6

# VALVE GEARS

We have seen from the previous section that a slide or piston valve actuated by one eccentric will rotate the driving wheels in one direction, but, as it is essential that the engine must work in both directions, additional valve gear becomes necessary.

Two-cylinder locomotives are constructed with the cranks set at right-angles to each other, one piston exerting its greatest effort whilst the other, on its dead centre, will not exert any rotating force on its crank. The piston on the front or back dead centre must receive steam at the end of the cylinder and travel away from the cylinder cover irrespective of whether the engine moves forward or backward. The other piston at mid-stroke will receive steam either at the front or back and will move in the direction of the force exerted, which will determine whether the engine moves forward or backward. The function of the slide or piston valve is to distribute the steam to the cylinder and that of the valve gear to control the valve events in correct sequence.

## The Stephenson Valve Gear

This type of valve motion, as shown in Fig. 41, employs two eccentrics, fitted to the crank axle, for each valve, one eccentric for fore- and one for back-gear working.

The backward and forward movement of the eccentrics is transmitted through the eccentric rods to a slotted link known as the expansion link, the fore-gear eccentric rod being coupled to the top and the back-gear rod to the bottom of the link. The links are suspended from a common reversing shaft by lifting links and may be raised or lowered at will from the reversing gear in the cab through the medium of the reversing rod.

Fitted in the slot of the expansion link is a die block, which is connected to the valve spindle by an intermediate valve rod. When the link is lowered to bring the fore-gear eccentric rod into line or almost in line with the intermediate valve rod or spindle rod, the movement of the eccentric is transferred to the valve. Conversely, if the link be raised, the movement of the back-gear eccentric rod will be transferred to the valve. With the link placed so that the die block is in the centre of the link, the mid-gear position, the link simply oscillates about the die block with a to and fro movement equal to the steam lap plus the lead of the valve, from its central



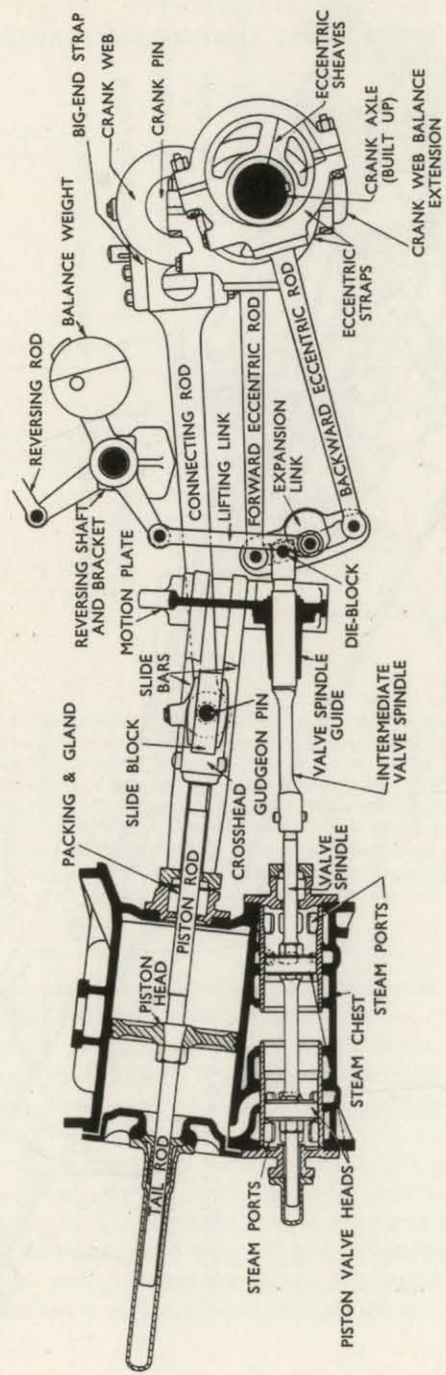



Fig. 41 STEPHENSON VALVE GEAR WITH OUTSIDE ADMISSION PISTON VALVES DIRECT MOTION

**Fig. 42 STEPHENSON VALVE GEAR WITH ROCKING SHAFT**

**Western Region Two-cylinder Locomotives**

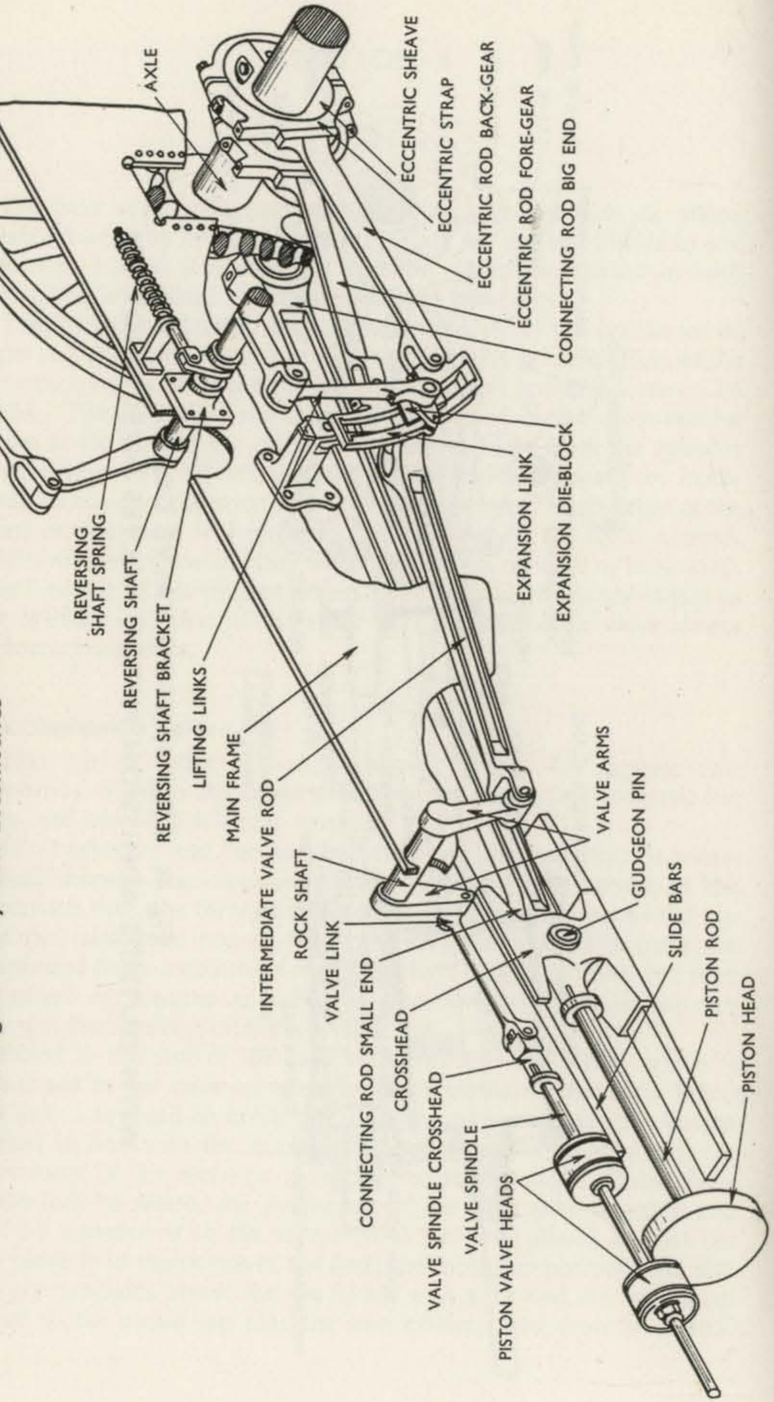



Fig. 42



## Fig. 43 STEPHENSON VALVE GEAR DIAGRAM SHOWING VARIATION IN LEAD

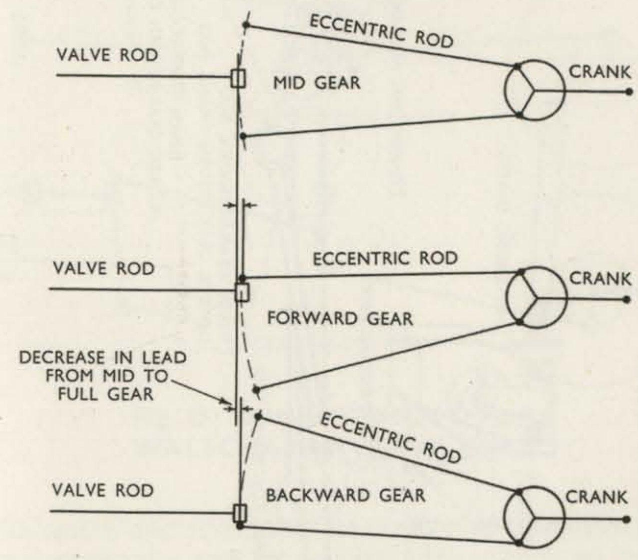



*DIAGRAM OF VALVE LEAD*

In Stephenson's Gear with Rods as shown in the sketch the valve head gradually increases as the gear is notched up from Full Backward or Full Forward to Midgear and becomes a *Maximum* in Midgear. This is owing to the control of the valve by the eccentrics having a varying effect from Midgear to Full Forward or Backward Gear. At Midgear both eccentrics exercise effect on the movement of the valves giving *Maximum Lead*. When Full Forward or Full Backward Gear is approached one eccentric exercises a decreasing control and the other eccentric an increasing control until Full Gear is reached. The forward eccentric has Full Control in Forward Gear and the backward eccentric Full Control in Back Gear giving *Minimum Lead*.

position. The full travel in mid-gear position is equal to twice the steam lap plus twice the mid-gear lead.

Intermediate positions of the die block in the link will allow for a variation of valve travel, according to the position of the reversing gear, varying the cut-off of steam to the cylinders and making use of the expansive property of the steam.

With the arrangement of the Stephenson link motion, as shown in Figs. 41 and 42, the lead of the valve increases as the gear is "notched up" to a maximum at mid-gear and a minimum at full forward or full backward gear. Fig. 43 illustrates the variation of lead for mid- and full-gear positions; the increase of lead at early cut-off positions is advantageous at high speeds.

## Fig. 44 WALSCHAERT VALVE GEAR

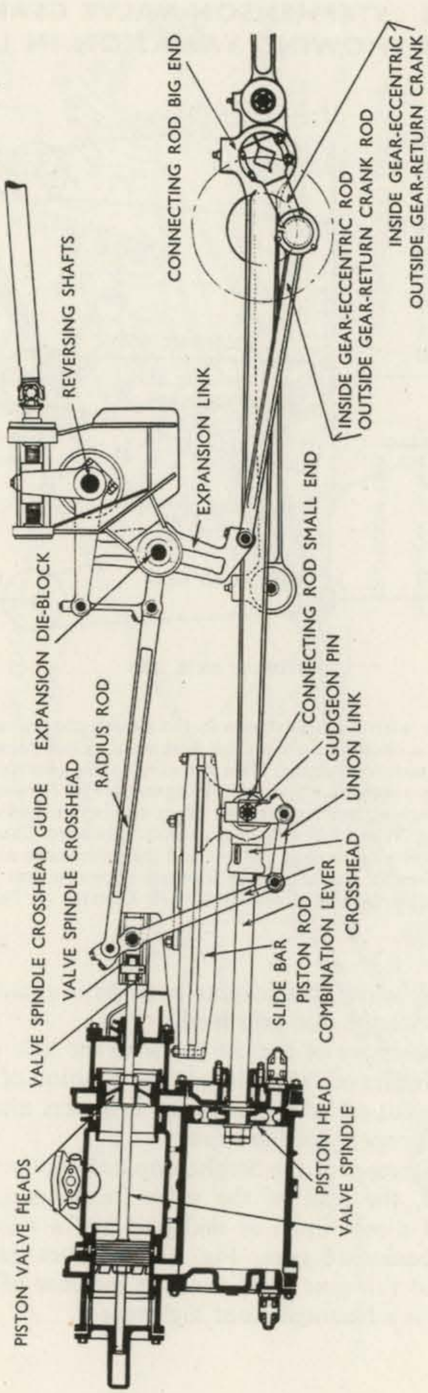



Fig. 44



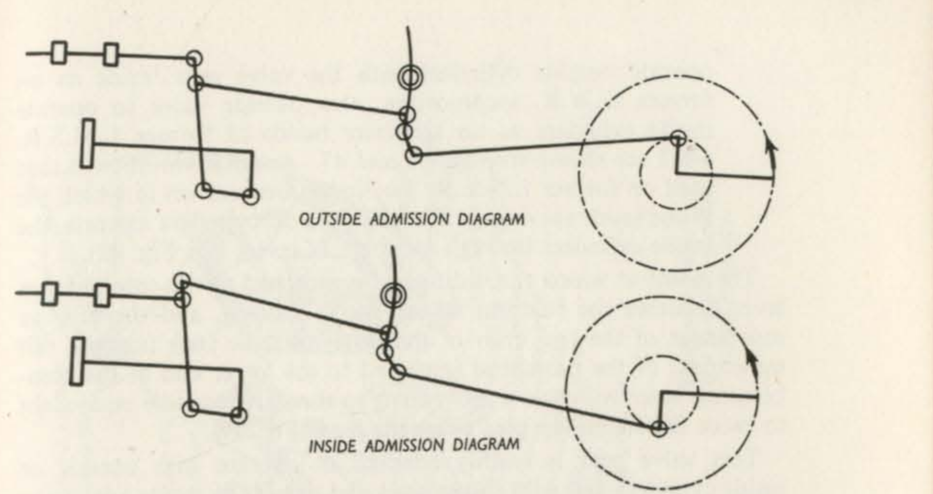



**Fig. 45 ARRANGEMENT FOR WALSCHAERT VALVE GEAR**

With outside-admission valves (slide and piston) actuated directly by Stephenson valve gear, the position of the eccentric on the crank axle is 90° plus the angle of advance in front of the crank for each direction of travel.

With inside-admission valves operated directly, the respective eccentrics follow the crank by 90° less the angle of advance.

If a rocking shaft, which reverses the direction of movement, is interposed between the inside-admission valve and the valve gear, the eccentrics are set as mentioned in the first example.

### The Walschaert's Valve Gear

With this type of valve gear the movement is derived from two distinct sources, as follows:—

(*a*) A single eccentric or return crank, eccentric rod or return crank rod, expansion link and radius rod (Fig. 44) which provides for the movement of the valve equal to twice the steam port opening, the expansion link being provided for varying the cut-off and reversing the direction of travel.

(*b*) A combination lever attached at its lower end to a union link which is connected to the piston crosshead, the upper end of the combination lever being coupled to both the valve spindle and the radius rod, the latter being attached above or below the valve rod, depending upon the use of inside or outside admission valves respectively. The layout of the gear for both types of valves is shown in Fig. 45. Variations of this gear to operate outside cylinders with the valve gear inside as on former G.W.R. locomotives, also outside valve to operate inside cylinders as on the later builds of former L.M.S.R. 4-6-2 are shown in Figs. 46 and 47. Another variation is that used on former L.N.E.R. 3-cylinder locomotives in which the Walschaert valve gear for the outside cylinders operate the inside cylinders through a system of levers (see Fig. 48).

The point at which the radius rod is attached to the combination lever becomes the fulcrum of the whole motion, and the relative movement of the two ends of the lever must be such that the full movement of the crosshead imparted to the lower end of the combination lever will give a movement to the valve spindle equivalent to twice the steam lap plus twice the lead (Fig. 49).

This valve gear is readily adapted to operate with outside or inside cylinders and with slide valves and outside or inside admission piston valves.

The arrangement of the eccentric or return crank to provide movement to the valve beyond that already provided by the combination lever for lap and lead steam depends on whether inside or outside admission valves are employed.

With inside-admission piston valves the eccentric or return crank is set at 90° behind the crank. With outside-admission valves the eccentric or return crank is set at 90° in front of the crank.

The expansion link, suspended at its centre by trunnions, is oscillated an equal amount forward and backward by the eccentric or return crank through the medium of the eccentric rod or return crank rod. An expansion die block slides in the expansion link and is attached to a radius rod which, attached at one end, connects with the combination lever and is attached at the other end to the expansion die block in the link. The raising or lowering of the rear end of the radius rod causes the die block to be raised or lowered in the link.

Normally the bottom of the link is used for fore-gear and the top of the link for back-gear working, giving a direct movement for fore gear and an indirect movement for back gear. The method of reversing is shown in the diagrams of the valve gear.

When the die block is in the centre of the expansion link for mid-gear position, the expansion link does not transfer any movement to the radius rod. Intermediate positions of the expansion die block above or below the centre of the link allow for proportional transfer of movement from the link to the radius rod and valve.

The combined movements of the two sections (*a*) and (*b*) of the gear result in a total movement of the valve equal to twice the



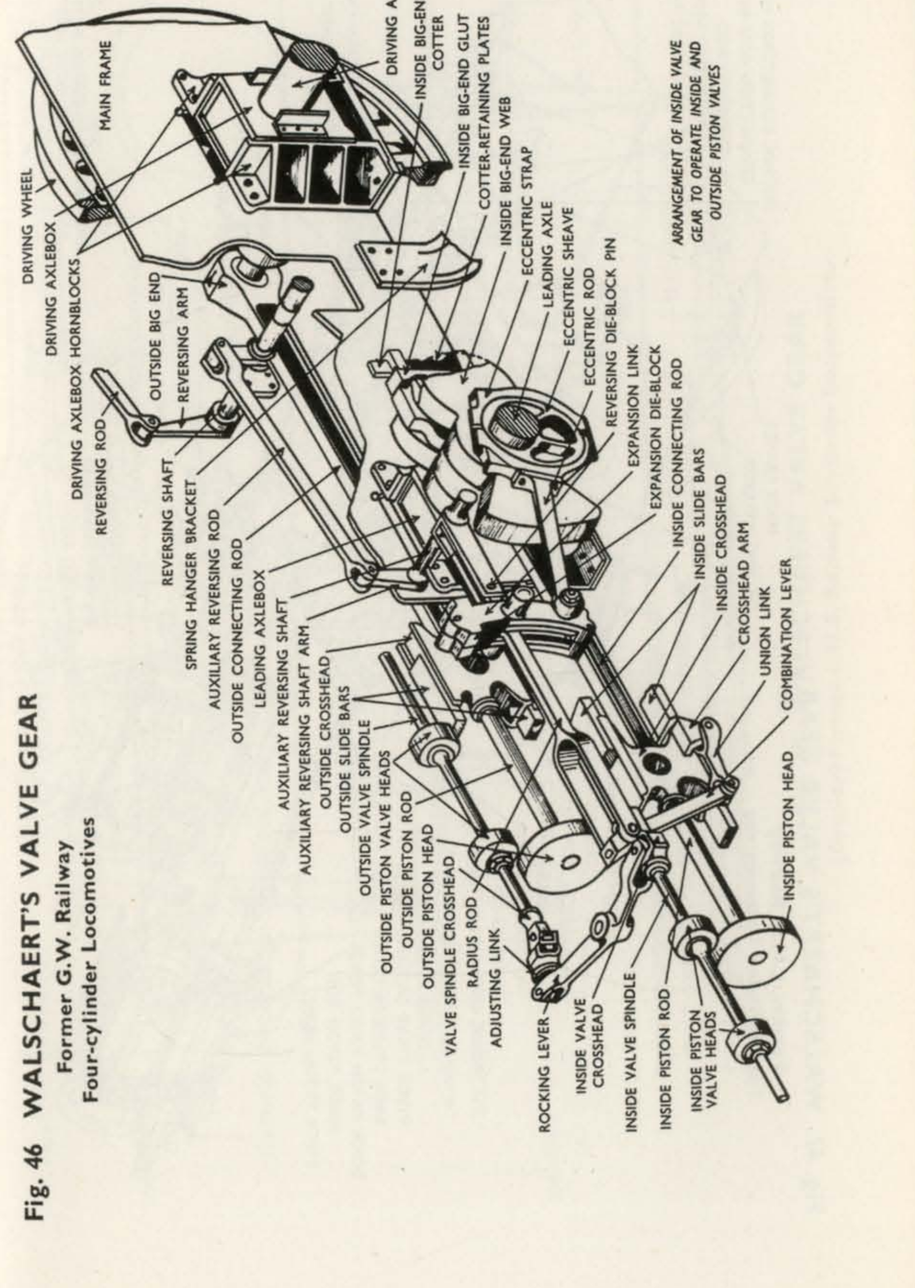
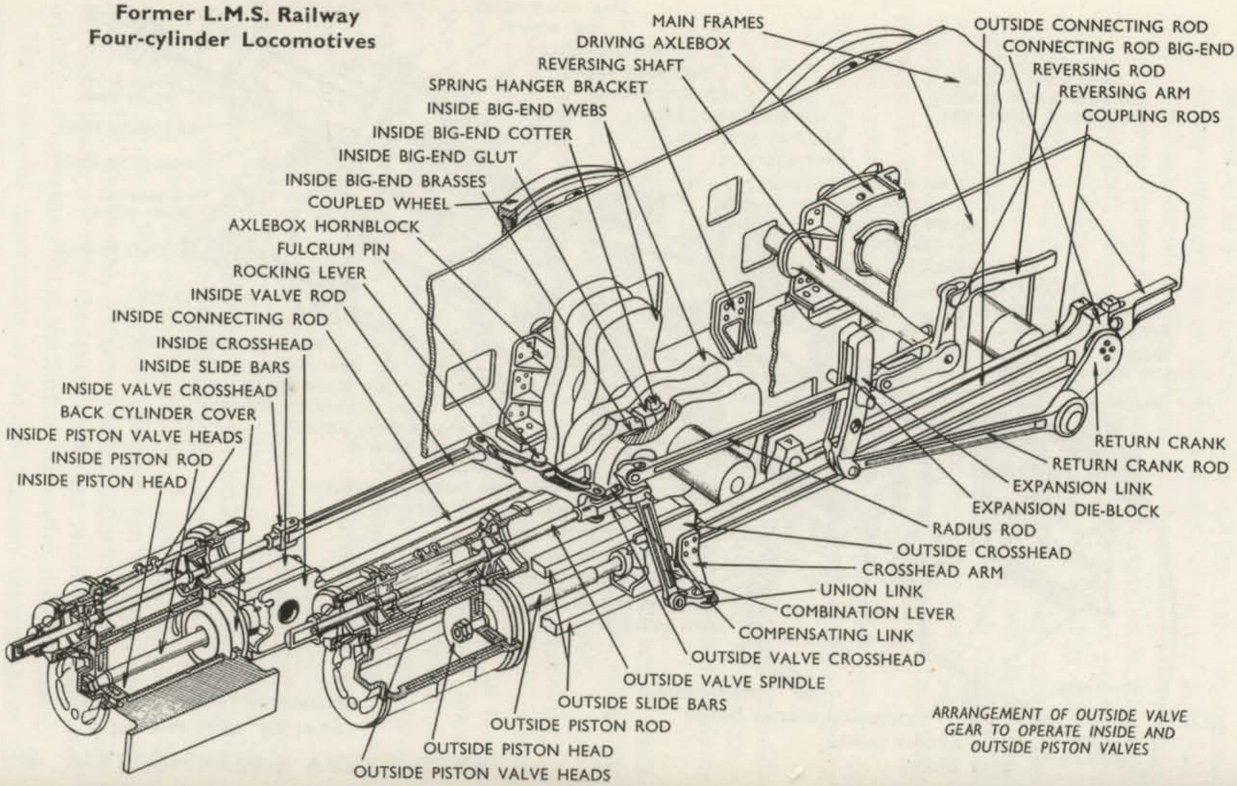



**Fig. 46 WALSCHAERT'S VALVE GEAR**
**Former G.W. Railway**
**Four-cylinder Locomotives**

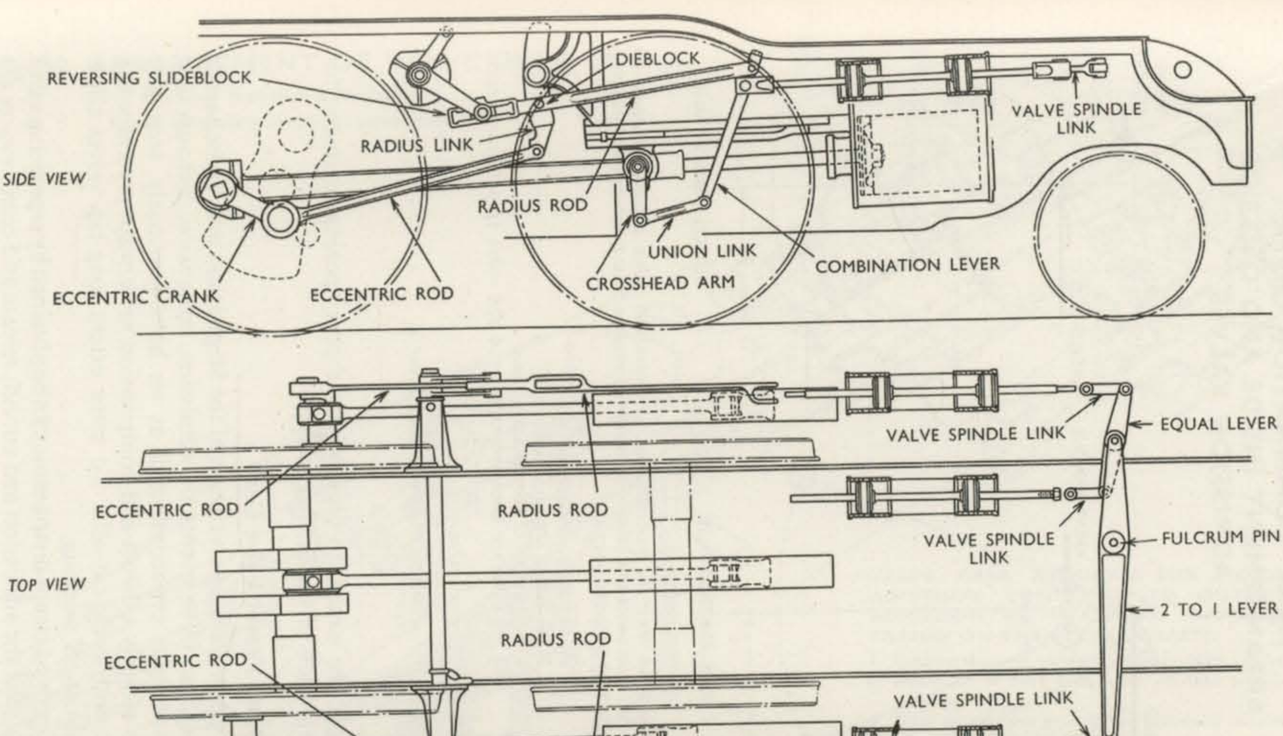
**Fig. 46**

# Fig. 47 WALSCHAERT'S VALVE GEAR

**Former L.M.S. Railway**
**Four-cylinder Locomotives**



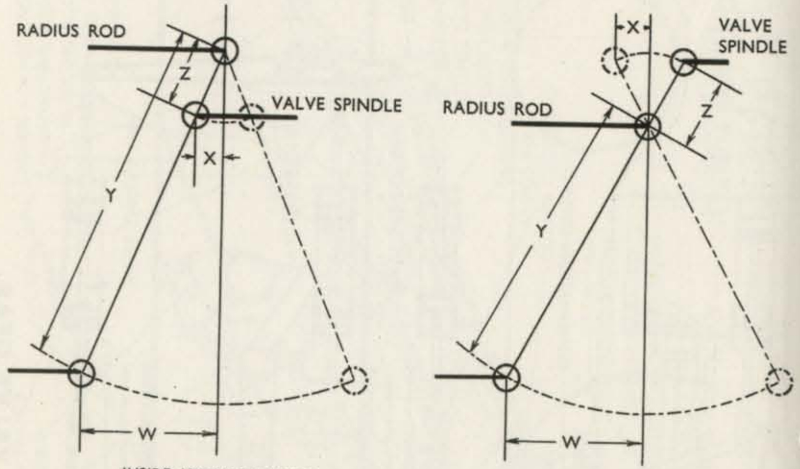



# Fig. 48 WALSCHAERT VALVE GEAR

**(Gresley) former L.N.E. Railway 3-cylinder Locomotives**

## Fig. 49 COMBINATION LEVER ARRANGEMENT INSIDE AND OUTSIDE ADMISSION VALVES




*INSIDE-ADMISSION VALVE* *OUTSIDE-ADMISSION VALVE*

The combination lever is proportioned to move the valve a distance equal to twice the lap plus twice the lead. For inside admission piston valves the following are the essential proportions:—

$$\frac{W}{X} = \frac{Y}{Z}$$

**W** = Half piston stroke
**X** = Steam lap plus lead
**Y** = Length of combination lever
**Z** = Distance between radius rod and valve spindle connection

For an outside admission valve

**Y** = Length of combination lever **Z**

amount of the steam lap plus twice the port opening to steam, for each revolution of the driving wheels.

### Rotary Cam Poppet Valve Gear

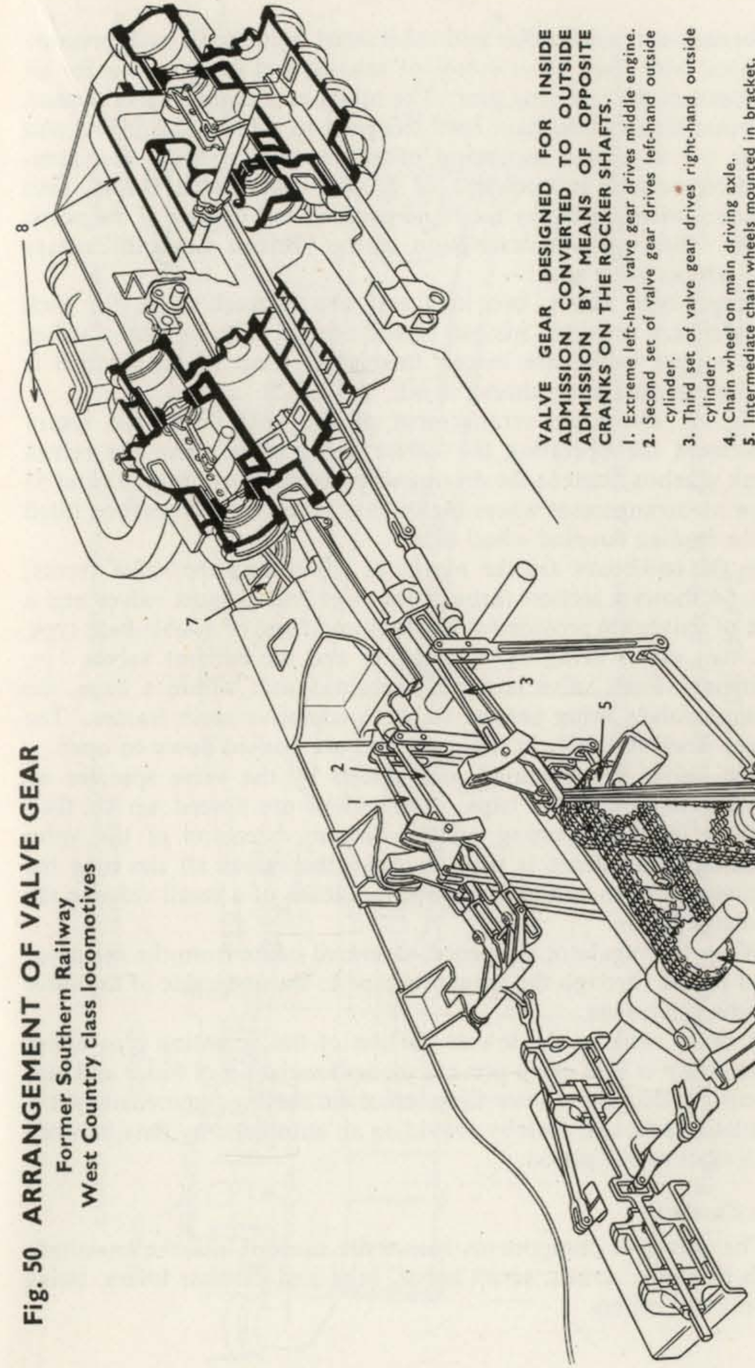
With reciprocating valve gears of the Stephenson and Walschaert's types, all the valve events of admission, expansion, exhaust and compression are interconnected, as we have previously seen and the evils of early exhaust and compression are always present when working with early cut-offs. To some extent long lap valves allow for short cut-off working.

An improved steam distribution can be obtained by separating valve events so that the admission and cut-off, release and compression are



## Fig. 50 ARRANGEMENT OF VALVE GEAR

Former Southern Railway
West Country class locomotives




**VALVE GEAR DESIGNED FOR INSIDE ADMISSION CONVERTED TO OUTSIDE ADMISSION BY MEANS OF OPPOSITE CRANKS ON THE ROCKER SHAFTS.**

1. Extreme left-hand valve gear drives middle engine.
2. Second set of valve gear drives left-hand outside cylinder.
3. Third set of valve gear drives right-hand outside cylinder.
4. Chain wheel on main driving axle.
5. Intermediate chain wheels mounted in bracket.
6. Chain wheel driving three-throw jockey shaft.
7. Hanging bracket to offset second valve drive.
8. Both left and right outside cylinder exhaust led back and up into exhaust of middle engine.

independent of each other and substantial decrease in back pressure attained with fixed valve events of exhaust and compression for all positions of the reversing gear. The rotary cam poppet valve systems of steam distribution have been designed to achieve this object and allow for a greater expansion of steam, with exhaust and compression periods independent of all the other valve events, thus avoiding wiredrawing by the rapid opening and closing of the ports.

The following is a description of the "British Caprotti" rotary cam poppet valve gear:—

Poppet-type valves, two inlet and two exhaust valves for each cylinder, are provided instead of the normal slide or piston valve. The poppet valves are driven through a form of gear which is totally enclosed and running in oil.

Fig. 51 shows an arrangement of the gear drive, the rotary movement for operating the valves being taken from the return crank gearbox fitted to the driving wheel crank pins. Figs. 52 and 53 show an arrangement where the drive is taken from a gearbox fitted to the leading coupled wheel axle.

In the camboxes are the means of controlling the valve events; Fig. 54 shows a section through the inlet and exhaust valves and a pair of valves are provided at the back and front of double-beat type, the inlet valves being 6¼ in. diameter and the exhaust valves 7 in. diameter. Each valve is a self-contained unit within a cage, the exhaust valves being nearest to the locomotive main frames. The valves work vertically in the cages and are pushed down to open.

The valves are operated and guided by the valve spindles on the top of which are caps. The valves are forced up to their seatings by steam acting on the bottom extension of the valve spindles. This steam is used to close the valves all the time the regulator is open and is controlled by means of a small valve in the regulator head.

When the regulator is opened, saturated steam from the regulator head passes through the actuating pipe to the underside of the valve spindle extensions.

A drain valve in the lowest portion of the actuating pipe opens when steam is shut off to prevent the accumulation of water and also to ensure that the valves drop off their seatings immediately the regulator is closed, thereby providing an automatic by-pass between both sides of the piston.

**The Cambox**

The principal components inside the cambox are the camshaft, with its cams, scrolls, scroll collar, inlet and exhaust levers, swing beams and rollers.



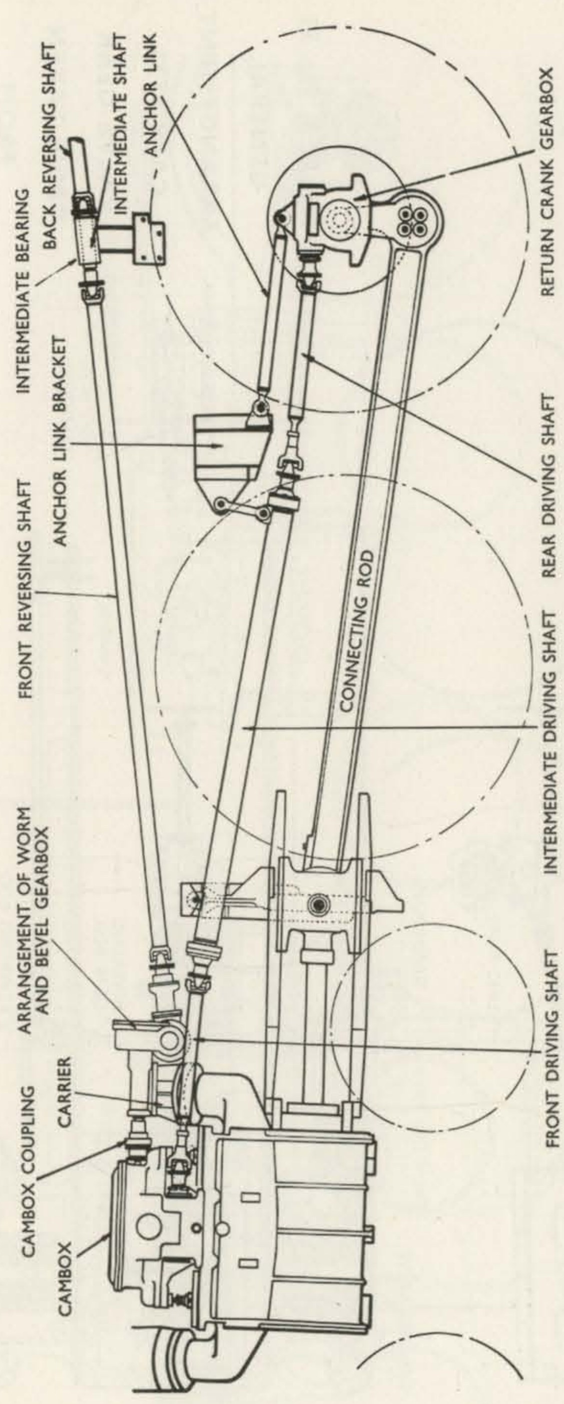



Fig. 51 GENERAL ARRANGEMENT OF BRITISH CAPROTTI VALVE GEAR, OUTSIDE DRIVE

Fig. 52 & Fig. 53 GENERAL ARRANGEMENT CAPROTTI VALVE GEAR DRIVE TAKEN FROM LEADING AXLE

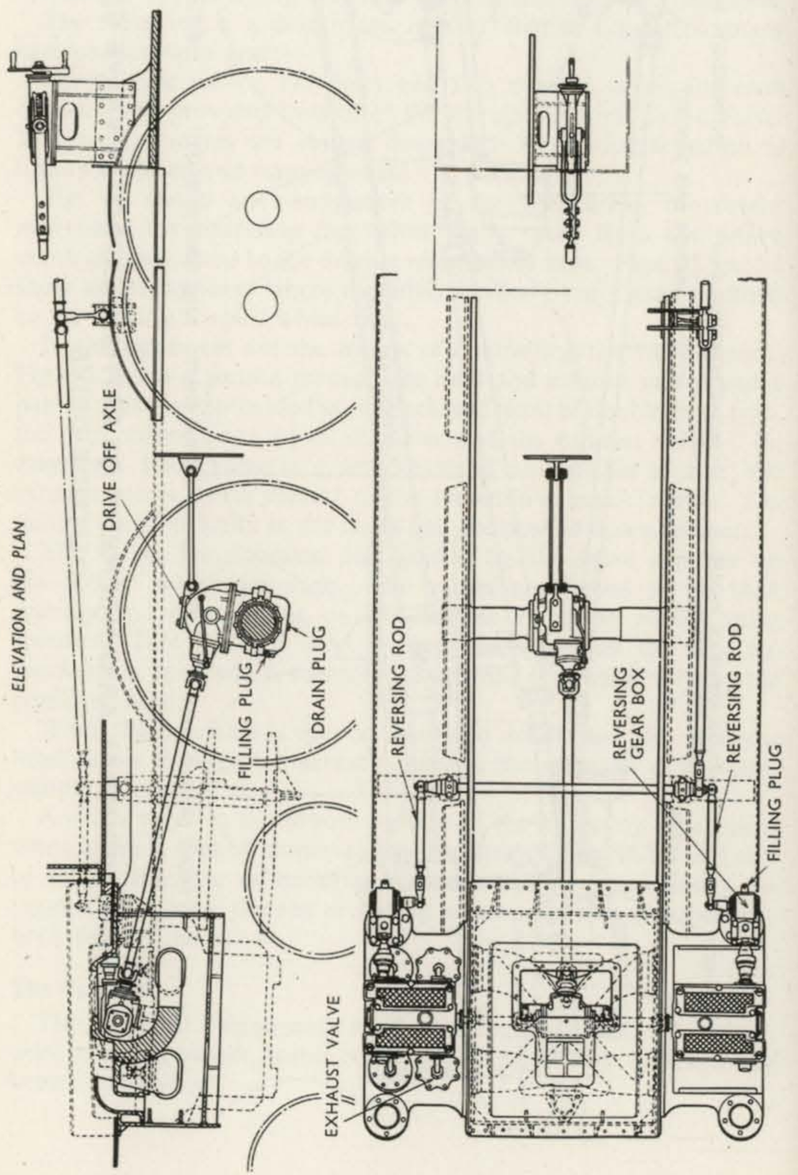



Fig. 52



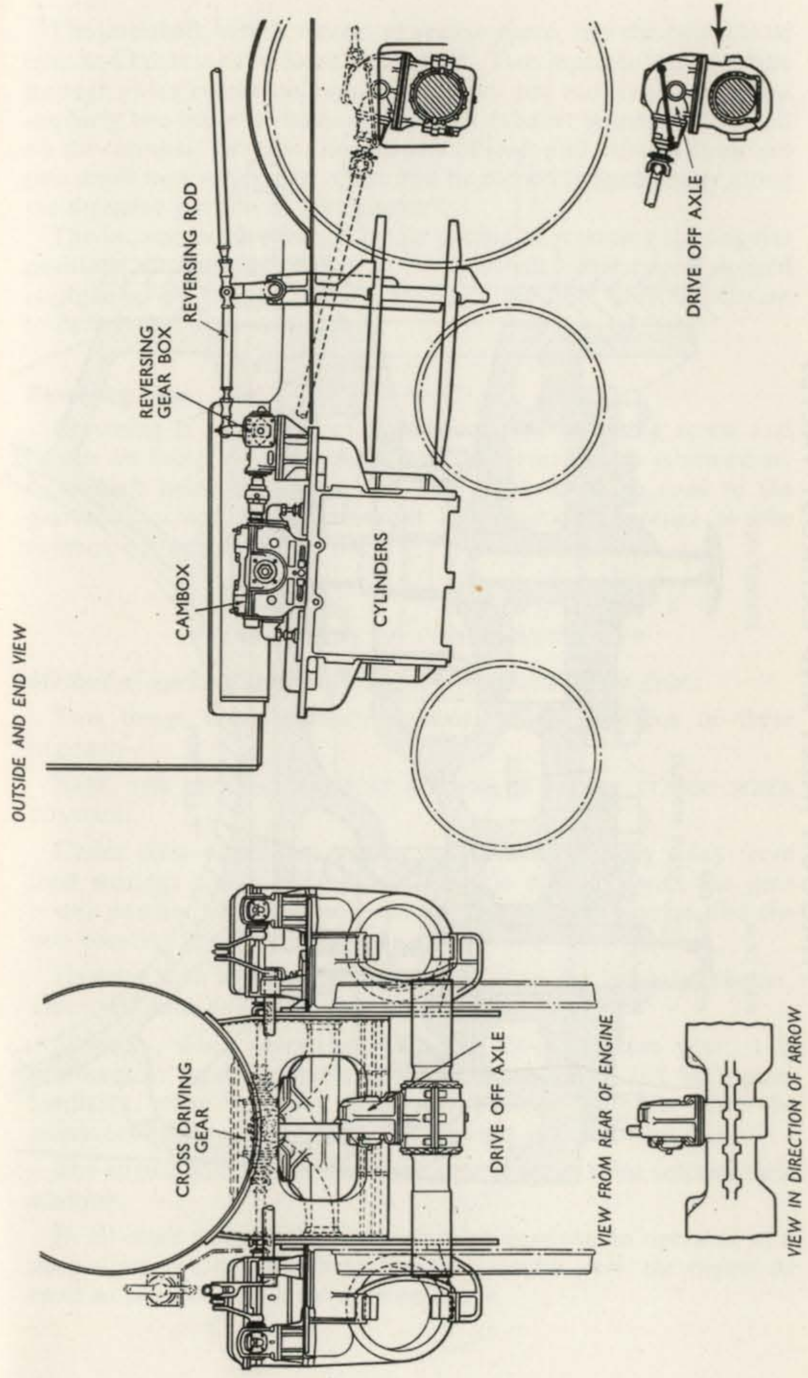



Fig. 53

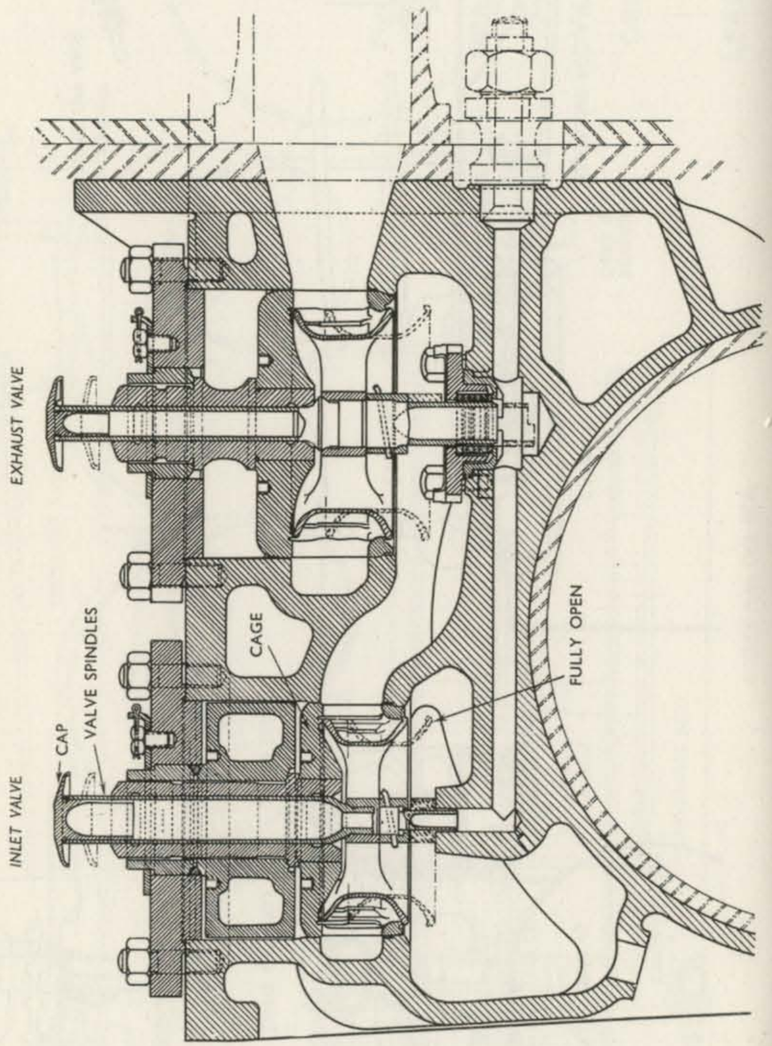



Fig. 54 BRITISH CAPROTTI VALVE GEAR SECTION THROUGH INLET AND EXHAUST VALVES

Fig. 54



The camshaft, which rotates at engine speed, has the two sets of inlet and exhaust cams loosely mounted. Two separate cams operate through swing beams and tappets, the front and back inlet valves and similarly two separate cams operate the exhaust tappets. Mounted on the camshaft between the two sets of inlet and exhaust cams are two scroll nuts which can rotate and be moved longitudinally along the threaded portion of the camshaft.

The locomotive is reversed by advancing or retarding the angular positions of the cams relative to the camshaft. Any cut-off desired is obtained by angular shifting round of the inlet cams in relation to each other.

**Reversing Gear**

Reversing is by means of a standard-type reversing screw and handle on footplate movement from two arms on the intermediate cross-shaft being transmitted by two short reversing rods to the gearboxes which finally transmit the reversing motion to the cambox on each cylinder.

INSTRUCTIONS TO FOOTPLATE STAFF

*Method of working engines fitted with "Caprotti" valve gear*

Two things are absolutely essential in the working of these engines:—

FIRST, THE REGULATORS MUST ALWAYS BE FIRMLY CLOSED WHEN COASTING.

Under these conditions all the valves will fall fully away from their seatings and a full by-pass effect is obtained with the gear *in any position.* There is no necessity to move the gear to find the best coasting position.

*Coasting with a breath of steam will cause the valves to chatter, which will adversely affect their efficiency.*

Secondly, when reversing from any cut-off in fore gear, it is necessary to wind the reversing screw right back to full back gear. Similarly, when reversing from any position in back gear, the indicator must be traversed to full forward gear position.

The engine will not reverse if the gear is set in some intermediate position.

In all other respects the Caprotti valve gear can be operated in a normal manner, but to obtain the best results *work the engine as much as possible with a full open regulator.*

**Defects on the Road**

1. *Complete failure of the engine.* This can be caused by fracture of the main driving shaft or its universal joints and couplings, or defects in either the axle drive or in the cross-driver gearbox under the smokebox.

2. *Failure of one side of the engine* will arise from any defect in the cross-driving shafts or couplings between the bevel pinions in the cross-driving gearbox under the smokebox and the cambox or from a defect in one of the camboxes.

3. *Valves sticking and blowing through may be due to:—*

(*a*) Valve spindles not working freely in their guides.

(*b*) Broken valves and cages or defective valve seatings.

(*c*) Leakage or stoppage in actuating steam pipe which supplies steam from the regulator head to the underside of the valve spindle extensions.

**Questions and Answers**

(1) *Q*. What operates the valves on a locomotive?

*A*. The valves are operated by a valve gear which also incorporates an arrangement for regulating the valve travel and for reversing the engine by changing the valve's position on the port face in relation to the piston.

(2) *Q*. Name two common types of valve gears in use.

*A*. The Stephenson's link motion; Walschaert's valve gear.

(3) *Q*. Describe the Stephenson's link motion.

*A*. This type of motion (illustrated in Figs. 41 and 42) employs two eccentrics for each valve, one being used for forward and the other for backward running. The fore-gear eccentric rod being coupled to the top and the back-gear eccentric rod to the bottom of the curved expansion link, which is supported by lifting links from the reversing shaft. The links and forward ends of the eccentric rods can be raised or lowered by means of a reversing gear in the cab for regulating the cut-off and reversing.

The expansion link contains an expansion die block, which is coupled to the intermediate valve rod, but on some locomotives having inside-admission piston valves, the drive from the die block is conveyed to the valve spindle through a rocking lever which serves to alter the direction of movement of the valve in relation to the die block.

On ex-G.W.R. two-cylinder locomotives employing outside cylinders and Stephenson valve gear the valve motion is transmitted from inside the frame to the outside to actuate the piston valve by means of a "rocking shaft" (see Fig. 42). This shaft does not reverse the direction of movement of the valve and the eccentrics are set as in the case of a valve operating piston valves direct.



(4) *Q*. Explain briefly the working of this valve gear.

*A*. The forward and backward eccentrics are each mounted in their correct position on the axle to drive the valve for the corresponding direction of running, the usual setting being 90° in advance of the crank in the direction of travel to give the necessary port opening plus an angle of advance equal to about 16° to provide a movement to correspond with the lap and lead of the valve. The total advance of each eccentric is approximately 106° in front of the crank in the direction of travel.

In operating the reversing gear the expansion link is raised or lowered in order to bring the expansion die block in line with, or closer to, the backward or forward eccentric rod according to the desired direction of travel and the cut-off required. In full gear positions the expansion link die block will be either at the top or the bottom of the link, in mid gear it will be central where it is acted upon equally by both eccentrics and obtains a travel which is transferred to the valve equal to twice (lead + steam lap).

It is to be noted that the amount of lead given to the valve by the Stephenson's motion is not constant in all positions of the reversing gear. In mid-gear the lead is increased above the amount obtained in full backward or full forward gear (see Fig. 43).

(5) *Q*. Describe an eccentric.

*A*. The eccentric is a form of auxiliary crank (see Figs. 35 and 35A) used to obtain a reciprocating or to and fro movement for the valves from the crank axle or other rotating part.

It consists of a circular disc called the "sheave" which is securely fixed to the axle so that it will rotate with it. The centre of the sheave does not coincide with the centre of the axle, the distance between these two centres being the amount of eccentricity of the eccentric in the same way as the distance between the crank-pin centre and the axle centre is the "throw" of the ordinary crank.

The eccentricity of the "sheave" causes it to describe a circular path about the axle centre, and consequently the eccentric strap, which encircles the sheave and works upon its outer surface, is also caused to follow the same circular path, producing a backward and forward movement at the front end of the eccentric rod.

(6) *Q*. Describe a return crank.

*A*. The action of the return crank is similar to that of the eccentric sheave (Figs. 35 and 44). It is in the form of an auxiliary crank fitted to the main crank pin at one end and to the return crank rod at the other. The difference between the centre of the axle and centre of eccentric crank pin being the amount of eccentricity as shown.

(7) *Q*. Give a brief description of the Walschaert's valve gear.

*A*. In this type of gear (Fig. 45) the valve travel is derived from two separate points. Movement amounting to twice the lap plus twice the lead is obtained from the piston rod crosshead, giving a constant lead for all positions of the gear, the remainder of the valve travel amounting to twice the port opening is obtained from the return crank through the medium of the return crank rod, expansion link, expansion die block and radius rod. The two movements, added together at the valve spindle pin in the combination lever, produce the full travel of the valve with the reversing gear in full forward or full backward position.

When the expansion die block is in the centre of the link it is in line with the link trunnion pins and consequently no movement will be imparted to the radius rod, the reversing gear being in mid-position. In this position the valve travel is confined to the lap and lead movement obtained from the crosshead drive, the ports being open to the extent of lead only at each end of the cylinder.

Fore-gear drive for the valve is obtained by lowering the expansion die block below and backward gear by similarly raising it above the link centre.

Adjustment of the valve travel is controlled from the reversing gear by raising or lowering the expansion die block in the expansion link, regulating the amount and direction of the movement transmitted to the valve spindle from the eccentric or return crank.

(8) *Q*. Why is Walschaert's valve gear fitted to modern locomotives?

*A*. Because it possesses a number of important advantages over certain other types. It is readily adapted for use with inside or outside admission valves and for inside or outside cylinders. It is capable of providing a long travel valve which makes for better steam distribution, it only requires one eccentric crank per cylinder and is not complicated, it gives greater facility to examine all parts and is much lighter than other gears.



(9) *Q*. What special points should the Driver bear in mind when working a modern engine fitted with Walschaert's valve gear?

*A*. That the long valve travel provides the means of taking full advantage of the benefits of expansive working, so that the best results may be obtained with the regulator well opened and the gear pulled up as far as possible, whenever the conditions of working will permit.

(10) *Q*. Are cases of damaged motion or rods common on modern locomotives?

*A*. No, but a case may arise where a knowledge of failures and remedies would minimise delay to a train and perhaps save the cost of sending for an assisting engine.

(11) *Q*. How would you deal with a broken piston rod?

*A*. With this failure it is practically certain that the front cylinder cover and piston head will be damaged, but that the piston crosshead, connecting rod and valve motion remain intact. If this is the case all that would be necessary would be to disconnect the valve on that side and secure it centrally over the ports of the affected cylinder.

(12) *Q*. How would you secure the valve central over the ports.

*A*. The drive must first be disconnected from the valve spindle, which on the Walschaert's gear is readily done by uncoupling the lower end of the combination lever. Uncouple the eccentric rod at the expansion link foot and secure it with the necessary freedom clear of any obstruction—see also Answer 16.

Obtain wooden rail keys and insert the necessary amount of packing to secure the valve spindle guide blocks centrally in the guides. Firmly secure the bottom end of the combination lever as far forward as possible to clear the gudgeon pin when running. It must be noted that this prevents any movement of the reversing gear without first freeing the combination lever.

It would not be necessary to disconnect the motion on the affected side from the reversing shaft. In all cases where engine failures require the dismantling of any detail and securing of other parts the engine should be moved slowly for the first turn to ensure that everything is clear for running.

(13) *Q.* To disconnect a valve on the Walschaert's gear is it necessary to remove the whole of the motion on that side?

*A.* No, it is only necessary to take down the return crank rod and to remove the union link which connects the crosshead arm to the lower end of the combination lever. The whole of the remaining rods may be left in position, the valve spindle can be secured central over the ports in the manner described previously.

It is unnecessary in this case to uncouple the radius rod from the reversing shaft arm due to the fact that the expansion link will be left swinging free, so that the movement of the reversing shaft will not be transmitted to the valve spindle.

(14) *Q.* What can be done if the radius rod breaks with the Walschaert's gear?

*A.* Disconnect the affected valve entirely by removing the union link from the crosshead, centralise the valve over the ports and secure as previously described. Tie up the broken portion of the radius rod clear of all moving parts, but do not waste time in trying to remove them. If the engine has not far to run, the connecting rod may be left in position and the cylinder cocks left open. Lubricate the piston generously by working the mechanical lubricator by hand before starting and occasionally during the journey.

(15) *Q.* What would you do if the combination lever broke?

*A.* Disconnect the affected valve entirely by removal of the return crank rod, centralise and secure the valve as described, then proceed as in previous question when locomotive can be worked on one side to nearest Motive Power Depot.

(16) *Q.* What would you do if the return crank rod broke with the Walschaert's valve gear?

*A.* Remove the rear portion of the broken rod and tie up the front part clear of moving parts. Disconnect the affected motion from the reversing shaft and then fasten the expansion die block centrally in the expansion link by means of packing. The engine may then be worked on the remaining cylinders with the damaged side working on lead steam only.

In the event of the return crank rod being fitted with ball bearings, the return crank rod would require to be removed complete and, as the connecting rod big end is retained in position by the return crank, a special washer would be required to be fitted to the main crank pin to retain the connecting rod in position. Assistance would be required from a Motive Power Depot.

If it is an outside motion affected it should be noted that the mechanical lubricators may be put out of action if they are driven from the disconnected link and they must therefore be worked by hand.



(17) *Q.* If when running in back gear the reversing rod broke, what would occur?

*A.* In this case the motion would creep into forward gear and the effect noted in the action of the locomotive.

(18) *Q.* If this occurred what would you do to make the engine fit to proceed?

*A.* If fitted with Walschaert's gear the reversing shaft arm would have to be levered until the expansion die blocks were raised to the desired position in the links and wooden packing should be inserted in each link below the die block to support it in position. The die blocks should also be packed on the opposite side of the link to prevent any tendency to jump when running. The packing pieces should be securely tied in position with rope or cord to prevent their working out of position.

If the engine were fitted with Stephenson's link motion it would be necessary to lift the links by levering the reversing arms upward until the die blocks are set in a suitable position for running backwards and then to insert wooden packing over each die block to support the links in the desired position. It would be desirable to insert packing below the die blocks also, to prevent any tendency of the links to jump when running, allowing a small vertical movement for slip of link.

(19) *Q.* If the valve spindle were broken between the heads on an inside-admission piston valve, what would you do?

*A.* In this case the front head would be driven forward and held at the forward end of the steam chest by the steam pressure, leaving the front port permanently open to steam; probably the quickest remedy in such a case would be to uncouple the valve spindle by removal of the union link and return crank rod on the Walschaert's motion and to draw the rear portion of the valve spindle right back and secure it there in order to open the back port to steam also. This will place the piston in equilibrium with steam at equal pressure front and rear so that the removal of the connecting rod will not be necessary.

With the Stephenson link motion it will be necessary to uncouple the valve spindle by removing the valve link from the rocking or rock shaft.

(20) *Q*. How would you make the engine fit to travel under its own power with a valve spindle broken behind the valve?

*A*. In this case the valve would come to rest in its forward position, so that if it were of the outside-admission type the back port would be left open to steam, and if it were an inside-admission valve the front port would be left open. It would be necessary, therefore, to remove the connecting rod and place the piston at the end of the cylinder remote from the open steam port and to secure the piston rod in this position by packing with wood ropes to the slide bar. The back portion of the valve spindle should be pushed against the front portion and wedged in that position to prevent the valve on the port face from moving, also the valve gear, of whatever type, would have to be disconnected from the valve spindle to ensure that no movement would be imparted to the defective valve.

*Note:* The former G.W.R. four-cylinder locomotives are fitted with Walschaert's valve gear between the frames and require to be dealt with in a slightly different manner.

(21) *Q*. If one of the outside cylinder pistons became defective, would it be possible to work on three cylinders?

*A*. Yes. Disconnect the outside valve at the knuckle joint of the defective side, place piston valve central and secure the adjusting link to prevent it striking the valve spindle.

(22) *Q*. How would you uncouple one of the inside Walschaert's valve gears to make the engine fit to travel?

*A*. Take down the combination lever and anchor (guiding) link and place reversing gear in mid-gear. There are three bridle rods to these engines, one from the screw to the reversing shaft and one on each side from the reversing shaft arms to the valve gear. To complete the uncoupling it would be necessary to take down the inside bridle rod on the other faulty side, then using the same pin, couple the auxiliary shaft arm to the emergency bracket fixed on the inside of the framing.



(23) *Q*. If, when running, your locomotive suddenly lost two beats and commenced to ride somewhat roughly, but developed no blow from the chimney, what would you conclude had gone wrong and what would be your procedure under such circumstances?

*A*. I should conclude that one valve had become uncoupled due to broken valve spindle, eccentric rod or other main portion of the motion. I should at once ease the regulator, open the cylinder cocks and keeping the reversing gear as near to mid-gear as possible (providing the trouble showed no signs of becoming worse) endeavour to bring my train under protection of fixed signals before stopping.

(24) *Q*. How would you deal with a broken back-gear eccentric rod or strap with Stephenson's link motion?

*A*. If working in fore gear the quickest procedure would be to remove back-gear eccentric rod and strap, drop the reverse into fore gear, secure the link so that the locomotive cannot be reversed and proceed.

Where the lifting link is secured to centre of expansion link, the bottom of the expansion link should be secured to the motion plate to prevent it striking. If necessary to run backwards, the forward eccentric rod and strap will require to be removed, the valve disconnected and secured in mid-position and the locomotive worked on one side.

### *Other Running Gear Failures*

(25) *Q*. In the case of a broken or bent side rod, what should be done?

*A*. Take down the broken or bent rod or section of rod and the corresponding rod or section of rod on other side of the locomotive. If the front section of six-coupled locomotive's coupling rods became broken or bent all side rods would have to be taken off; similarly, if the middle section of an eight-coupled locomotive's side rod broke, all coupling rods would have to be dismantled.

(26) *Q*. For what breakdown is it necessary to take down the connecting rod and/or side rods?

*A*. Broken connecting rod, big- or little-end straps, main crank pin, crosshead guide or a defective valve which cannot be closed.

The side rods must be taken down on both sides for broken main crank pin or broken side rod pin.

(27) *Q*. What should be done if a bearing spring dropped, spring badly broken or a broken spring hanger?

*A*. Bring the train under such control in order to proceed cautiously to the protection of fixed signals where an examination can be made.

If the leading spring is broken or lost and the engine is a considerable distance from a Motive Power Depot, as quickly as possible raise the locomotive by running the second pair of wheels, on the same side, on to a suitable packing, such as a steel chisel, coal pick or fishplate placed on the rail, so that the leading end of the engine will be lifted high enough to enable a suitable piece of packing to be inserted on the top of the axlebox affected, then slowly move off the packing on the rail and proceed at reduced speed until a fresh locomotive can be obtained. By this procedure the weight is transmitted direct to the axlebox instead of through the spring. In the event of driving, or any of the other bearing, springs being affected, run the next pair of wheels on to packing on the rail and proceed as for the leading wheel spring.

(28) *Q*. When an engine or tender has been re-railed after derailment, what should the Driver be very careful about?

*A*. He should see that the springs, pins and hangers are correct and that no packing has been left on the axleboxes or underkeeps. He should also have the wheels gauged.

The tender, pony truck or bogie brasses must be examined to see that they are in their proper position and the packing or oil pads are in position.

(29) *Q*. If you discovered that your locomotive had a hot big end and that there was a risk of the metal being fused, how would you handle the engine?

*A*. I should keep a breath of steam on at all times and would even bring the train to rest with the regulator open slightly. The cut-off should be maintained as long as possible in order to maintain a more even pressure on the journal and keep the brass in contact with it.

(30) *Q*. Why should you handle the locomotive in this way?

*A*. Because, if the metal did fuse in the big-end brasses, the excessive knock might break up the bearing if the steam were shut off. In this event it is possible that one or other of the cylinder covers may be fractured. By keeping a breath of steam on, however, the moving parts are cushioned and damage to the cylinder and piston may possibly be averted.



(31) *Q*. What are some causes for knocks?

*A*. Driving or coupled wheel axleboxes worn on the bearing or between the horns, worn connecting rod and side rod bushes, worn crossheads, piston rod loose in crosshead, loose piston head, fractured frame or obstruction in the cylinder.

(32) *Q*. How may a knock be usually located?

*A*. Place locomotive on top or bottom quarter on side to be tested. Reverse from forward to back gear with the regulator open, noting the movement of the axleboxes, connecting rod and side rod bushes, crosshead and piston rod. Ensure the cylinder is not working loose on the frame.

(33) *Q*. What point do you regard as of special importance in connection with sand gear?

*A*. That the sand boxes on each side of the locomotive are filled and that the ends of the sand pipe nozzle are properly adjusted to deliver the sand between the tread of the wheel and the face of the rail. Both sanders must work simultaneously, for if only one sander is working there is a grave risk of broken coupling rods and crank pins.

(34) *Q*. Would you apply sand to the rail when the locomotive is slipping and the regulator open?

*A*. No. To avoid sudden strains on the motion the regulator must be closed and slipping have ceased before applying the sand.

SECTION 7

# LUBRICATION

Lubricating oil is used to keep the bearing surfaces apart and permit easy running and reduced wear and tear. This is brought about by forming a film or layer of oil between the bearing and shaft or between the sliding surfaces to prevent metallic contact. When oil is allowed to spread over a clean metallic surface it forms a thin film of great stability. This film may be only 100,000th of an inch in thickness, but it adheres strongly to the metal and two such films, one on each surface, slide over each other and protect the metals from contact and wear. "Oiliness" is the property of a liquid which enables it to form a powerful lubricating film when spread as a layer between the two surfaces.

When a locomotive is working, the chief kinds of motion are:—

(1) Rotating—as in axle and big-end bearings.
(2) Sliding—as in pistons, crossheads and valves.
(3) Rocking—as in parts of a valve gear and little-end bearings.

In the first of these types it is easier to maintain a fluid film as the rotation assists the distribution of the oil, but in the other two cases it is more difficult. For example, a piston slows down and stops at the end of each stroke and reverses direction; again, a small end has only a limited amount of movement. Under these conditions, which are unfavourable to the maintenance of a fluid film, we depend upon the "oiliness" of the lubricant to prevent metallic contact.

**Methods of Lubrication**

A. *Hand Lubrication*

Example: Hand brake gear, firedoor slides, screw couplings, etc.

Description: Oil is applied by a hand oil feeder daily or as required.

B. *Pad Lubrication (Worsted)*

Example: Chiefly used in underkeeps of axleboxes.

Description: The worsted pad is supplied with oil by tail feeders attached to the pad and dipping into a bath of oil in the underkeeps.

C. *Syphon Lubrication*

Example: Axleboxes, slide bars, horn cheeks, etc.

Description: The oil is fed to the bearing or surface from an oil box by means of a worsted tail trimming (see Fig. 55).



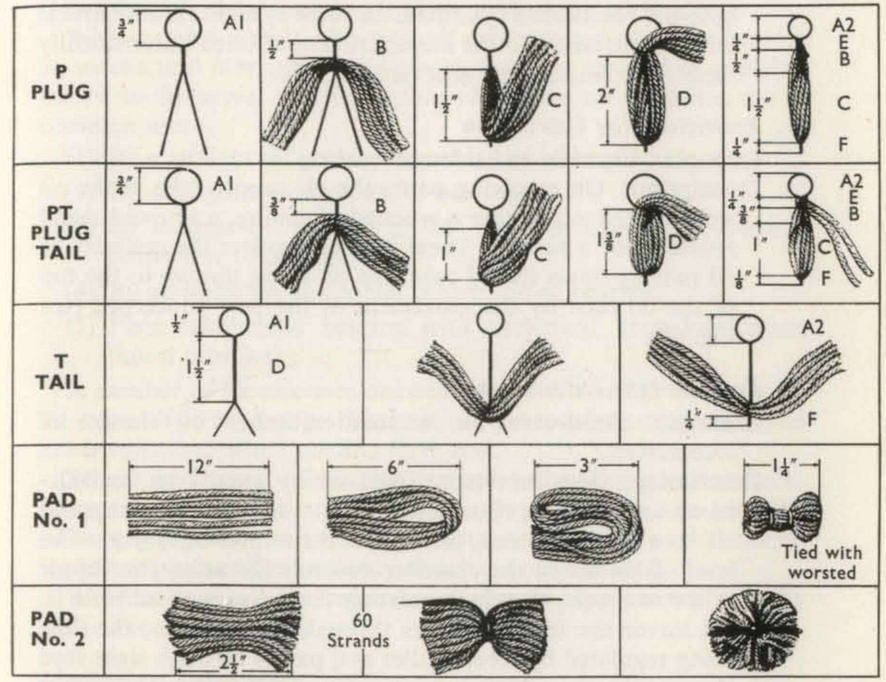



**Fig. 55 WORSTED TRIMMINGS**

**Details of Preparation**

D. *Mechanical Lubrication*

Example: Axleboxes, pistons, valves and cylinders, etc.

Description: Lubrication is effected by means of a mechanical pump (see Figs. 56 and 57).

E. *Hydrostatic Sight Feed Lubrication*

Example: Valves, pistons and cylinders.

Description: Lubricators of this type work on the principle of the displacement of oil by means of condensed steam (see Fig. 58).

F. *Atomised Lubrication*

Example: Valves, pistons and cylinders.

Description: With both mechanical and sight feed lubricators the oil is atomised with steam and sprayed through a choke before it reaches the cylinders. In some systems of mechanical lubrication, steam to the atomisers is controlled automatically from the cylinder cock gear (see Fig. 59).

G. *Restrictor Plug Lubrication*

Example: Big ends and side rod bushes.

Description: On revolving parts, the oil supply tube in the oil well is fitted with either a worsted trimming, a screwed metal restrictor or a needle. These devices regulate the quantity of oil passing down the oil tube, the oil being thrown to the top of the oil tube by the movement of the part concerned (see Fig. 60).

H. *Fountain-type Lubrication*

Example: Axleboxes on a small number of classes of locomotives.

Description: This lubricator feeds oil by gravity to the axleboxes and consists of an airtight oil reservoir which supplies oil to a feed chamber through a main shut-off valve. The level of the air in the chamber controls the admission of air to the reservoir, thereby regulating the delivery of oil from it. Oil leaves the feed chambers through drip nozzles, the flow being regulated by feed needles and passes through sight feed glasses into the oil pipes, thence by gravity to the axleboxes (see Fig. 61).

I. *Grease Lubrication*

Example: Ball and roller bearings, return crank, motion parts, brake gearings, water pick-up gearings, pony trucks, reversing screw, etc.

Description: Grease nipples are screwed into each lubricating point, being sealed with a spring-loaded valve to prevent dirt getting into the hole. A grease gun is used to force lubricant through the nipples to the point of lubrication.

**Lubrication of Axleboxes**

Locomotive axleboxes can be divided into two types, viz. (*a*) dead load bearings as fitted to bogie, pony truck, bissel trucks and tenders; (*b*) dead load-power bearings, as on the driving and coupled wheels, which in addition to taking the dead weight are also called upon to transmit a considerable proportion of the piston thrust to the locomotive frames to form the tractive force.

On modern locomotives the former type of bearing depends entirely on oil supplied by the underfeed keep pad, and care must be taken during preparation to check the underkeep oil level.



With coupled wheels, although oil can be supplied to the bearing by mechanical lubricator or trimming feed, the method of applying the oil to the actual bearing surface varies, but the following are in common use:—

(1) By a straight oil groove cut on crown of bearing.

(2) By oval groove on crown of bearing.

(3) By straight oil grooves at 45° on each side of the vertical centre line of bearing.

(4) By oil holes on horizontal centre line of bearing.

(5) Plain whitemetal bearing with underfeed keep lubrication (latest practice).

A number of locomotives are being fitted with roller bearings on all axles. The advantages of these are lower lubricating costs and lower resistance when starting from rest.

Where mechanical lubrication is employed a spring-loaded back-pressure valve is fitted on the axlebox, whose function is to keep the oil supply pipe full whilst the locomotive is standing, so that the oil supply commences immediately the locomotive moves.

With bearings as described in item (5) the oil supply is mechanically fed to the underkeep.

**Mechanical Lubricators**

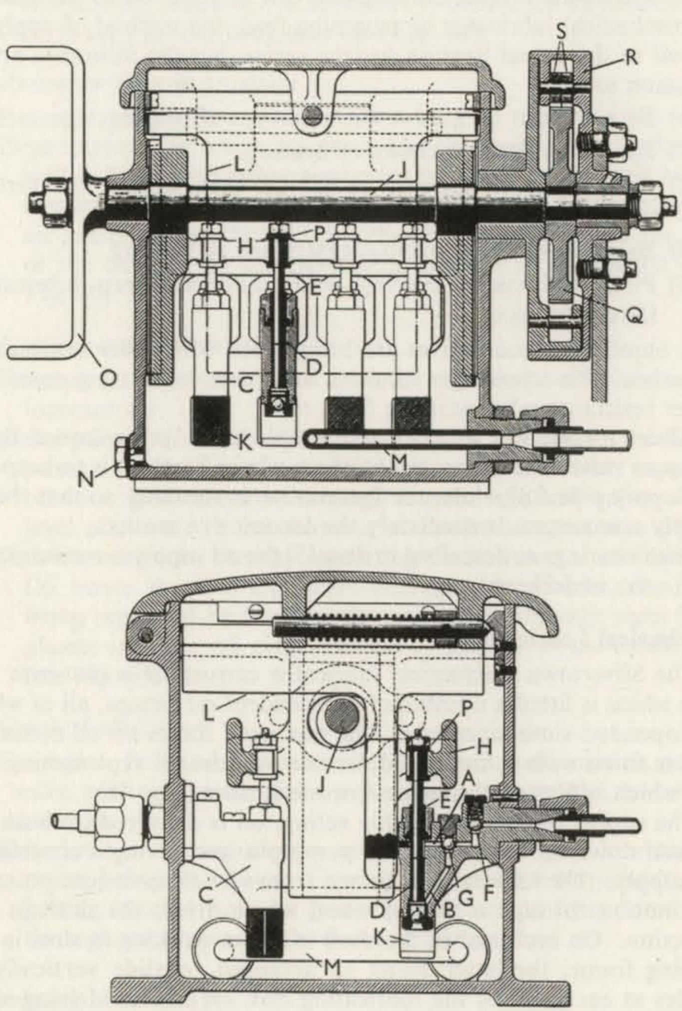
The Silvertown mechanical lubricator consists of a cast-iron box into which is fitted a number of independent oil pumps, all of which are operated simultaneously. The box itself forms an oil container and is fitted with a hinged lid for the purpose of replenishing the oil, which is filtered through a fine-mesh sieve (Fig. 56).

The supply pumps are double acting, oil is delivered on both the up and down movements of the pump plunger, giving a continuous oil supply. The lubricator is driven from some convenient point on the motion through a ratchet wheel which drives the shaft in one direction. On each end of the shaft is a cam working in slots in the driving frame, the latter being so arranged to slide vertically in guides at each end of the lubricating box. When the driving shaft revolves a reciprocating motion is given to the frame which is connected to the pump plunger by means of thimbles.

The action of the pump is as follows:—

On the upward movement of the plunger, oil is drawn via a small sieve past a ball valve, thus filling the space below the plunger. During the downward movement of the plunger the ball valve is held on its seat and the oil is forced up the passage past the ball valve, half of the oil filling the cavity on the top of the plunger and the

**Fig. 56 SILVERTOWN MECHANICAL LUBRICATOR**




A. CAVITY
B. PASSAGE
C. SUPPLY PUMPS
D. PUMP PLUNGER
E. PACKING
F. BALL VALVE
G. BALL VALVE
H. DRIVING FRAME
J. SHAFT
K. SMALL SIEVE
L. FINE-MESH SIEVE
M. WARMING PIPE
N. DRAIN PLUG
O. DRIVING SHAFT HANDLE
P. THIMBLES
Q. DRIVING WHEEL
R. FIXED WHEEL PLATE
S. PAWL



remaining oil being forced past the ball valve into the lubricating system. It will be seen that on the upward movement, in addition to the oil being drawn into the lower passages of the pump, the oil remaining in the cavity is also forced past the ball valve, during which operation the ball valve is held on its seat. Special packing is provided to prevent leakage of oil from the top side of the plunger.

The rotary movement of the shaft is obtained by six spring-loaded pawls fitted to the outer case of the ratchet box and engaging in teeth on the outside edge of the driving wheel which is keyed to the main shaft, so that when the case is moving in one direction the driving wheel is rotated, but in the return direction is held in position by means of the six retaining pawls provided in the fixed wheel plate.

Each pump feeds approximately 2 oz. per 100 miles.

On the opposite end of the driving shaft a handle is fitted which can be turned by hand to operate the pump independent of the action of the locomotive. This handle should be rotated a few times before leaving the shed.

These lubricators can be used to supply oil to the axleboxes or to the cylinders. When used for the latter purpose, as a thick oil is used for cylinder lubrication, it is necessary to provide means for preventing the oil from congealing in cold weather and this is achieved by fitting a warming pipe through which a supply of steam is passed. This supply of steam can be cut off during the summer weather. When necessary the oil can be drained from the lubricator through a drain plug.

**Hydrostatic Displacement Lubricator**

The principle of the hydrostatic displacement lubricator is the utilisation of condensed steam from the condenser coil, which on entering the oil reservoir displaces the oil causing it to overflow into the feed passages. Oil is controlled by the oil-regulating valve and, after passing this point, it rises through the water in the sight glass into a delivery chamber from which it is carried by steam through the lubricator pipes to the choke which is inserted in the lubricator pipe near the delivery point on the main steam pipes. The choke plug gives a constant resistance to the lubricator and so prevents the feed being affected by variations of pressure in the steam chest.

On the former G.W.R. locomotives the oil is atomised by passing through a small orifice from the delivery chamber.

The usual rate of feed should be two to three drops per feed per minute, according to the class of work performed.

A Detroit hydrostatic lubricator is shown in Fig. 58. This is a four-feed lubricator and the working instructions are as follows:—

To fill: Turn oil control valve to closed position. Shut water valve and steam valve, open the drain plug in order to empty water from oil reservoir and release pressure, next remove filling plug slowly. (The reason for removing this plug slowly is to allow any pressure which may have built up in the reservoir to escape past the threads.) Close the drain plug and fill reservoir with clean oil; if there is insufficient oil on hand use water to fill reservoir completely. (Some lubricators of this type are not fitted with oil control valve; in this case when filling close all feed regulating valves.)

To start: Fully open the steam valve and allow three or four minutes to elapse in which to fill the condenser and sight feed glasses with water, then fully open water valve, turn oil control valve to "open" position and regulate the oil feed valves.

To shut down lubricator: For short stops shut down oil control valve only; for long stops close oil control valve, water valve, and lastly steam valve.

*Note:* Always start the lubricator ten minutes before leaving the shed.

## Fig. 57 WAKEFIELD MECHANICAL LUBRICATOR

**No. 7 Pattern**

### HOW THE LUBRICATOR WORKS

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** decreased the oil pumped by one-fifth as follows:—

| | |
|---|---|
| Plug **G** screwed right down | = full feed. |
| Plug **G** screwed one turn out | = four-fifths feed |
| Plug **G** screwed two turns out | = three-fifths feed |
| Plug **G** screwed three turns out | = two-fifths feed |
| Plug **G** screwed four turns out | = one-fifth feed |
| Plug **G** screwed five turns out | = feed cut off |

### TO OPERATE

When starting the Lubricator for the first time when newly fitted—

(1) See that each of the oil regulating plugs **G** is screwed right down.
(2) Fill the oil reservoir, taking care to pass the oil through the strainer.
(3) Open the oil-test plug on the combined check valve and oil-test plug.
(4) Work the Lubricator by turning the flushing wheel until the oil is seen at the oil-test plug.
(5) Close the oil-test plug and work the Lubricator a few more times to make sure that the oil-delivery pipes are quite full.

The above operations are essential when the lubrication is first fitted up. The lubrication system is then in working order.

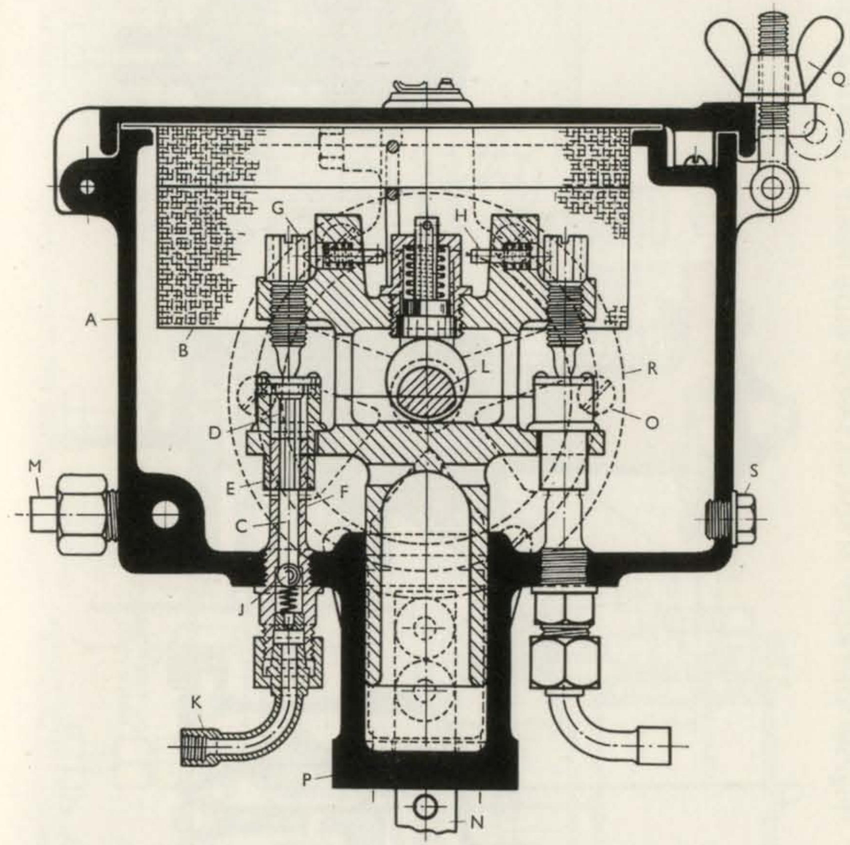
It is advisable before leaving the shed, with the engine going into traffic, to



examine the test plugs and make sure the oil is there by giving the flushing wheel a few turns.

The level of the oil in the reservoir must never be allowed to fall below the ports **F** in the pump barrels or no oil will be delivered.

The oil MUST pass through the sieve. It is advantageous to WARM the cylinder oil before filling the lubricator.

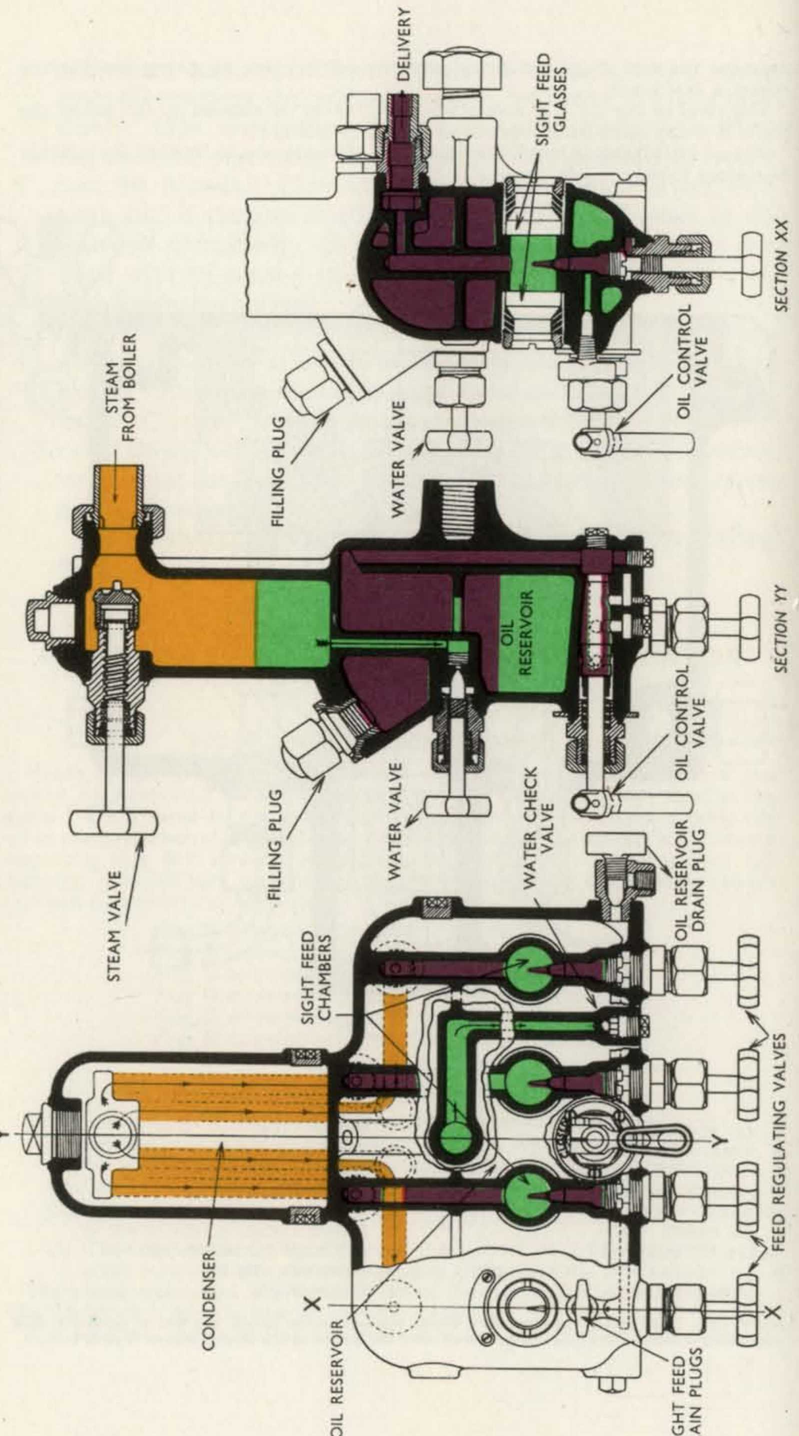



*SECTIONAL ELEVATION*

A. OIL RESERVOIR
B. WIRE GAUZE STRAINER
C. PUMP BARREL
D. PUMP PLUNGER
E. SLEEVE VALVE
F. OIL PORTS
G. OIL REGULATING PLUG
H. OIL REGULATING LOCKING PEG
J. NON-RETURN VALVE
K. OIL OUTLETS
L. DRIVING ECCENTRIC SHAFT
M. OIL WARMING PIPE
N. DRIVING ARM
O. RATCHET DRIVE AND GEAR CASE
P. FIXING LUGS
Q. FLY BOLT TO SECURE LID
R. FLUSHING WHEEL
S. DRAIN PLUG

*NOTE.*—No. 7 (a) pattern operates in a similar manner to the above, but the oil outlets K lead out from the sides of the oil reservoir, level with the centre of the driving eccentric shaft L.

Fig. 58 DETROIT HYDROSTATIC SIDE FEED LUBRICATOR







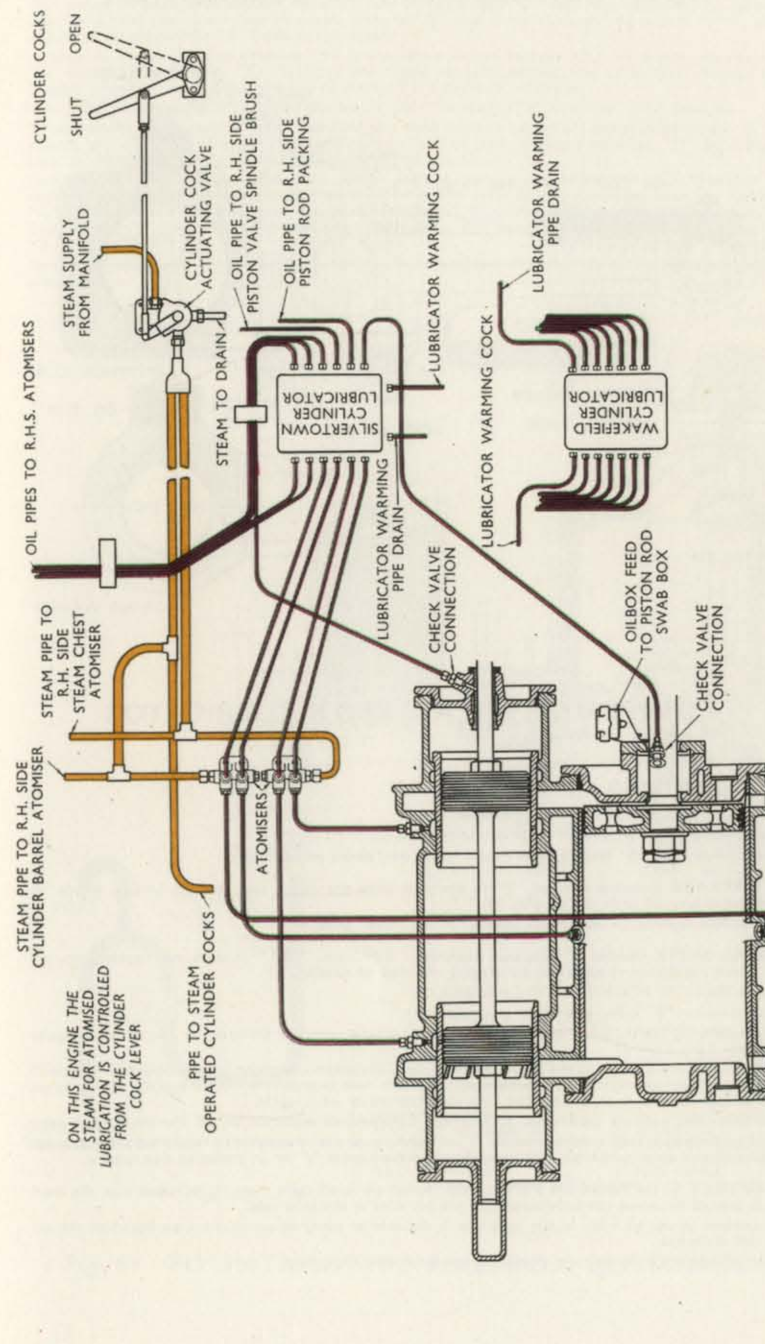
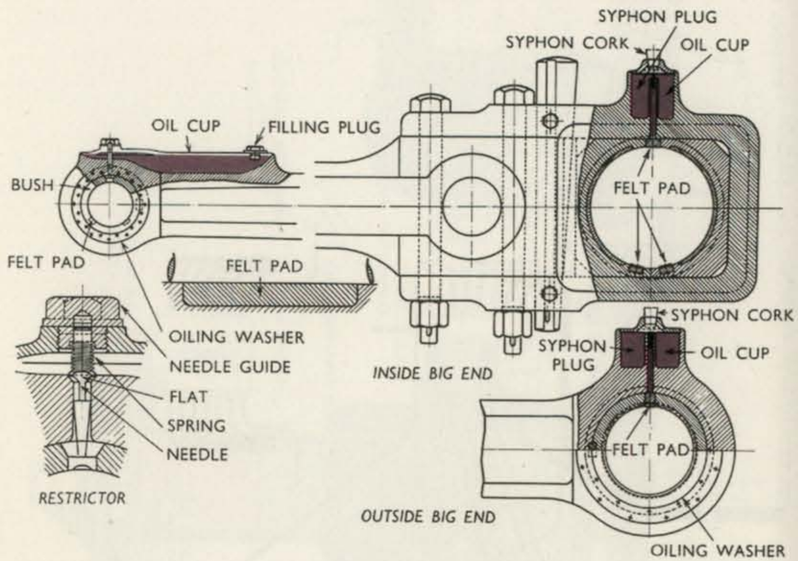




Fig. 59 ARRANGEMENT OF ATOMISER LUBRICATION

## Fig. 60 CONNECTING ROD LUBRICATION




## FOUNTAIN-TYPE AXLEBOX LUBRICATOR

### INSTRUCTIONS FOR OPERATING

**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 air tight.

**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 on 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 Axle-box heat, remove needle "J" of the Axle-box feed concerned to temporarily increase 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 Axle-box.
Air inlets should be periodically examined 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."

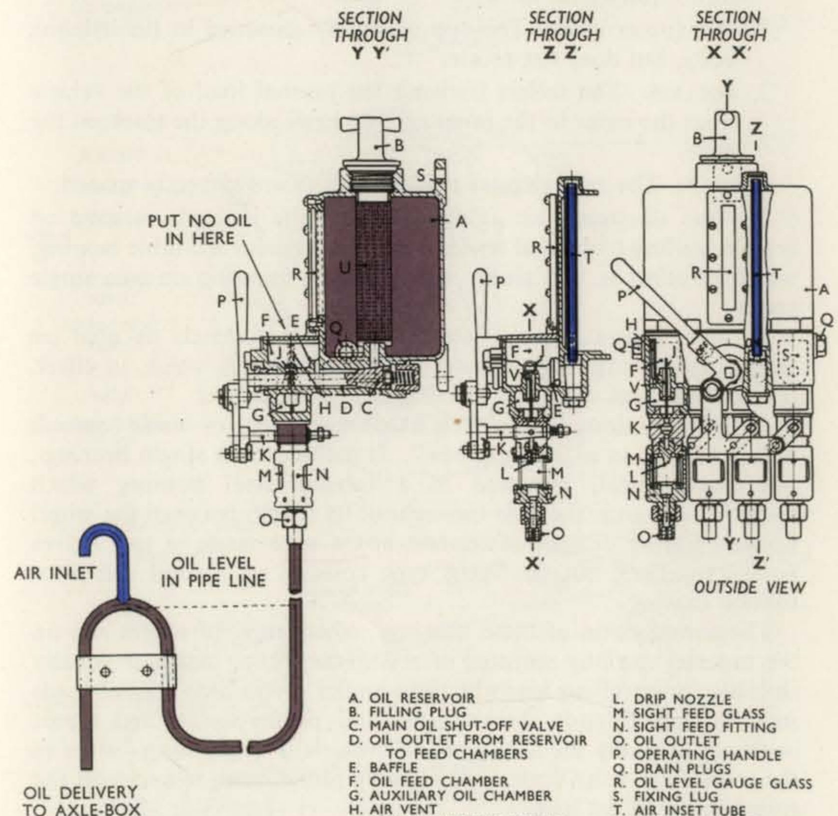
As soon as the oil level in chamber "F" drops below top of passage "D," air enters the reservoir "A" through the air tube "T," destroys the partial vacuum, permits the oil to flow through until it again rises to a level above the top of passage "D" and cuts off the air.

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, due to variation of temperature in reservoir "A."

By strictly observing the above instructions, an appreciable economy in oil consumption will be effected.




A. OIL RESERVOIR
B. FILLING PLUG
C. MAIN OIL SHUT-OFF VALVE
D. OIL OUTLET FROM RESERVOIR TO FEED CHAMBERS
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
Q. DRAIN PLUGS
R. OIL LEVEL GAUGE GLASS
S. FIXING LUG
T. AIR INSET TUBE
U. WIRE GAUGE STRAINER
V. FEED NIPPLE

**Fig. 61 FOUNTAIN-TYPE AXLEBOX LUBRICATOR**

### Roller Bearings

With a view to obtaining economies brought about by more trouble-free running and increased mileages between shop repairs, roller bearings are being fitted to locomotives in increasing numbers, especially to axlebox bearings.

### Roller-bearing Axleboxes

Fig. 62 illustrates typical inside and outside journal roller-bearing axleboxes. The bearings used in these axleboxes consist of four main components as follows:—

1. CONE (inner race). The cone is pressed on the axle and therefore rotates with the axle.
2. CUP (outer race). The cup is loosely mounted in the axlebox body, but does not rotate.
3. ROLLERS. The rollers transmit the journal load of the vehicle from the outer to the inner race and roll along the track on the cone.
4. CAGE. The cage ensures that the rollers are correctly spaced.

*A*. This illustrates an axlebox for outside journals as used on certain trailing truck and tender axles. It includes a double bearing, which in effect is two single sets of rollers running on two single cones.

*B*. This illustrates an axlebox for outside journals as used on certain tender axles. It includes a double bearing, which, in effect, is two single sets of rollers running on a double cone.

*C*. This illustrates a cast-steel axlebox as used for inside journals and is known as a "cannon box". It includes two single bearings, one per journal, mounted in a tubular steel housing which entirely surrounds the axle throughout its length between the wheel bosses. Earlier designs of cannon boxes were made in two halves bolted together, but the latest type consists of a solid one-piece tubular casting.

The construction of these bearings, where tapered rollers run on the tapered working surfaces of a cone and cup, makes it equally suitable for handling loads at right-angles to the axle (radial loads such as spring loads, brake loads and piston loads) and thrust loads set up along the axle when the vehicle is negotiating curves in the track. Only the upper rollers carry radial load, whereas all the rollers carry thrust load.

The bearings are lubricated by oil which is automatically circulated in the axlebox by the action of the tapered rollers. Oil level, which is checked with a gauge, should be topped up with the correct grade of oil when the level is down to the lower mark on the gauge.



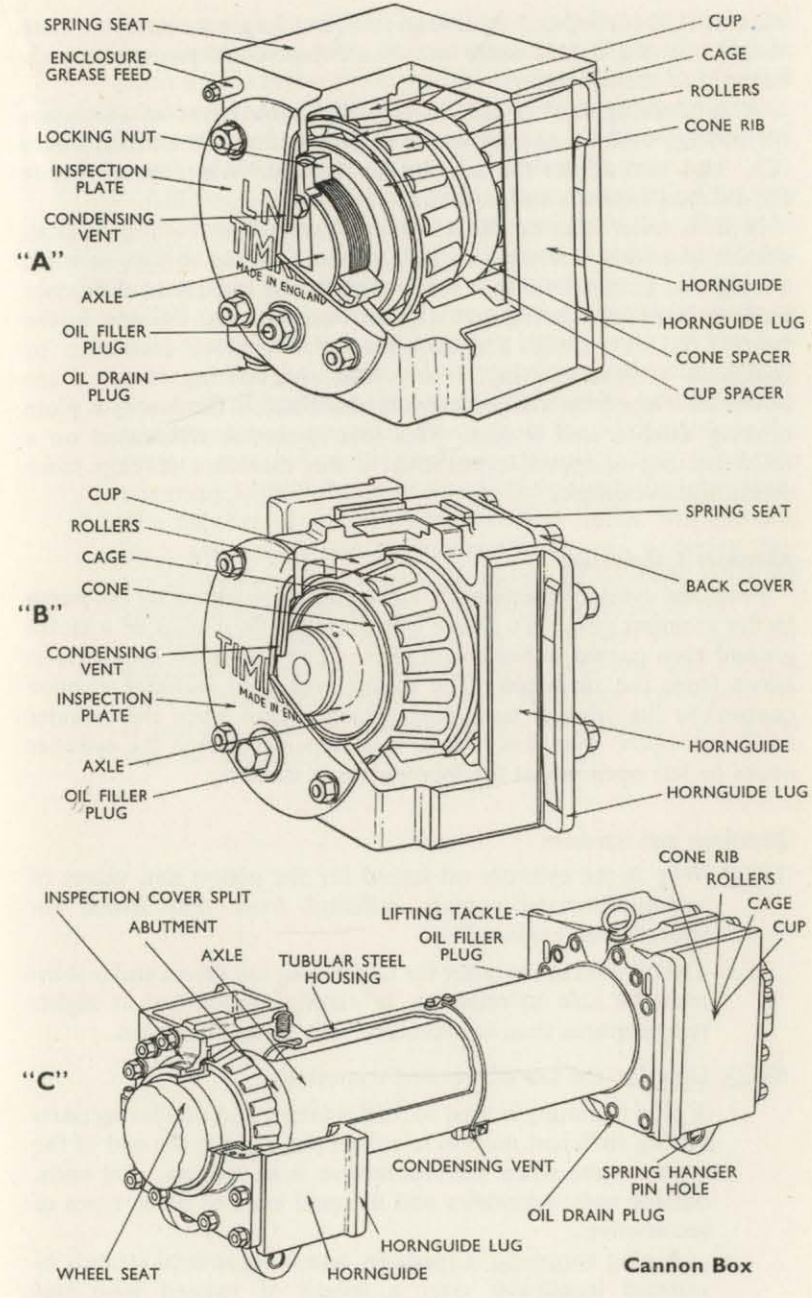



**Fig. 62 TYPES OF ROLLER-BEARING AXLEBOXES**

This work is carried out by artisan staff, but Enginemen should note that the entry of dirt or water into the axlebox would prove extremely harmful to the bearings.

A condensing vent is cast in the inspection cover of axleboxes (A and B), whilst a condensing vent pipe is fitted to cannon boxes (C). This vent allows the axlebox to "breathe" when the air inside the axlebox expands and contracts.

With a roller bearing the loads are handled on rolling surfaces similar to a wheel rolling on a rail, not on a sliding surface as when a weight is dragged along a road. This is the important difference between a roller bearing and a plain bearing. The friction in the bearing is very small and therefore the tractive resistance or resistance to free running is very low. At starting some of the power developed by a locomotive is absorbed as friction in a plain bearing axlebox and is lost. This loss is almost eliminated on a roller-bearing-equipped locomotive; it can therefore develop more useful tractive effort.

### Atomiser Lubrication

From the cylinder mechanical lubricator oil is forced by the pump to the atomiser (Fig. 59), where it is atomised by means of a steam jet and then passed to the steam chest. The steam for atomisers is taken from the manifold. The steam pipe also includes a valve coupled to the cylinder cock gear, which is shut when the cylinder cocks are open. For this reason it is imperative that the cylinder cocks be left open whilst the locomotive is standing.

### Questions and Answers

(1) *Q*. Why is the cylinder oil issued for the piston and valves of non-superheated engines different from that issued for superheated engines?

*A*. The oil used in the latter for lubricating the valves and pistons must be able to retain its lubricating properties at higher temperatures than is necessary with saturated steam.

(2) *Q*. Describe the use of worsted trimmings.

*A*. A plug trimming is used to feed rotating and oscillating parts having sufficient motion to splash the oil over the end of the syphon tube when the locomotive is in motion. Big ends, outside rods, eccentrics and in small ends of older types of locomotives.

A plug trimming is made by wrapping several strands of worsted lengthwise over a length of twisted wire and forming a plug, which should be a comfortable fit in the syphon tube, and when in position the top of the plug should reach a little below the top of the syphon tube to form a well to accommodate a small quantity of oil above the trimming. The extreme length of the plug should be shorter than the length of the tube to obviate it touching the bearing.

Although, within certain limits, the amount of oil fed will vary according to the number of strands in the plug, care must be taken to adhere to the standard as too many strands may restrict the passage of oil to the bearing.

Tail trimmings are used for non-rotating parts such as axleboxes, piston and valve spindle glands, etc., and they are made of the same material as plug trimmings, the strands being left of sufficient length to fit the syphon tube and hang into the oil box to syphon the oil from the oil chamber to the syphon tube when in position, the oil falling from the trimming in the tube by gravity to the point to be lubricated. The number of strands, within certain limits, will increase the supply of oil with the increase in strands, provided they are kept clean. Tail trimmings should be removed from the syphon tube, when not required, to avoid waste of oil.

Other trimmings in the form of a pad are used for expansion die blocks, expansion link pins and side blocks; these pads being saturated with oil each time the locomotive is prepared, the oil lubricating the part slowly during the time of working.

SECTION 8

# BRAKES

The function of the brake is to absorb by friction the momentum of the train; in other words, the energy stored in the moving train is converted to heat at the brake blocks when the brakes are applied.

In the working of freight and mineral trains not made up of power-braked vehicles, the braking of the train is dependent upon the brakes of the locomotive together with the screw hand brake on the guard's brake van, supplemented on certain sections of the line, where there are severe gradients, by stopping the train and applying the hand brake on a number of vehicles before descending the incline.

For the working of passenger trains it is necessary, in order to comply with an Act of Parliament passed in 1889, that (1) the brake on the train should be continuous and capable of being applied to every vehicle of the train; (2) be instantaneous in action and capable of being applied by Driver and/or Guard; (3) be self-applying in the event of the train becoming divided.

These conditions are fulfilled by the two main braking systems in common use to-day, namely, the "automatic vacuum brake" and the "Westinghouse automatic air brake".

The "automatic vacuum brake" is used almost exclusively on steam-hauled trains in this country and makes use of the atmospheric pressure.

The system consists essentially of an exhausting device on the engine known as the vacuum ejector, which has a large ejector used to create quickly the regulation amount of vacuum in the train pipe, connections and reservoir and both sides of the brake cylinder pistons throughout the train, together with a small ejector to maintain the vacuum. Some locomotives are fitted with a vacuum pump which serves a similar purpose to the small ejector.

The pressure of the atmosphere is approximately 15 lb. per sq. in. and the vacuum is measured in inches of mercury. A perfect vacuum corresponds to approximately 30 in. of mercury, i.e. 0 lb. per sq. in. pressure. This varies slightly with the atmospheric pressure as measured by a barometer. Therefore, it will be evident that each 2 in. of vacuum represents approximately 1 lb. per sq. in. of atmospheric pressure.

The regulation vacuum for working the brakes is 21 in. on all Regions except the former G.W.R., where the amount is 25 in.



To apply the brakes, air is admitted to the train pipe and train pipe connections so that the vacuum on the lower side of each brake piston is partially or completely destroyed. The vacuum on the reservoir and upper sides of the brake pistons, however, is retained, being sealed off by a ball valve.

In a normal application of the brakes the Driver can admit the desired amount of air to the train pipe by way of the ports in the Driver's application valve, the quantity of air admitted regulating the power of the application. Full power is utilised when the vacuum in the train pipe is totally destroyed.

Some arrangements of the automatic vacuum brake are worked in conjunction with steam brakes on the engine and tender or in conjunction with the steam brake on the engine only and vacuum brake on the tender.

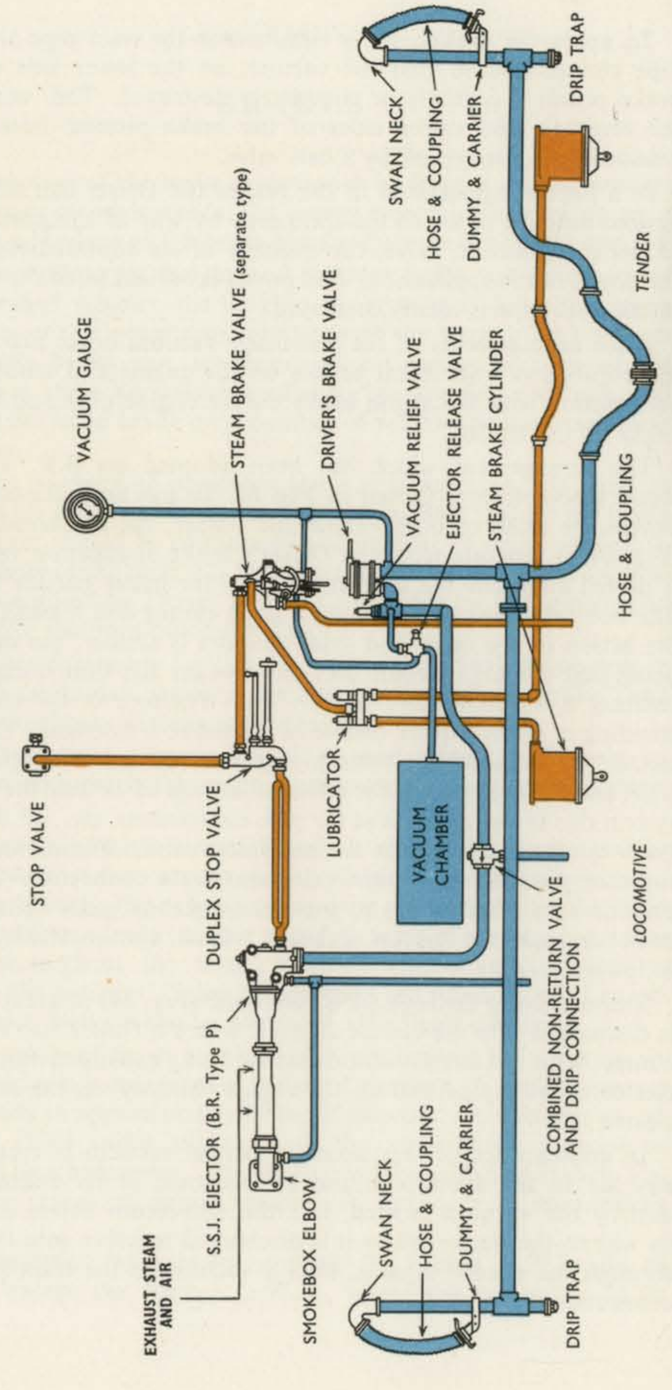
The arrangement which has been adopted on B.R. standard steam locomotives is shown in Fig. 63. In this arrangement steam brakes are fitted to both engine and tender, the combined ejector (Fig. 64) is separate from the Driver's brake application valve and is placed alongside the left-hand side of the boiler outside the cab. The body contains two ejectors, a large ejector and a small ejector, the action of the large and small ejectors is similar, the difference being that the large ejector uses more steam and thus is capable of creating a vacuum more quickly and therefore is for use when standing or when a quick release of the brake is essential. The small ejector is provided for maintaining the vacuum throughout the train and for overcoming the effect of leakage of air into the vacuum system due to faulty joints at the pipe connections, etc., on the train. Each ejector is fitted with a non-return valve. These two valves, together with the non-return valve and drain connection (Fig. 63), provide an air lock so as to prevent smokebox gases being drawn back through the ejector exhaust. Each ejector works in the following manner:—

Steam passing through the steam cone (Fig. 64) at great velocity is discharged into the ejector air cone where it comes into frictional contact with the air, the steam and air being exhausted through the ejector exhaust pipe and up the engine chimney via the smokebox elbow.

In consequence of this action a partial vacuum is created and any air in the train pipe and connections, in its endeavour to destroy the vacuum created, lifts the non-return valves and finds its way to the ejector where it is discharged together with the steam through the ejector exhaust, thus a vacuum in the train pipe and connections is created.

Fig. 63 GENERAL ARRANGEMENT OF VACUUM AUTOMATIC BRAKE ON ENGINE AND TENDER

B.R. Standard Arrangement







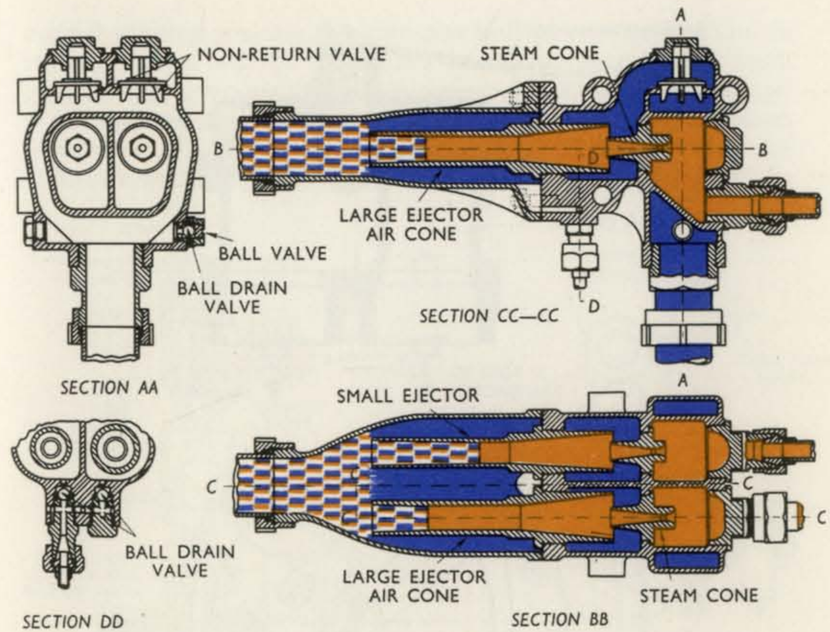




**Fig. 64 S.S.J. EJECTOR**

Under each ejector, ball drain valves are provided; whilst the ejectors are in use the ball is forced to its seating, preventing air entering; when the steam supply is shut off, the ball falls away from the seating and allows any condensation to drain away. A ball valve is provided so that in the event of leakage taking place in either of the non-return valves, the ball valve will open to the atmosphere and smokebox gases will not be drawn back through the ejectors when they shut off, but the vacuum maintained in the train pipe.

*Driver's brake application valve* is shown in Fig. 65 and is designed to admit air into the train pipe so as to reduce or destroy the vacuum. It has only two handle positions, "off" and "on".

*Vacuum-operated graduable steam brake valve.* This arrangement is shown in Fig. 66 and is designed to admit steam to the steam brake cylinders as the train pipe vacuum is reduced or destroyed and to release the steam from the steam brake cylinders as the train pipe vacuum is restored; in action the brake is applied on the engine and tender slightly later and released slightly earlier than the vacuum

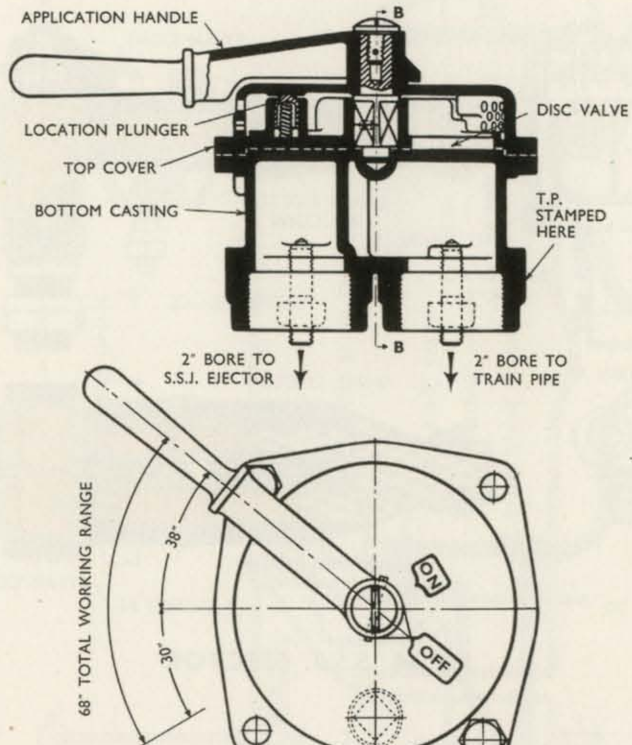



**Fig. 65 DRIVER'S BRAKE APPLICATION VALVE**

**B.R. Standard Locomotive**

brake on the train in order to minimise bunching of the carriages and strain on the engine and tender draw-gear; moreover, the pressure of steam in the steam brake cylinder is proportional to the amount by which the vacuum in the train pipe is reduced.

*Vacuum relief valve.* This is provided to prevent the regulation vacuum being exceeded (see Fig. 63). It consists of a spring-loaded valve which lifts and allows air into the train pipe if the ejectors create more than 21 in. of vacuum (25 in. in the case of the former G.W.R.).

*Operation.* The operation of brake arrangement as fitted to B.R. standard locomotives (see Fig. 63) is as follows: when in the



normal running position the train pipe will be registering 21 in. of vacuum, which will be maintained at this amount by the small ejector. Any over-creation which the small ejector might manage, if not satisfactorily adjusted, will be taken care of by the vacuum relief valve. There will be the normal train pipe vacuum below the vacuum cylinder piston (Fig. 66) due to the direct connection of the

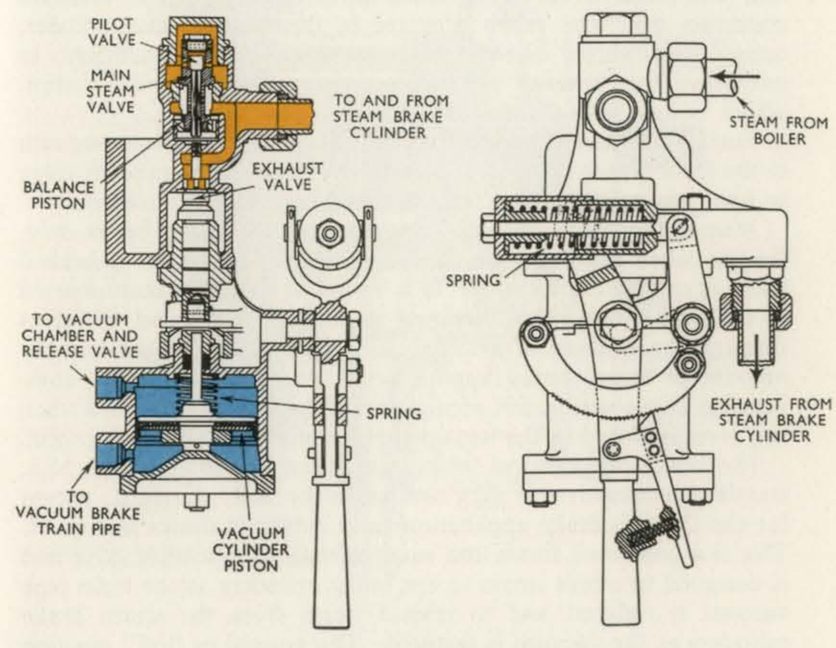



**Fig. 66 VACUUM-OPERATED GRADUABLE STEAM BRAKE VALVE**

**(Mark IV)**

bottom of the vacuum cylinder to the train pipe. On the upper side of the piston there will also be a normal vacuum due to the connection of the upper portion of the piston with the vacuum chamber through the ejector release valve, and the piston will be at its lowest position due to the action of the spring. Steam at boiler pressure is supplied to the chamber above the two valves and the steam brake cylinders are empty of steam, the cylinders being open to atmosphere past the exhaust valve.

When the Driver's brake valve is moved towards the "on" position, the vacuum in the train pipe is reduced due to air being admitted through the brake valve. This also admits air to the underside of vacuum cylinder piston which moves upward, causing the steam brake cylinder exhaust valve to close. Further movement next raises the pilot valve to admit steam below the balance piston which causes it to lift, thus allowing the main steam valve to open and pass steam direct to the steam brake cylinder. This condition continues until the steam pressure in the steam brake cylinder, acting downwards on the exhaust valve, is just sufficient to overcome the upward pressure on the vacuum cylinder piston, which is then forced down until the valves close.

Further downward movement of the air piston, when the vacuum in the train pipe is re-created, permits the steam brake exhaust valve to open and release steam from the brake cylinders to exhaust.

*Manual Operation.* Manual operation of the steam brake only, for use when running light engine or when working an unbraked train, is carried out by means of a lever and quadrant incorporated in the brake unit. The operating lever gives movement to valves through the medium of a compression spring so arranged that the amount of steam brake application is proportional to the compression of the spring, full application of the brake is obtained when this lever is placed in the last notch, the spring box then being solid.

The brake arrangement which was fitted to the former L.M.S. standard locomotives is very similar to the B.R. standard, except for the Driver's brake application valve, which is shown in Fig. 67. This is a combined steam and vacuum brake application valve and is designed to admit steam to the brake cylinders as the train pipe vacuum is reduced and to release steam from the steam brake cylinders as the vacuum is restored. The normal or "off" position is when the small ejector is in operation and a vacuum is maintained in the train pipe and on the inner side of the air piston, the opposite side of the air piston being under atmospheric pressure entering through the hollow piston rod, the air pressure holding the piston in the "in" position which, through the fulcrum lever, maintains the steam brake supply plug in the closed position and at the same time allows the exhaust passage and ports to be in communication with the pipe to the steam brake cylinders.

A movement of the application valve handle to the "on" position admits air into the train pipe through the holes in the application valve disc and to the inner side of the air piston, the air piston then being in equilibrium, the steam behind the steam plug exerts a pressure, forcing the steam plug out. The movement of the steam plug spindle closes the passage and ports, preventing the steam



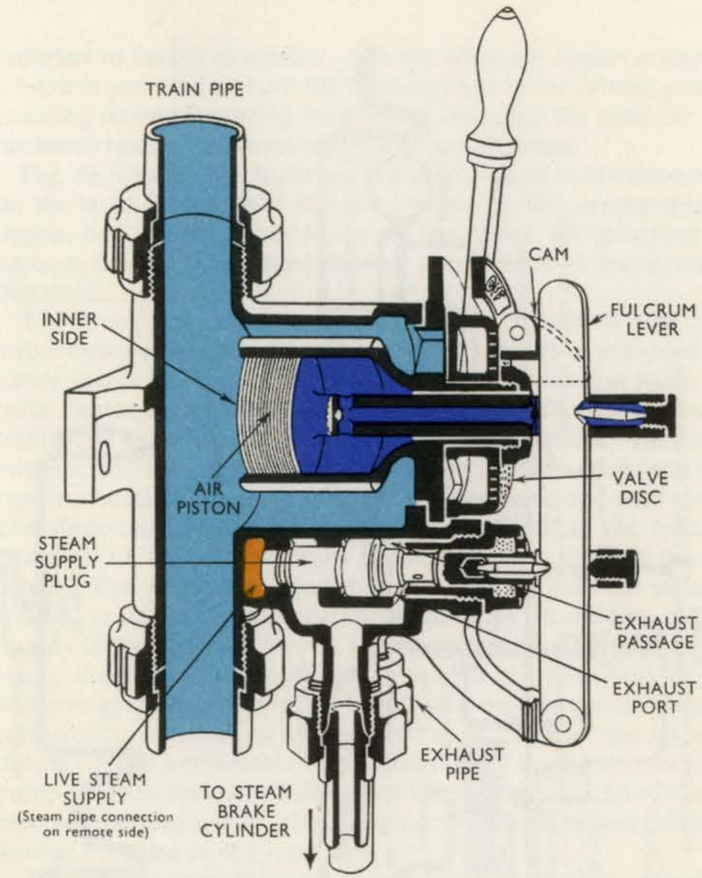



**Fig. 67 DRIVER'S BRAKE VALVE**

passing out to exhaust and at the same time, through the fulcrum lever, forces the air piston out. Steam from the plug passes down the steam pipe to the engine and tender steam brake cylinders. A cam, which is part of the application valve disc, ensures the positive movement of the lever to open the steam plug as the vacuum is being destroyed.

Replacing the application valve to "off" position, the vacuum will be restored in the train pipe and inner side of the air piston. The atmospheric pressure acting on the outer side of the air piston will exert a pressure to force the piston in and through the fulcrum lever, close the steam plug, and allow the steam in the steam brake

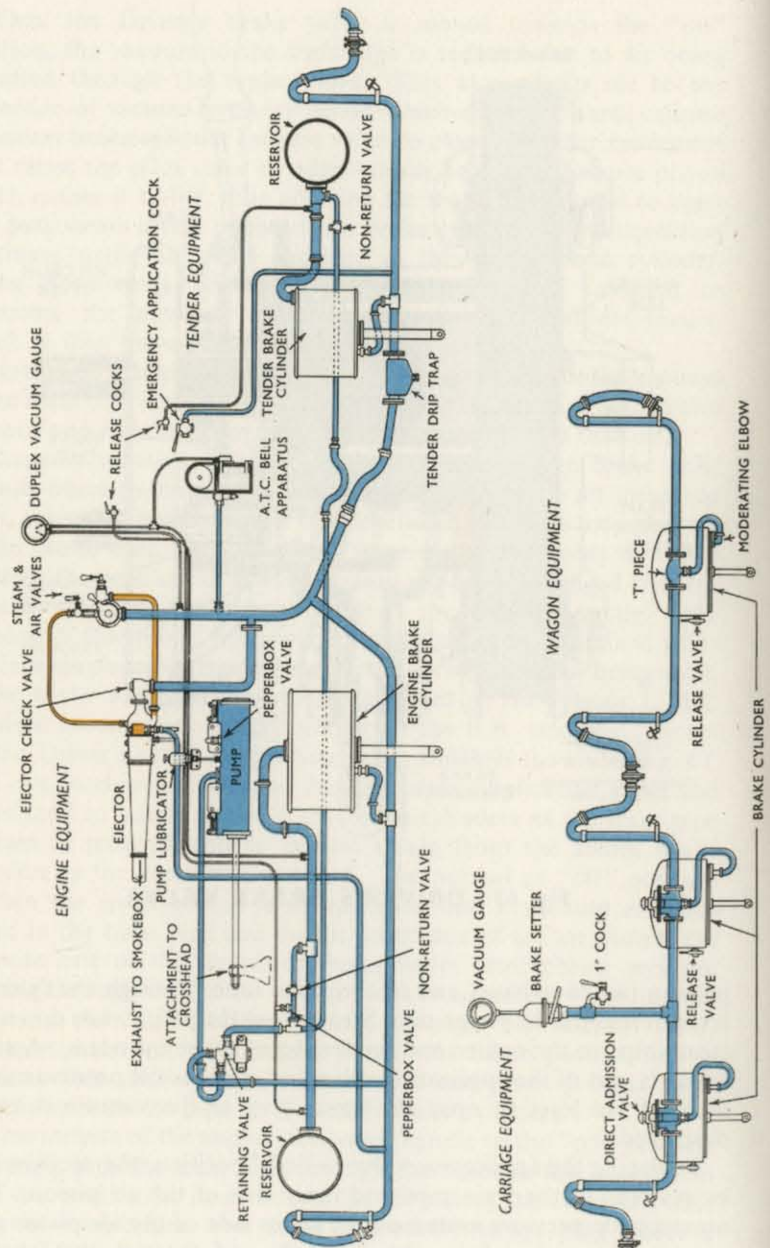



**Fig. 68 BRAKE ARRANGEMENT ON ENGINE AND TENDER**
**Former Great Western Railway**





cylinders to escape to exhaust. For use when the engine is standing, a hook is provided to hold the fulcrum lever in the inward position, ensuring steam plug being held closed, avoiding the need for using the small ejector and resulting in a saving of steam.

Fig. 68 illustrates a brake arrangement which is in common use on the large former G.W.R. locomotives. In this arrangement the engine and tender, in addition to the train, are provided with vacuum brakes. The arrangement is very similar to that previously described.

The four-cone ejector is located on the right-hand side of the boiler outside the cab. The steam to the ejectors is provided from steam valves located on the Driver's brake application valve. The main ejector steam valve supplies steam to the three cones and the small valve supplies steam to the remaining single cone. The vacuum pump is provided to maintain the vacuum when running, and this is supplemented as necessary by the single-cone ejector (small ejector). The three-cone ejector (large ejector) is coupled to the train pipe extension to the Driver's brake application valve through the check valves. The single-cone ejector (small ejector) and the pump are coupled to the train pipe at the front end of the locomotive, the latter by way of the retaining valve. The arrangement of these pipes is the result of protracted experiments to obviate the possibility of water which might accumulate in the flexible train pipe connections through condensation caused by the admission of air into the train pipe during cold or wet weather. The action of the small cone ejector and pump tends to draw any moisture towards the front end of the train pipe on the locomotive, thus keeping the moisture away from the flexible coupling of the train pipe.

The vacuum pump (Fig. 69) consists of a piston which reciprocates

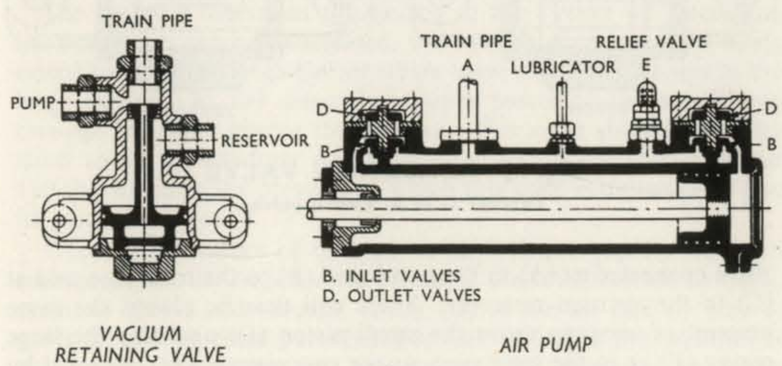



**Fig. 69 VACUUM PUMP**
**Former Great Western Railway Locomotives**

in the cylinder, being driven directly from one of the locomotive piston crossheads. A chamber extends above the cylinder and flat clack valves (B) are fitted between the chamber and the cylinder, one at each end. Similar flat clacks (D) are also fitted at each end of the cylinders which lift to provide access to the atmosphere. Train pipe (A) provides communication to the retaining valve.

As the piston travels from the left-hand cover air is induced from the chamber and pipe (A), past clack (B), clack (D) being held on its seating by the pressure of the outside atmosphere. On the return stroke the air previously induced into the cylinder is expelled from the cylinder past clack (D) into the atmosphere, valve (B) being held on its seating by the air being expelled. The pump is double acting so that when air is being induced from the train pipe on one side of the piston, the air induced during the previous stroke is being expelled at the other side.

The retaining valve is shown in Fig. 70. Position 1 shows the

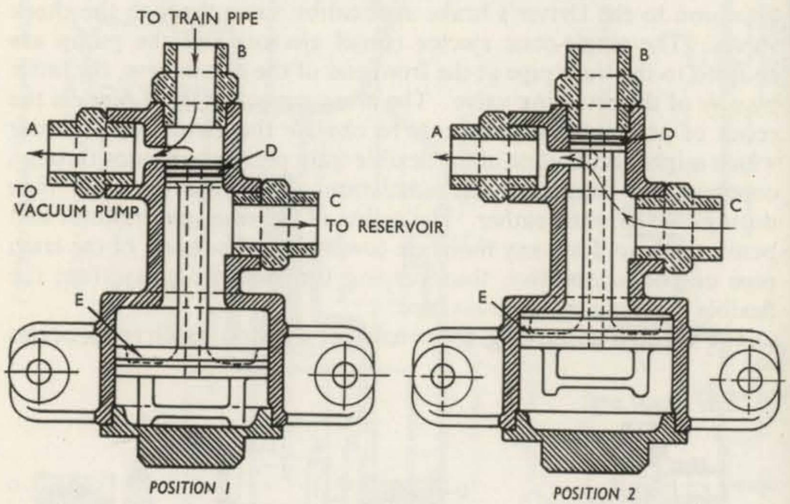



**Fig. 70 RETAINING VALVE**
**Former G.W.R. Locomotives**

valve connected at (A) to the pump and (B) to the train pipe and at (C) to the vacuum reservoir. There will thus be always the same amount of vacuum above the small piston (D) and also the large piston (E) as in the train pipe, as the two pistons are connected by means of a hole through the piston rod. In the space between the



piston heads there will be the same amount of vacuum as in the reservoir. When running, air is extracted from the train pipe by the vacuum pump.

When the brake is applied air enters the train pipe and then flows underneath the large piston (E) and raises the pistons to the position shown in *Position* 2. It will be noted that the piston (D) seals the passage (B) and being raised above the passage (A) opens communication between the latter and the passage (C), and the effect of the pump being transferred to maintaining the vacuum in the reservoir.

The vacuum relief valve or pepper-box valve on the connecting pipe prevents the vacuum in the reservoir from rising to an excessive amount and preventing the brake pistons from returning to their normal position when the brake is released. The relief valve is set to lift at 23 in. vacuum.

Returning to Fig. 68, when the brake is applied air is admitted to the train pipe and from there to the undersides of the brake pistons on the engine, tender and train. This action of the retaining valve transfers the effect of the pump to the reservoir side of the brake cylinders, therefore maintaining the reservoir vacuum.

When the brake is released the single-cone ejector should be used, whereas the three-cone ejector (large ejector) should only be used when it is necessary to create the vacuum quickly. By avoiding the use of the three-cone ejectors a considerable amount of steam will be saved.

Another brake arrangement in common use is shown in Fig. 71.

A combined ejector and Driver's brake application valve is fitted; this may be of the Dreadnought or solid jet type. (Fig. 72.)

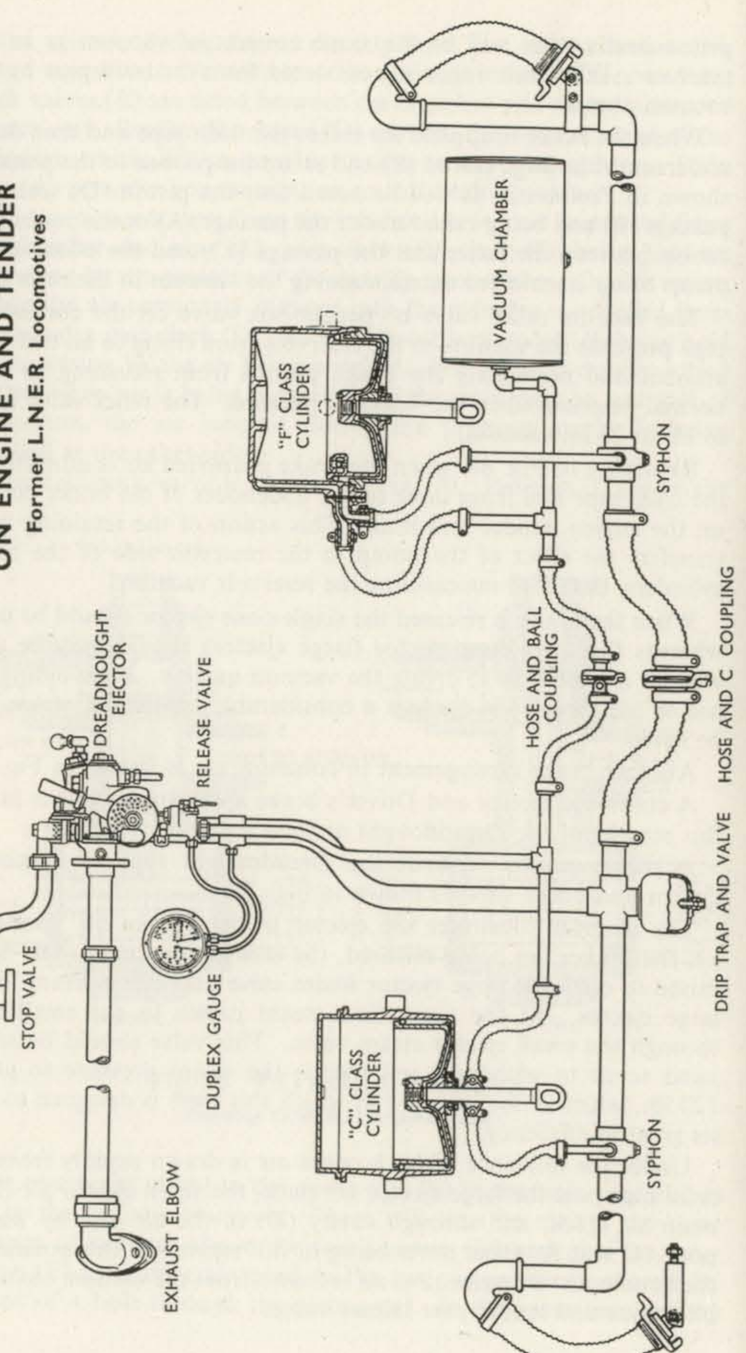
A diagrammatic view of the Dreadnought type of combined ejector and brake valve is shown in Fig. 73.

The diagram illustrates the ejector in the "brake off" position, i.e. the brakes are being released, the cam on the main shaft being raised to open the large ejector steam valve and admit steam to the large ejector. At the same time steam passes to the small cone through the small ejector steam valve. This valve should be set by hand so as to withdraw and reduce the steam pressure to about 120 lb., which is the pressure at which this cone is designed to give its greatest efficiency.

Under the influence of both cones air is drawn rapidly from the train pipe past the large ejector air clack, the small ejector air clack, main air clack, and through cavity (D) in the air disc by way of ports (C and B), these ports being in full register in this position of the handle. At the same time air is drawn from the vacuum chambers on engine and tender past release valve.

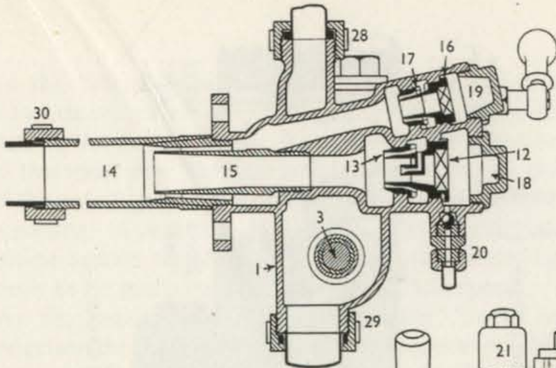
## Fig. 71 ARRANGEMENT OF VACUUM BRAKE ON ENGINE AND TENDER

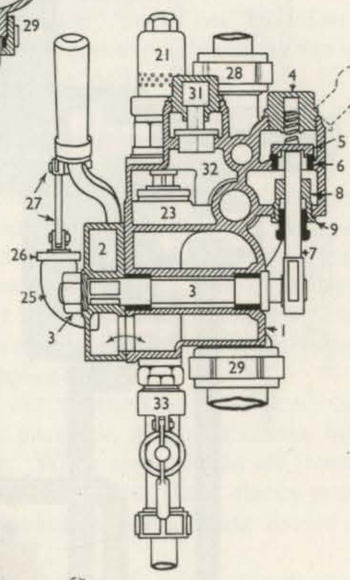
Former L.N.E.R. Locomotives









1. BODY
2. AIR DISC WITH HANDLE
3. SHAFT, WITH NUT AND LEVER
4. LARGE EJECTOR STEAM VALVE GUIDE NUT
5. LARGE EJECTOR STEAM VALVE CLACK
6. LARGE EJECTOR STEAM VALVE SEATING
7. LARGE EJECTOR STEAM VALVE SPINDLE
8. LARGE EJECTOR STEAM VALVE PACKING BOX
9. LARGE EJECTOR STEAM VALVE GLAND
10. SMALL EJECTOR STEAM VALVE SPINDLE
11. SMALL EJECTOR STEAM VALVE HANDLE
12. LARGE CONE (INNER PART)
13. LARGE CONE (OUTER PART)
14. EJECTOR EXHAUST BARREL
15. LARGE EJECTOR EXHAUST NOZZLE
16. SMALL CONE (INNER PART)
17. SMALL CONE (OUTER PART)
18. LARGE CAP.
19. SMALL CAP
20. DRIP CONNECTION, WITH NUT AND BALL
21. VACUUM REDUCING VALVE COMPLETE
22. AIR CLACK (BACK)
23. AIR CLACK (FRONT)
24. AIR CLACK GUIDE (BACK)
25. AUXILIARY APPLICATION VALVE
26. AUXILIARY APPLICATION VALVE CLACK
27. AUXILIARY APPLICATION VALVE LEVER WITH PINS, LINK AND SPRING
28. STEAM PIPE UNION AND RING
29. TRAIN PIPE UNION AND RING
30. EXHAUST PIPE UNION AND RING
31. SMALL AIR CLACK GUIDE
32. SMALL AIR CLACK
33. RELEASE VALVE

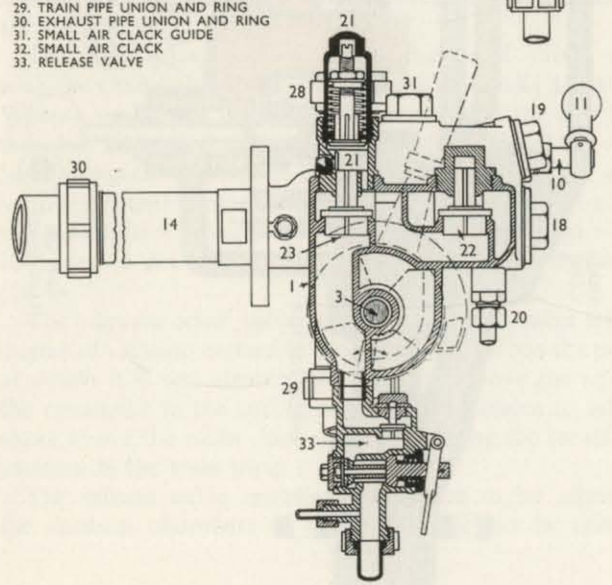
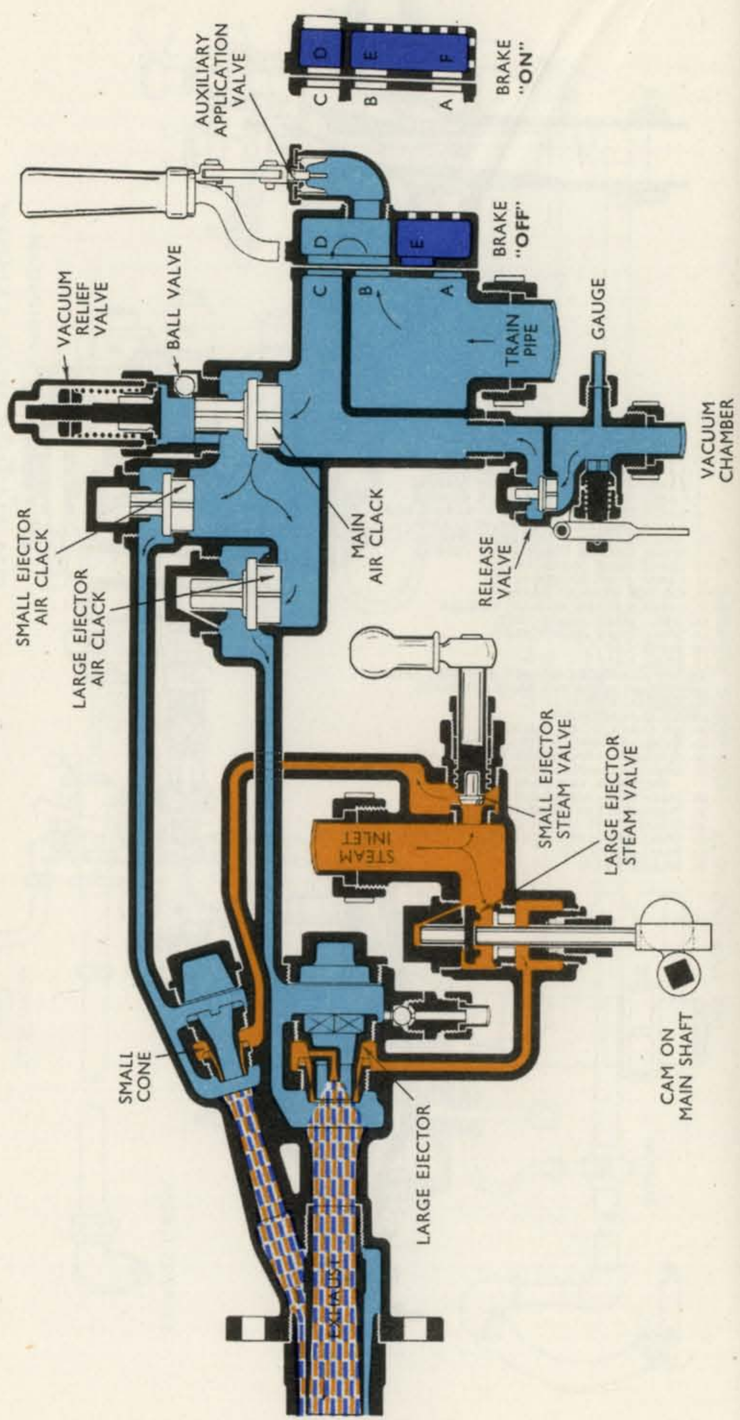


**Fig. 72 DREADNOUGHT EJECTOR**

Fig. 73 **WORKING DIAGRAM OF DREADNOUGHT VACUUM EJECTOR AND DRIVER'S BRAKE VALVE**








In the "running position" of handle, the cam lowers the large ejector steam valve on to its seat, thus cutting off the supply of steam to the large ejector. The connection between the small cone and the train pipe through cavity (D) in the air disc remains open and the small ejector maintains the working vacuum whilst the train is running. Operation of the auxiliary application valve in this position admits air to the train pipe and enables light brake applications to be made for controlling the train speed.

As the handle is moved towards the "brake on" position the connection through the cavity (D) is progressively closed. At the same time ports (E and F) in the air disc gradually uncover ports (B and A) in the ejector face and air is admitted to the train pipe to apply the brake. This air is prevented from passing to the engine and tender vacuum chambers by the non-return valve in release valve.

In the full "brake on" position ports (A and B) in the ejector face are completely open to atmosphere through ports (F and E) in the disc and the brake is rapidly applied. At the same time the small cone is isolated from the train pipe by the wall of cavity (D) and draws only on the engine and tender vacuum chambers past the release valve. In this way the maximum possible locomotive brake power is assured in emergency applications.

The air passages in the ejector are so arranged that, in all cases, air from the train pipe is drawn past two gunmetal clacks before coming in contact with the steam. When steam is cut off from the cones and a vacuum is left in the train pipe, these clacks prevent moisture, and more especially smokebox gases, being drawn into the train pipe.

The ball valve, located below the relief valve, communicates with the chamber between the two ejector clacks and the main clack. When a vacuum is created in the instrument the ball is drawn to its seat, but falls off as soon as steam is shut off and the vacuum drops. Should ejector air clacks be leaking it provides an outlet for any vapour or steam. Should the main air clack leak, it admits air from the atmosphere being drawn into the train pipe and so prevents any tendency to draw vapour and smokebox gases through ejector air clacks.

The vacuum relief valve is a spring-loaded valve which limits the degree of vacuum carried in the train pipe. When the point is reached at which it is set, atmospheric pressure above the valve overcomes the resistance in the spring and the valve opens to admit air to the space above the main clack, thus preventing the creation of a higher vacuum in the train pipe.

The release valve enables atmosphere to be admitted direct to the vacuum chambers so that the brake can be released by hand

**Fig. 74 WORKING DIAGRAM OF S.J. VACUUM EJECTOR AND DRIVER'S BRAKE VALVE**

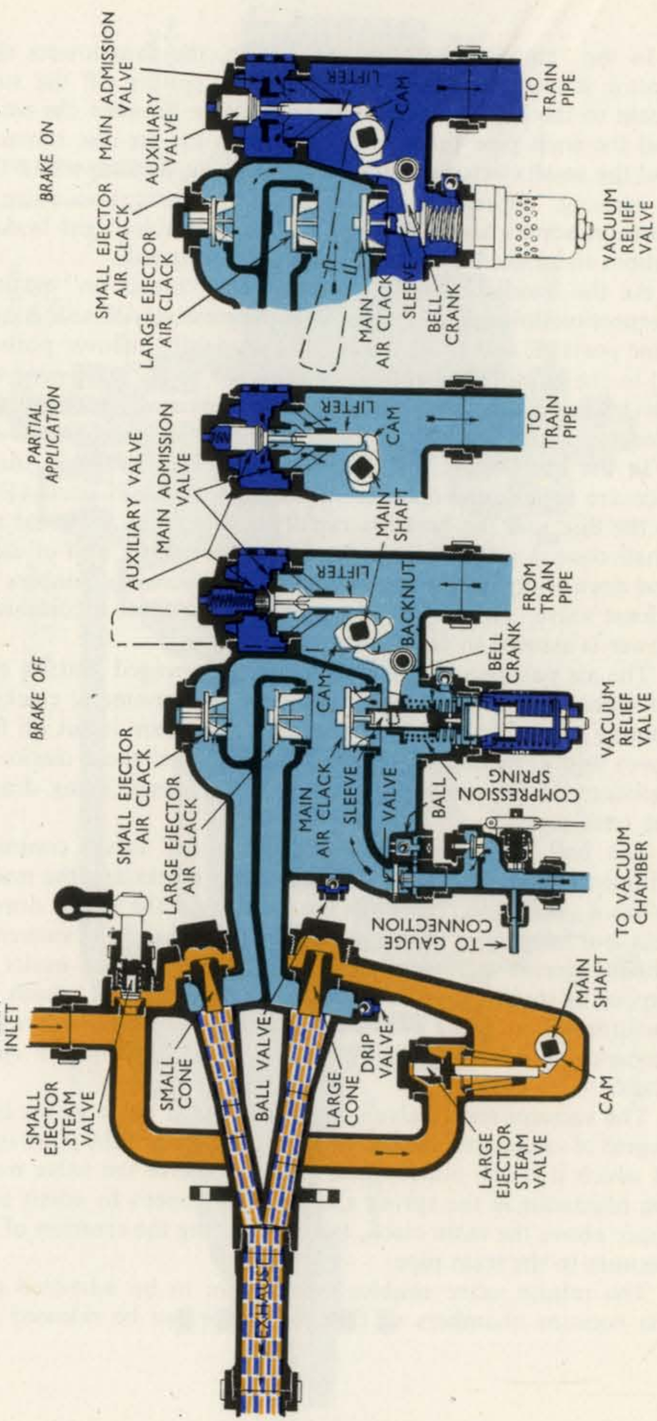



Fig. 74



when the locomotive is uncoupled and when steam is not available.

Fig. 74 shows a diagrammatic arrangement of the solid jet type combined ejector and brake valve.

The left-hand illustration is of the ejector in "brake off" position, the cam on the main shaft being raised to open the large ejector steam valve and admits steam to the large cone. At the same time steam passes to the small cone through the small ejector steam valve which is opened just sufficiently to admit the quantity of steam necessary to maintain the required vacuum.

Under the influence of both cones air is drawn rapidly from the train pipe past the air clacks, also from the chambers on the engine past the valve and the ball.

In the "running position" of the Driver's handle, the cam lowers the large steam valve on to its seat and the working vacuum is maintained throughout the running train by the small cone only, which is prevented from drawing back on the exhaust branch of the large ejector by air clack closing down.

The "partial application" shows the first admission of air as the Driver's handle is moved towards the "brake on" position. The finger on cam engages the lifter to open an auxiliary valve, and after this valve has attained its full lift the shoulders on the wing of the lifter come in contact with the main admission valve.

To effect isolation of the main train pipe from the action of the small ejector in the full "brake on" position, the main air clack is provided with a spindle extension actuated by the sleeve. Bell crank, worked from the cam, is operated increasingly as the Driver's handle comes to the "full on" position. In the "full on" position illustrated the arm of the bell crank has fully depressed the sleeve, taking with it the main clack, so shutting off the small ejector connection from the train pipe. The actual holding down of the main air clack is through the compression spring, which is capable of adjustment as regards tension by means of the backnut. The light spring only serves the purpose of holding this assembly together to prevent chatter.

When the brake is applied and the small ejector is left drawing upon the cavity below the small air clack, the large air clack remains closed and the main air clack is held closed by the bell crank, the valve lifts and connects the engine chambers to the ejector. In this way the maximum possible locomotive brake power is assured in emergency applications. To provide against the creation of an excessive vacuum in the top side of the brake cylinders the main air clack is held down by the bell crank through the tension of the compression spring which is so arranged that, when the brake is "full on" and the cavity all round the bell crank and the train pipe is in a state of atmospheric pressure, the creation of anything exceeding 21 in. above the main air clack will cause the atmospheric pressure under it to overcome the resistance of the compression spring and so allow the main air clack to lift, and this acts as an internal relief valve, obtaining its air from the train pipe which is in a state of atmospheric pressure due to the main admission valve being open.

A ball valve is located in the cavity between the two ejector clacks and the main clack, and is drawn to its seat when a vacuum is created, but falls off as soon as steam is shut off and the vacuum drops. Should the small and large air clacks be leaking, it provides an outlet for any vapour or steam. Should the main air clack leak, this ball valve prevents any tendency to draw vapour and smoke box gases through the small and large air clacks. The ball above the relief valve serves to allow any moisture to escape.

For the purpose of maintaining the brake operative on a "dead engine" which requires moving and may have vacuum brake cylinders without ball valves, the ball is provided within the ejector. By this means, when a vacuum is created in the train pipe, air is also drawn from the chambers of the dead engine, thus created in the train pipe; air is also drawn from the chambers of the dead engine, thus creating a vacuum above and below the brake pistons. This necessitates that the Driver's handle on the dead engine ejector is in the "running position".

The vacuum relief valve is a spring-loaded valve which limits the degree of vacuum carried in the train pipe. When the point is reached at which it is set, the atmospheric pressure below the valve overcomes the resistance of the spring and the valve opens to admit air to the space below the main clack, thus preventing the creation of a higher vacuum in the train pipe.

The release valve operates in the usual manner.

Fig. 75 shows the brake arrangement on ex-L.N.E.R. A.3 Pacific locomotives.

The combined ejector and Driver's brake valve is of the combined type and the vacuum brake cylinders are of the combined "C" class without release valve.

On the arrangement Figs. D and A illustrate the normal running position with the brakes "off" and the small ejector maintaining the vacuum in the train pipe and vacuum cylinder. Figs. F and B illustrate the position when the brake is in the "on" position.

It will be noted that air has entered the train pipe through the Driver's control handle and has acted on the underside of the brake cylinders causing the brakes to be applied. The effect of the small ejector has been cut off from the train pipe and its whole effect transferred to maintaining the vacuum in the vacuum chamber on the top side of the brake cylinders so as to overcome any slight leakages which might decrease the vacuum.



### Vacuum Brake Cylinders

Figs. 76-79 show four types of vacuum brake cylinder which are in common use on British Railways. Fig. 76 illustrates the combined "C"-type cylinder which is in general use on carriage and wagon stock as no vacuum chamber is required, this being incorporated in the design. The piston is rendered airtight by means of a rubber rolling ring (9).

Fig. 79 illustrates a similar cylinder, but the piston is fitted with a slipping rubber band instead of a rolling ring, and this type was adopted as standard for British Railways stock.

With rolling ring cylinders the vacuum chamber side vacuum is obtained either through a non-return ball valve in the piston or in an external fitting on the cylinder. These allow air to flow from the chamber side and shut when the brake is applied, so as to maintain the vacuum in the vacuum chamber.

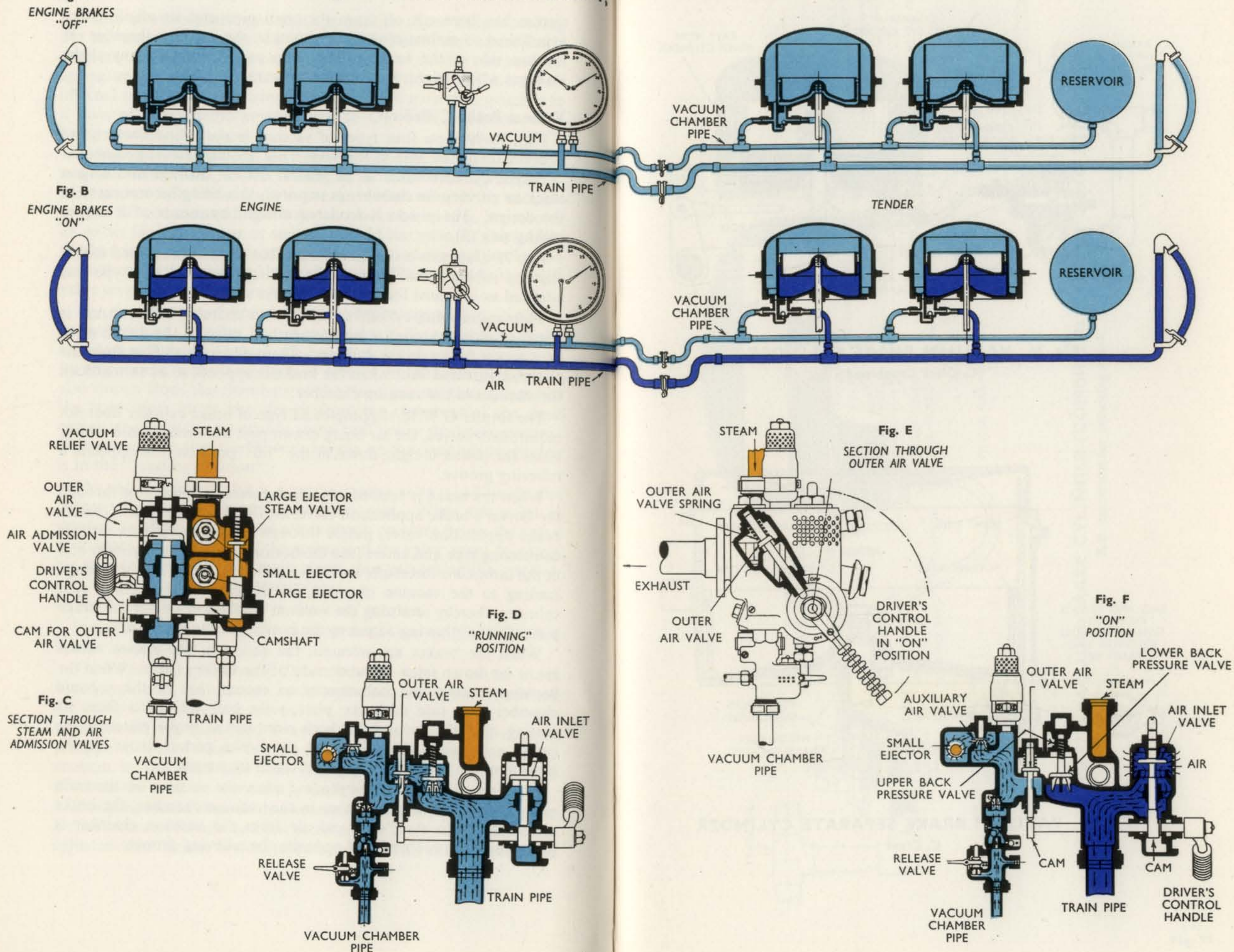
The former G.W.R. slipping-band type of brake cylinder does not require ball valves, the air being drawn past the rubber band which, when the piston is right down in the "off" position, lies opposite a relieving groove.

When the brake is applied, air which enters the train pipe through the Driver's brake application valve, or, for that matter, the Guard's brake application valve, passes through the brake cylinder flexible connecting pipe and enters into the bottom of the brake cylinder and at the same time forces the ball valve on to its seating on the passage leading to the vacuum chamber, in the case of the rolling ring cylinder, thereby retaining the vacuum on the top side of the brake piston, the air having access to the bottom of the piston only.

When the brakes are released, the action of the ejector causes air to be drawn from the underside of the brake piston. When the vacuum reaches and commences to exceed that in the vacuum chamber (top side of brake piston) the ball valve lifts from its seating until the vacuum on both sides of the brake piston is the same, and being in equilibrium the brake piston drops to the bottom of the brake cylinder by virtue of its weight.

With the slipping-band cylinder, when the vacuum in the train pipe commences to exceed that in the vacuum chamber, the brake piston drops to the "off" and air from the vacuum chamber is drawn past the rubber band opposite the relieving groove.

## Fig. 75 BRAKE ARRANGEMENT, Former L.N.E.R. A.3 Pacific Locomotive



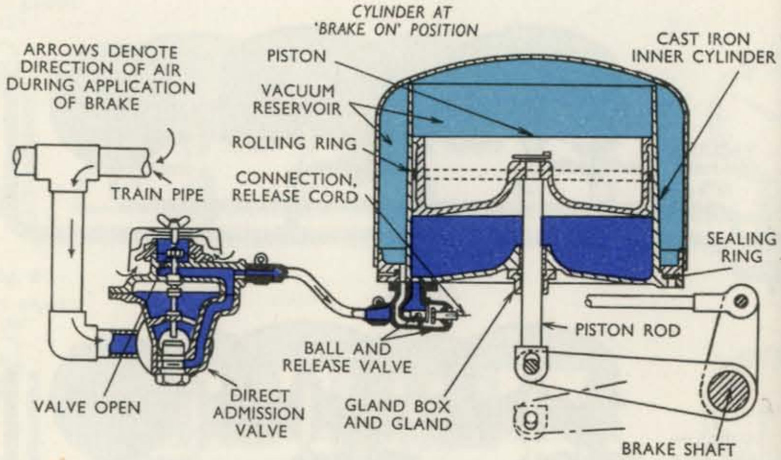



**Fig. 76 VACUUM BRAKE CYLINDER**

**C. Class Combined**

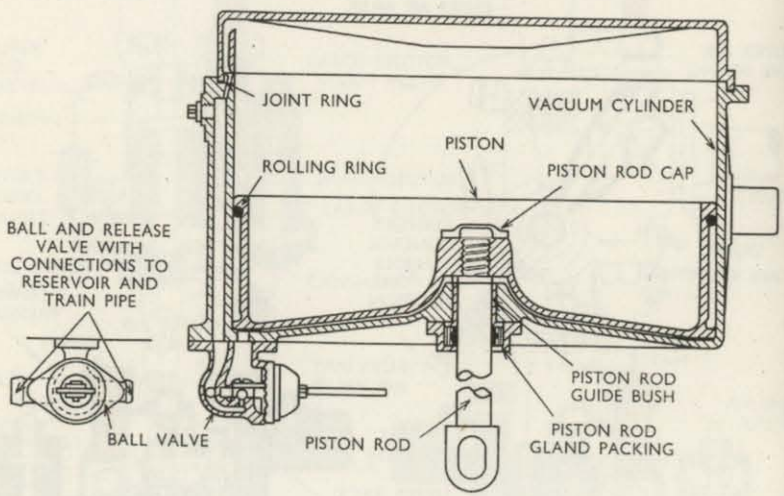



**Fig. 78 VACUUM BRAKE SEPARATE CYLINDER**

**C. Class**



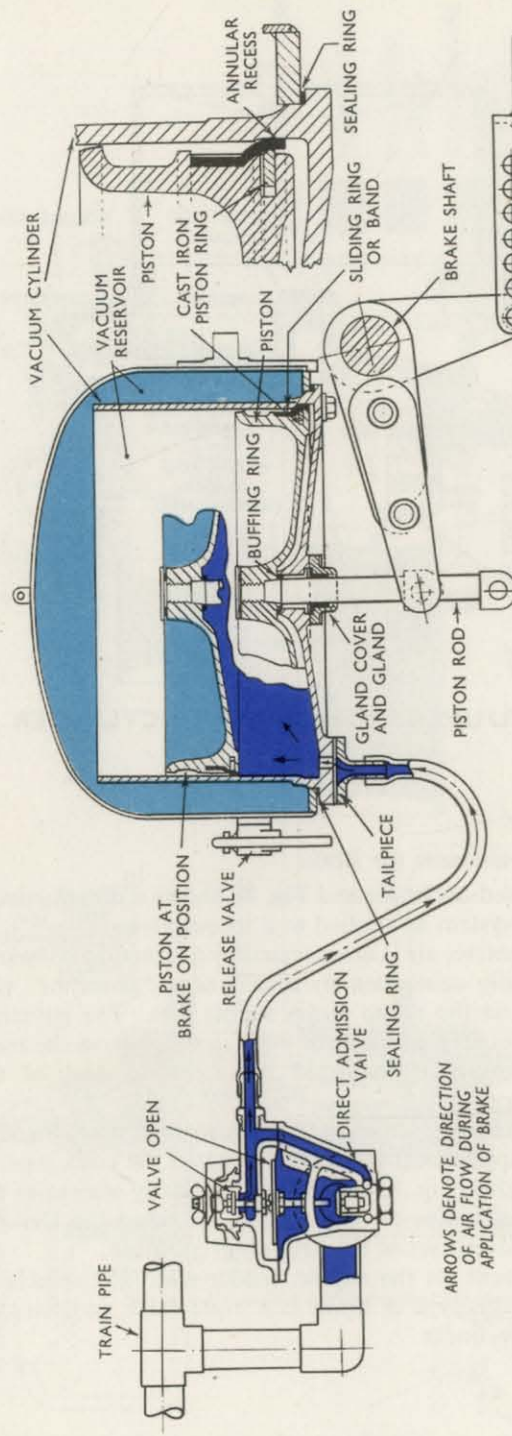



**Fig. 77 VACUUM BRAKE CYLINDER (COMBINED) SLIPPING-BAND TYPE**

**B.R. standard for coaching stock**

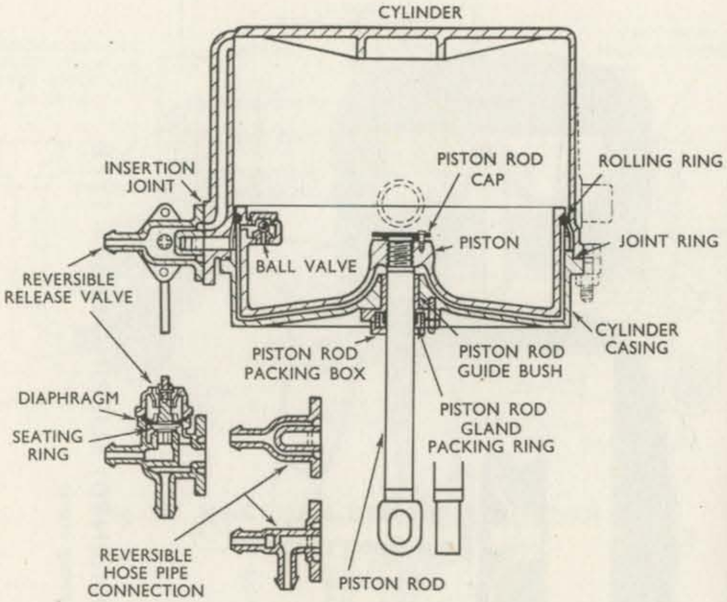



**Fig. 79 VACUUM BRAKE SEPARATE CYLINDER**
**F. Class**

**The Westinghouse Automatic Air Brake**

This is a compressed-air brake and Fig. 80 shows a diagrammatic arrangement of the system as applied to a locomotive.

On a steam locomotive, air is compressed by a steam-driven pump which is automatically controlled by means of a "governor" (see Fig. 81) positioned on the pump steam supply line. The governor is usually set to maintain a pressure of 90 lb. per sq. in. in the main reservoir, which pressure is indicated by the red hand of the duplex air pressure gauge.

The compressed-air supply from the main reservoir passes through the Driver's brake application valve (Fig. 82) into the train pipe by means of the feed valve (Fig. 83) which automatically maintains the air pressure in the train pipe at 70 lb. per sq. in. when the Driver's brake application valve is set in the "running" position.

The brake equipment on the engine, tender and each vehicle of the train fitted with this type of brake is a triple valve, auxiliary air reservoir and brake cylinder.



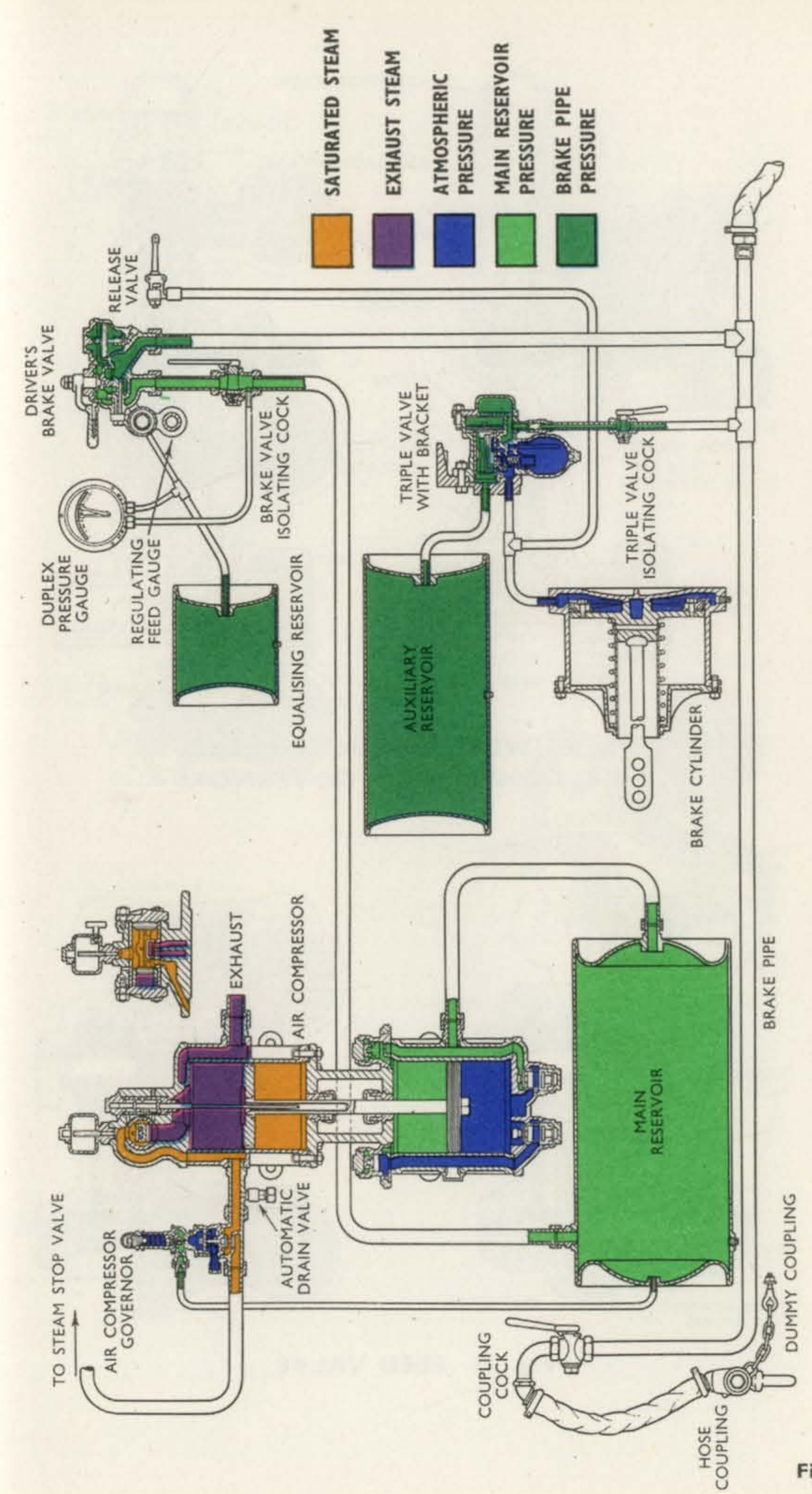



**Fig. 80 DIAGRAM OF WESTINGHOUSE AUTOMATIC BRAKE**

Fig. 80

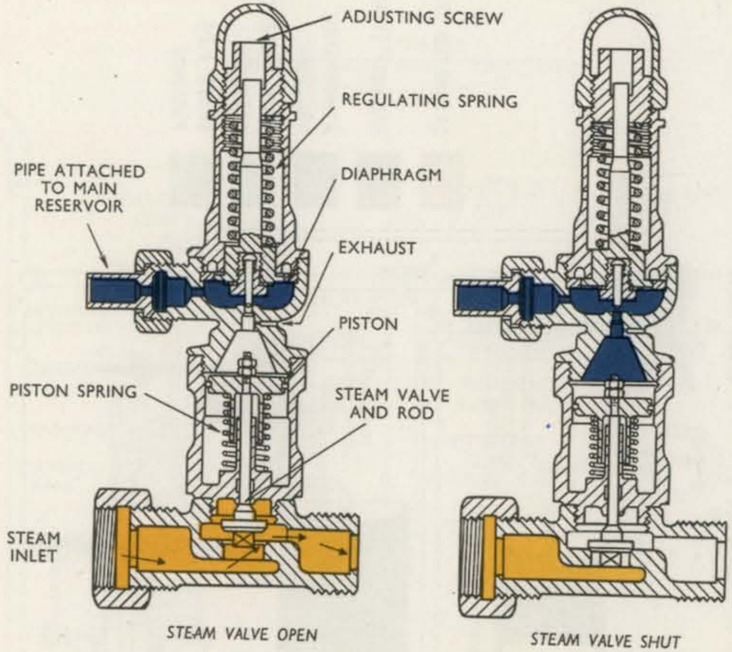



**Fig. 81 WESTINGHOUSE BRAKE AIR COMPRESSOR GOVERNOR**

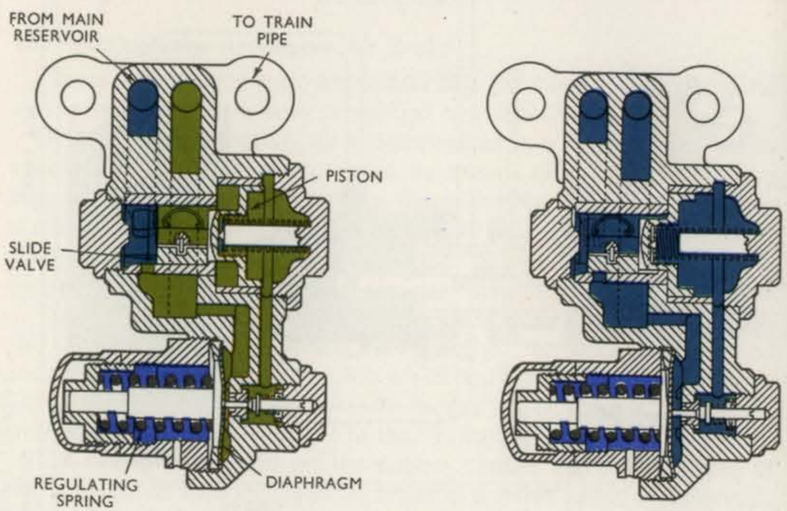



**Fig. 83 FEED VALVE**



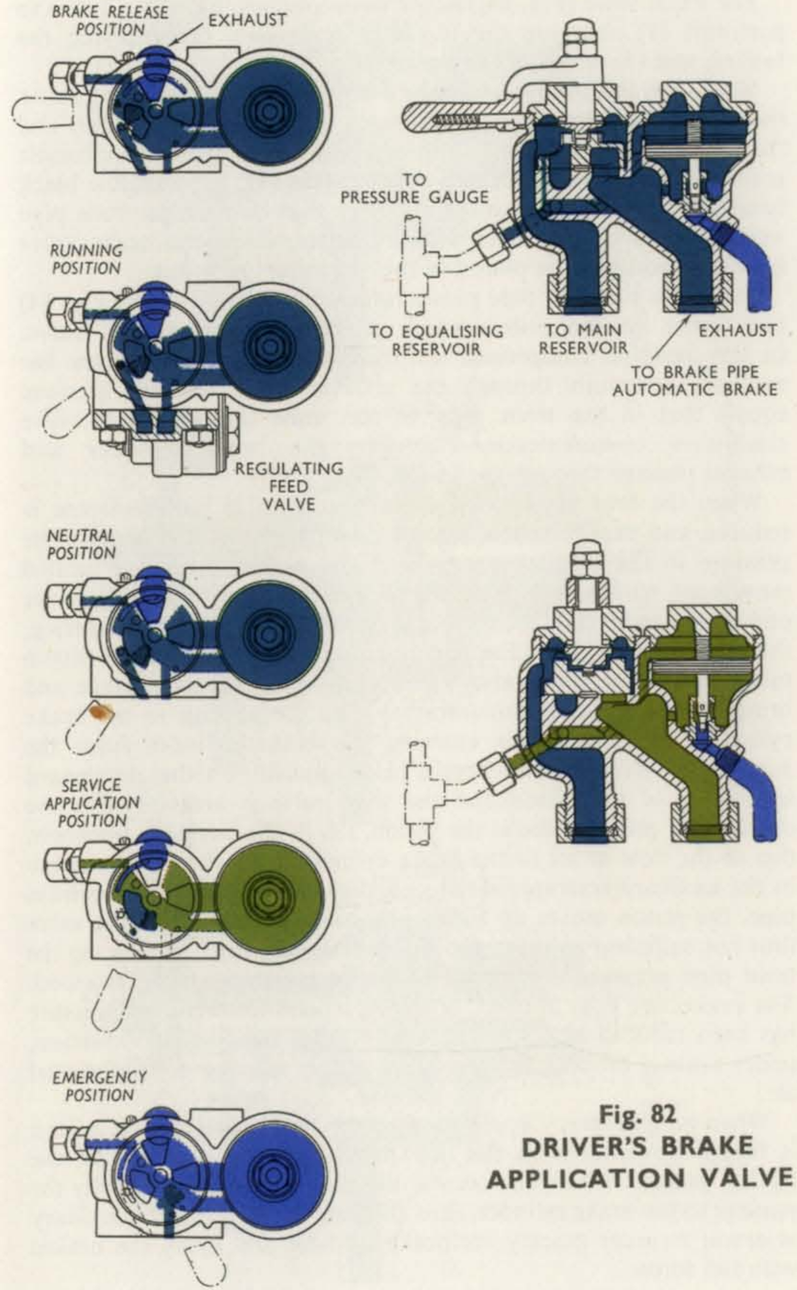



**Fig. 82 DRIVER'S BRAKE APPLICATION VALVE**

The triple valve (Fig. 84), as the name implies, has three duties to perform: (1) charging the auxiliary reservoirs, (2) applying the brakes, and (3) releasing the brakes.

When the locomotive is coupled to the train, air is admitted to the train pipe after the cocks between the locomotive (tender) and the train have been opened. Driver's brake application valve handle is then placed in the "release" position (see Fig. 82) until the black hand of the duplex air gauge indicates that the normal train pipe working pressure has been reached, after which the brake valve handle should then be placed in the "running" position.

The air in the train pipe passes into each triple valve (see Fig. 84) and forces up the piston which is connected to a slide valve. In this position compressed air from the train pipe charges the auxiliary reservoirs through the grooves until the air pressure equals that in the train pipe, at the same time the slide valve establishes communication between the brake cylinder and exhaust passage through the cavity.

When the brake is applied the air pressure in the train pipe is reduced and the piston is moved downwards by the greater air pressure in the auxiliary reservoir. The piston, having a limited movement, without acting on the slide valve, closes the feed groove and at the same time moves the graduating valve from its seating, thus opening the port. Further downward movement of the piston takes with it the slide valve which closes the exhaust passage and brings the port into communication with the passage to the brake cylinder, resulting in air entering the brake cylinder from the auxiliary reservoir and the brakes being applied. Further downward movement of the piston and the slide valve is arrested with the decrease of pressure above the piston, i.e. in the auxiliary reservoir, due to the flow of air to the brake cylinder, and when the pressure in the auxiliary reservoir is reduced slightly below that in the train pipe, the piston moves up sufficiently to close the graduating valve (but not sufficient to move the slide valve). By further reducing the train pipe pressure any degree of brake pressure can be attained. The brakes are fully applied, however, when the train pipe pressure has been reduced by 25 lb. per sq. in., and any further reduction, under normal braking conditions, is merely a waste of compressed air.

When an emergency application of the brake is made, the piston is forced downwards to the limit of its stroke and seats on the leather gasket. When this occurs, the slide valve uncovers fully the passage to the brake cylinder, thus allowing the air from the auxiliary reservoir to enter quickly the brake cylinder and apply the brakes with full force.



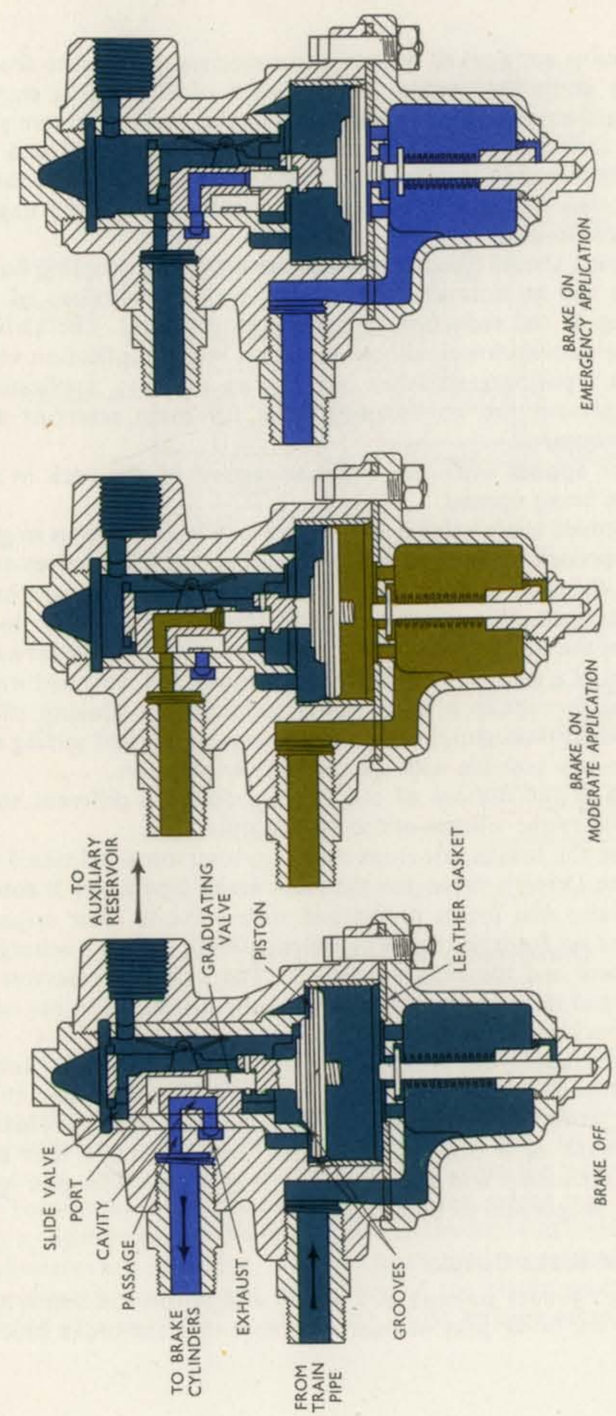



Fig. 84 TRIPLE VALVE (Ordinary)

When trains are worked with two locomotives, the brakes should be entirely under the control of the Driver of the leading engine. On the train engine the isolating cock to the main reservoir pipe under the Driver's brake application valve must be closed and the brake valve placed in the "release" position. Care should be taken to ensure that this isolating cock is opened on the train engine whenever the leading engine is uncoupled.

If the train should become divided, or a flexible coupling burst, the brakes will be automatically applied on both portions of the train owing to the reduction in train pipe pressure. The Driver, under these circumstances, should move his brake application valve to the "on" position, as when making an ordinary application. This will prevent the air escaping from the main reservoir and assist the stopping.

The same applies when the brake is applied by the cock in the guard's van being opened.

The improved triple valve is shown in Fig. 85; its object is to give a closer approach to simultaneous action of all the triple valves on a train when the slide valve is moved by applying the brakes, the bulb is closed to atmosphere and opened to the train pipe. The local reduction of the train pipe pressure thereby produced by the forward triple valves of a train causes an earlier action of the rearward triple valves, which results in a more nearly simultaneous braking effect being produced throughout the train in every case of first setting the brakes than was possible with the ordinary triple valve.

The bulb at the bottom of the valve is made in different sizes proportioned to the volume of the vehicle train pipe.

To release the brakes, air from the main reservoir is admitted by means of the Driver's valve into the main brake pipe where it enters the triple valve and forces piston and slide valve to their original position; the air from the brake cylinders of bulb is then discharged to atmosphere and the brakes released. The auxiliary reservoir is then recharged through the grooves, past the piston, as in the case of the ordinary triple valve.

Fig. 86 illustrates the brake arrangement of a dual-fitted locomotive; whilst the brakes on the engine are Westinghouse, it is possible to work coaches equipped with vacuum brakes. This is done by means of a proportional valve, which ensures that the degree of application and release of the brakes on the engine and train are in proportion to each other.

**Westinghouse Brake Cylinder**

The brake cylinder consists of a piston and piston rod which are attached to the brake gear in such a manner that the brake blocks



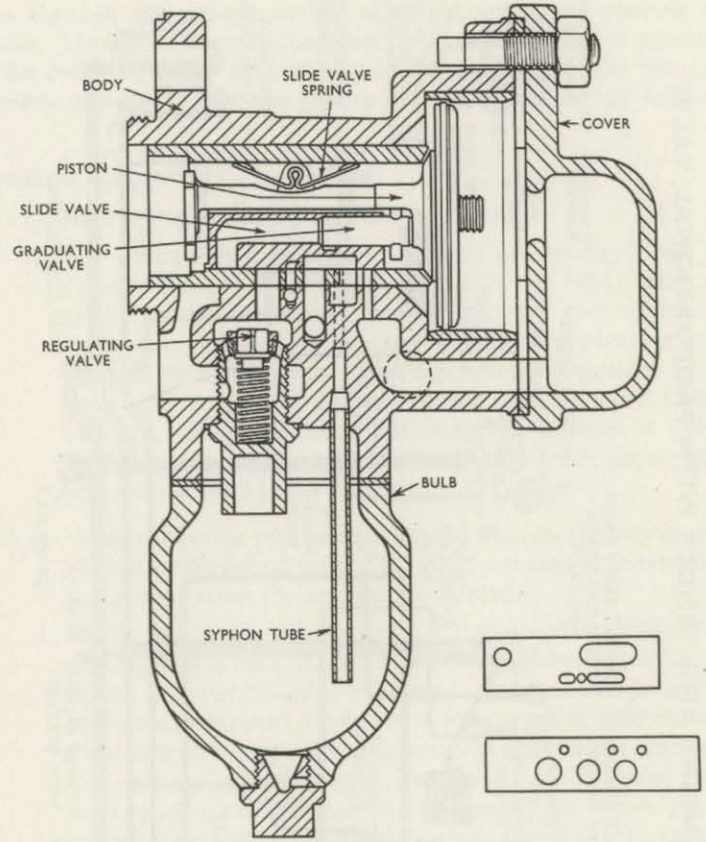



**Fig. 85 TRIPLE VALVE (Improved)**

are pressed against the wheels when the piston is moved in the brake cylinder by air pressure. A spring is fitted which is compressed when the brake is applied, and when the brake is released the spring expands and returns the piston and brake gear to their original position, thus releasing the brake blocks from the wheels.

To prevent the application of the brakes, which might be caused by a slight leakage in the brake pipe to the brake cylinder, the brake cylinders are provided with a small groove which establishes communication between both sides of the piston when the brake piston is in the "off" position. If a slight leakage occurs the air will

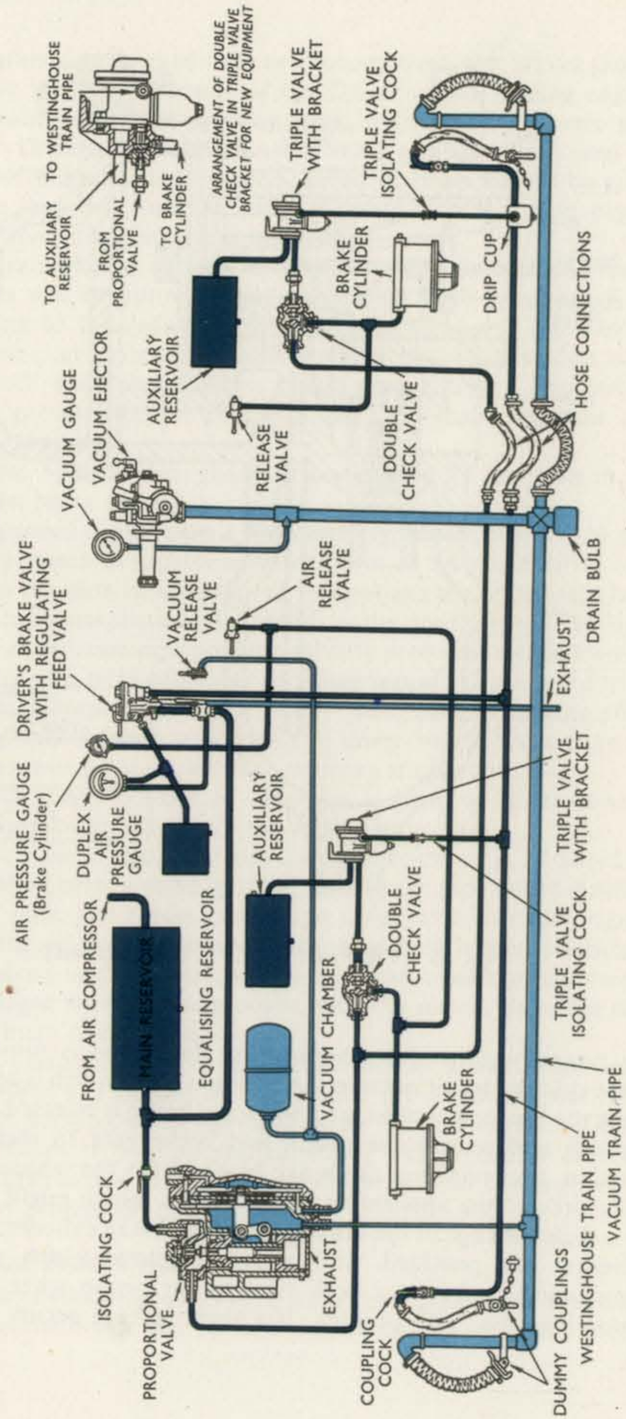



Fig. 86 WESTINGHOUSE BRAKE DIAGRAM
AUTOMATIC BRAKE ON ENGINE AND TENDER WITH PROPORTIONAL VALVE





pass through the groove to the atmosphere without moving the piston. However, when a considerable quantity of air is admitted to the cylinder, as by an ordinary brake application, the piston is immediately forced past the groove and the escape of air sealed.

## Questions and Answers

(1) *Q*. How is the train pipe vacuum measured?

*A*. The vacuum is measured in "inches of mercury" and the vacuum gauges on the engine and in the brake vans are graduated in inches. A perfect vacuum corresponds to approximately 30 in. of mercury, atmospheric pressure or no vacuum to zero inches. The regulation of vacuum in the train pipe to 21 in. of mercury, which it is important to bear in mind, along with other intermediate readings, is only a partial vacuum. Each 1 lb. pressure of air extracted is represented by 2 in. of vacuum on the gauge.

(2) *Q*. What will be the pressure per square inch on the piston when the brake is applied fully if 21 in. of vacuum is recorded on the gauge before the application is made?

*A*. $10\frac{1}{2}$ lb. per sq. in. Atmospheric pressure or the weight of air pressing upon the earth's surface is approximately 15 lb. per sq. in. at sea level and it has been found that this pressure is sufficient to support a column of mercury nearly 30 in. high. Consequently every inch of mercury in the column represents a pressure of $\frac{1}{2}$ lb. per sq. in., so that 21 in. indicated in the vacuum gauge represents $10\frac{1}{2}$ lb. per sq. in. which can be exerted upon the piston head when the brake is applied. Some idea of the power available can be obtained by considering a 20-in. diameter cylinder. The area of the piston is 314 sq. in. and the pull produced on the brake piston rod would be $10\frac{1}{2} \times 314$ lb., which equals 3,297 lb. or more than 1 ton.

(3) *Q*. How does the combination ejector create vacuum?

*A*. A jet of steam issuing at high velocity from a cone of special shape within the ejector (see Fig. 64) carries the surrounding air forward by frictional contact through a second and larger cone, known as the air cone, to exhaust in the smoke-box.

The removal of air in this manner from the space in the immediate vicinity of the steam jet sets up a partial vacuum inside the ejector; air, in its endeavour to fill this space, flows past the non-return valve from the train pipe and other portions of the brake apparatus connected to it.

In this way it is possible to maintain the desired amount of vacuum at will in the train pipe and connections so long as the ejector is kept at work and the brake is not applied. The combination ejector contains two separate ejectors constructed on the above principle, each one independent of the other and possessing its own non-return valves.

(4) *Q.* What purpose do the non-return valves serve?

*A.* The non-return valves and the air lock chamber are for the purpose of preventing loss of vacuum through the ejector cones when the ejector is shut down, and also to guard against steam and smokebox gases being allowed to enter the train pipe and connections.

(5) *Q.* How is the train pipe vacuum prevented from rising above the regulation amount of 21 in.?

*A.* A vacuum relief valve is provided for the purpose. This is a spring-loaded valve capable of being adjusted so that it will open and admit air to the train pipe as soon as the regulation vacuum of 21 in. has been exceeded. The relief valve is generally mounted inside the cab in an accessible position and contains a fine-gauge filter to prevent entry of dust and dirt into the train pipe. This filter requires to be cleaned and examined periodically by the Shed Staff. If the filter or the air holes become choked with dirt or any other obstruction, free passage of air to the relief valve is prevented and may result in an excessive amount of vacuum being created in the train pipe.

(6) *Q.* Describe one type of vacuum brake cylinder in common use.

*A.* A type of vacuum brake cylinder frequently used on passenger and freight vehicles is illustrated in Fig. 76.

It will be seen to consist of a vacuum reservoir and cylinder combined, the cylinder proper being open at the top and enclosed within the reservoir. The brake piston is of fairly deep section and is kept airtight within the cylinder by a rubber rolling ring nipped between the piston head and the cylinder wall. The piston rod passes through the bottom of the cylinder and is kept airtight by a gland.

The brake cylinder is connected to the train pipe by a small flexible hose attached to the ball valve housing at the base of the vacuum chamber.

The purpose of this ball valve is to control the movement of the brake piston in accordance with the variations in the train pipe vacuum, and also to provide a means of releasing the brake by hand when necessary.



This ball valve can close the vacuum chamber port, or it can place the lower side of the brake piston and the vacuum chamber in communication with each other and with the train pipe when off its seating.

Running with the brake off, the ball valve is unseated, leaving the train pipe in communication with both sides of the piston, which will then be in equilibrium and resting by its own weight at the bottom of the cylinder. Immediately air is admitted to the train pipe it passes up the connecting pipe and forces the ball valve to its seating on the port leading to the vacuum chamber, thereby retaining the vacuum on the top side of the piston. The port to the underside of the piston is, however, left open, and the air accordingly flows into the bottom of the cylinder, lifts the piston and applies the brake.

Restoration of the train pipe vacuum extracts the air from below the piston until the vacuum below equals that in the chamber above, after which the piston, being equalised, will sink to the bottom of the cylinder by its own weight, allowing the brake to release. At the same time the ball valve will drop away from its seating on the chamber port, leaving both sides of the piston in communication with the train pipe, ready for the next brake application.

The hand release arrangement is effected by a ball valve enclosed inside a sliding cage connected to an external lever, as shown in Fig. 76. When the release cord is pulled, the cage is displaced, forcing the ball valve away from the vacuum chamber port, thereby placing both sides of the brake piston in communication with the train pipe.

(7) *Q.* Passenger vehicles are fitted with a communication cord which, when operated, gives an indication to the Driver in order to stop the train in case of emergency. Describe how the arrangement operates.

*A.* The communication cord consists of a chain passing through each compartment of the coach and connected at the end of the vehicle to the passengers' alarm valve and indicating disc.

The alarm valve, when operated by the chain being pulled, opens and allows air to enter the vacuum train pipe, causing a reduction in vacuum of 5 to 10 in., which is sufficient to apply the brake with moderate force and to attract the Driver's attention.

(8) *Q*. Describe the brake action on a train fitted throughout with the vacuum automatic brake.

*A*. The brake is applied by the pressure of air being admitted through the ports of the Driver's application valve, passing down the train pipe from the engine to the train.

During release, the blocks on the leading vehicles will be freed first and for this reason the small ejector only should be used for release purposes when the train is in motion, in order to avoid surging and shocks on the drawgear caused by the early release in front and continued retardation of the rear portion of the train, which would be intensified if the large ejector was used.

(9) *Q*. How should the brake be handled to obtain the best results?

*A*. In the case of "service application", in which full brake power is not called for, the Driver should begin by destroying 7 to 10 in. of train pipe vacuum and should hold this application until he feels the slight check which will indicate the brake has taken hold. This is known as "setting the brake"; after this, the brake block pressure can be varied at will by regulating the train pipe vacuum to suit requirements of the stop.

To make a full-power application, the Driver would put the application valve right over to "full on" position in a single movement, destroying all train pipe vacuum, and would leave it thus until speed was reduced sufficiently to permit the application to be somewhat eased.

(10) *Q*. Name a few bad faults to be avoided when handling vacuum-fitted trains.

*A*. Do not "see-saw" the brake handle between "running" and "brake on" positions several times when commencing an application. This practice retards the action of the brake cylinder ball valves and will increase the time required to "set" the brake.

In all normal cases avoid the use of the large ejector to release the brake except when the train is stationary.

Do not bring the train to rest with all the train pipe vacuum destroyed and the brake applied with full power.

Ease the application in the final stages by allowing the train pipe vacuum to build up slowly to about 12 in., which will prevent complete release of the engine brake and also the risk of locked wheels on the train.



(11) *Q*. How would the Driver carry out his test of the brake on an engine fitted with the automatic steam and vacuum brake?

*A*. He would test for obstruction in the engine train pipe by applying the large ejector with first the front and then the rear hose bag off the stopper; in neither case should the vacuum gauge show more than 3 in. of vacuum. If the gauge shows an appreciable amount of vacuum with either pipe off the plug, an obstruction in the train pipe is indicated and must be located and removed. Having replaced the hosebags on the stoppers he should then create the full 21 in. of vacuum in the train pipe, using the small ejector for the purpose; shut off the ejector and note the time taken for the vacuum to fall to 12 in. on the gauge.

If this is less than 20 seconds the train pipe leakage is excessive and should be located.

The large ejector should be tested and the brake worked once or twice by the application valve to prove the mechanical parts of the apparatus.

(12) *Q*. If bad leakage on the train pipe is indicated by this test, what points should be looked at to find the fault?

*A*. See that both vacuum hose pipes are properly on the stop plugs and that the rubber washers are good. Test the drip valves for leakage and all joints in the train pipe, using the torch-light flame for the purpose. See that the disc of the application valve is not sticking away from the face and check all the train pipe connections on the footplate. If no leakages are disclosed, suspect the non-return valves in the combination ejector. Whilst making the above test the small ejector should be kept at work and the brake valve should be left in "running" position.

(13) *Q*. How would you test engines fitted with the vacuum brake before leaving the shed?

*A*. Examine the flexible train pipes and see that the couplings fit properly on the plugs. Then put the brake handle to the "on" position, close the auxiliary release valve and open the small ejector steam valve slightly. This will extract air from the top sides of the pistons and admit air to the bottom sides and train pipe and will also deposit in the smokebox any water which may be in the exhaust pipe instead of throwing it out over the boiler, as may be the case if the large ejector was suddenly opened after the engine had been standing for some time. Close the small ejector and watch the chamber side needle on the gauge, which will fall if the ball valve leaks. If the needle remains stationary, then test the train pipe side by creating 21 in. with the application valve in "running" position, close the steam valve and watch the gauge. If the vacuum is rapidly destroyed, the defect must be located and made good.

The large ejector must be tested separately, preferably outside the shed, whilst the small ejector remains shut. Then test the train pipe on the engine by taking first the front hosepipe and afterwards the rear hosepipe off the plugs separately, and opening the large ejector fully and then closing it; if any vacuum is registered on the train pipe side of the gauge when the ejector is closed whilst either of the hosepipes is off the plug, a stoppage or obstruction in the train pipe is indicated, which must be put right.

(14) *Q*. On engines fitted with vacuum brake only, how would you decide if a chamber-side leakage was internal or external?

*A*. Create a vacuum on both sides, close the small ejector and leave the application valve in "running" position. If the chamber-side pointer should fall it will be an external leakage.

(15) *Q*. How would you test for a faulty ball valve, burst diaphragm or faulty rolling ring?

*A*. Create 21 in., close the small ejector and apply the brake quickly, returning the application valve into "running" position. A fault will be shown by the chamber-side needle falling and the train pipe needle rising until equal.

(16) *Q*. Is it possible to have a defect without indication on the engine vacuum gauge?

*A*. Yes, an obstruction in the train pipe might prevent the creation of vacuum in the train, but the engine gauge would show the correct amount of vacuum. It would be necessary to test the engine with the vacuum hosepipe off the plug, as previously explained. (It should be borne in mind that the vacuum gauge shows the degree of vacuum but can give no indication of the quantity of air the ejector can eject to overcome leakage. The small ejector may maintain 21 in. of vacuum on the engine alone, but when coupled to the train is unable to create or maintain the requisite vacuum. The test for this is by the use of a disc with a standard size leak-hole; this is carried out by the Fitting staff at the shed or by C. & W. staff when in traffic. See General Appendix and Supplement "Working of Vacuum Brake".)



(17) *Q*. How should the brake be operated when two engines, coupled together, are attached to a vacuum-fitted train?

*A*. It is the duty of the Driver of the leading engine to create and maintain the vacuum and to operate the brake. The ejectors on the second engine must be kept closed, but the Driver of the second engine is not relieved from responsibility of the due observance of all signals affecting the working of the train and in case of need he must apply the brake.

(18) *Q*. How does the compressed air used in the Westinghouse brake system apply the brake?

*A*. By the air being admitted to a brake cylinder and forcing the piston out, which by means of connecting rods and levers forces the brake blocks against the wheels.

(19) *Q*. What essential parts of the brake are fitted to engine and tender carriage or other vehicle?

*A*. An auxiliary reservoir, triple valve and brake cylinder.

(20) *Q*. Where is the pressure which supplies the brake cylinder stored?

*A*. In the auxiliary reservoir under each vehicle fitted with the brake.

(21) *Q*. How much main reservoir pressure should be carried?

*A*. 90 lb. per sq. in.