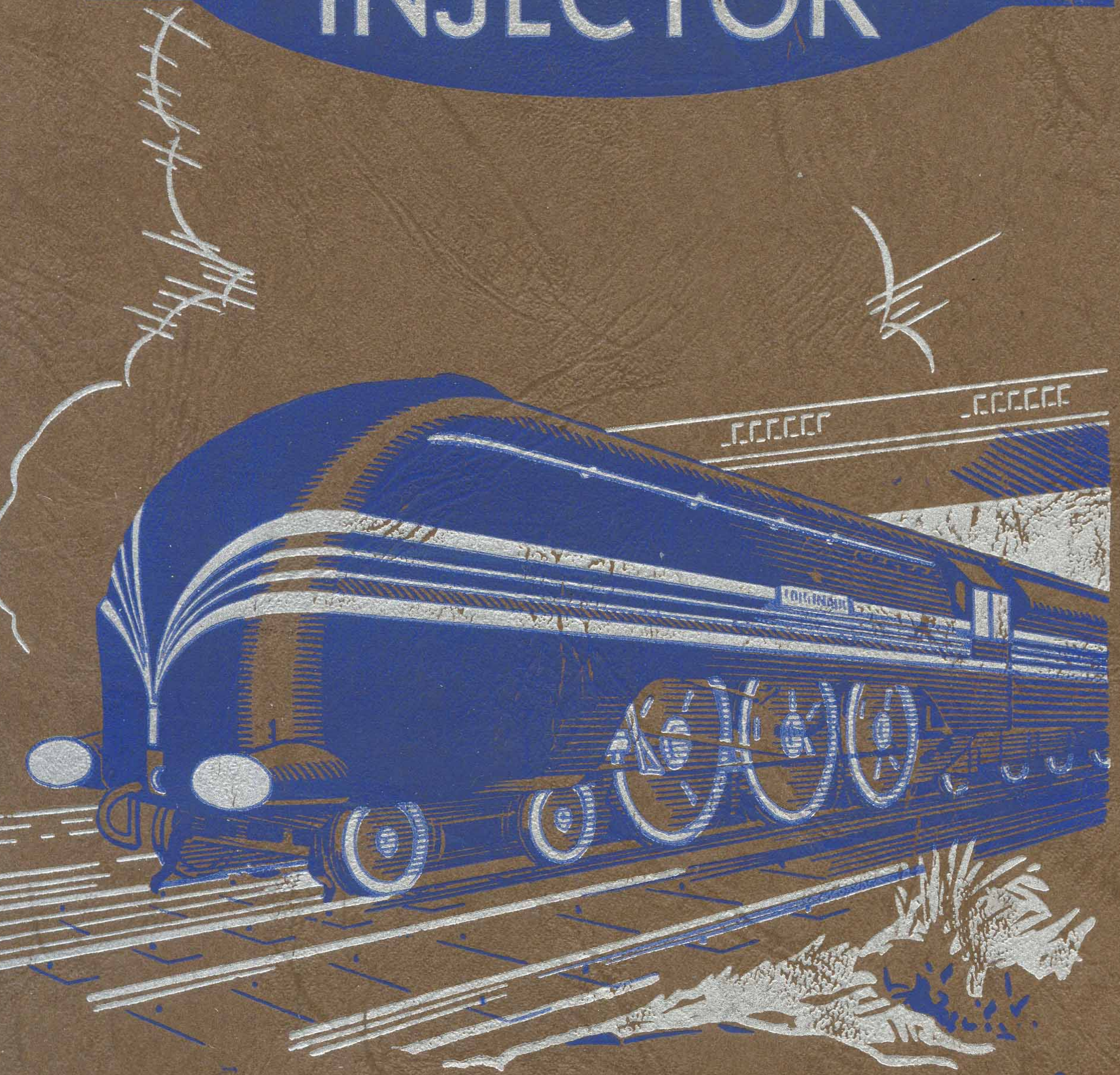
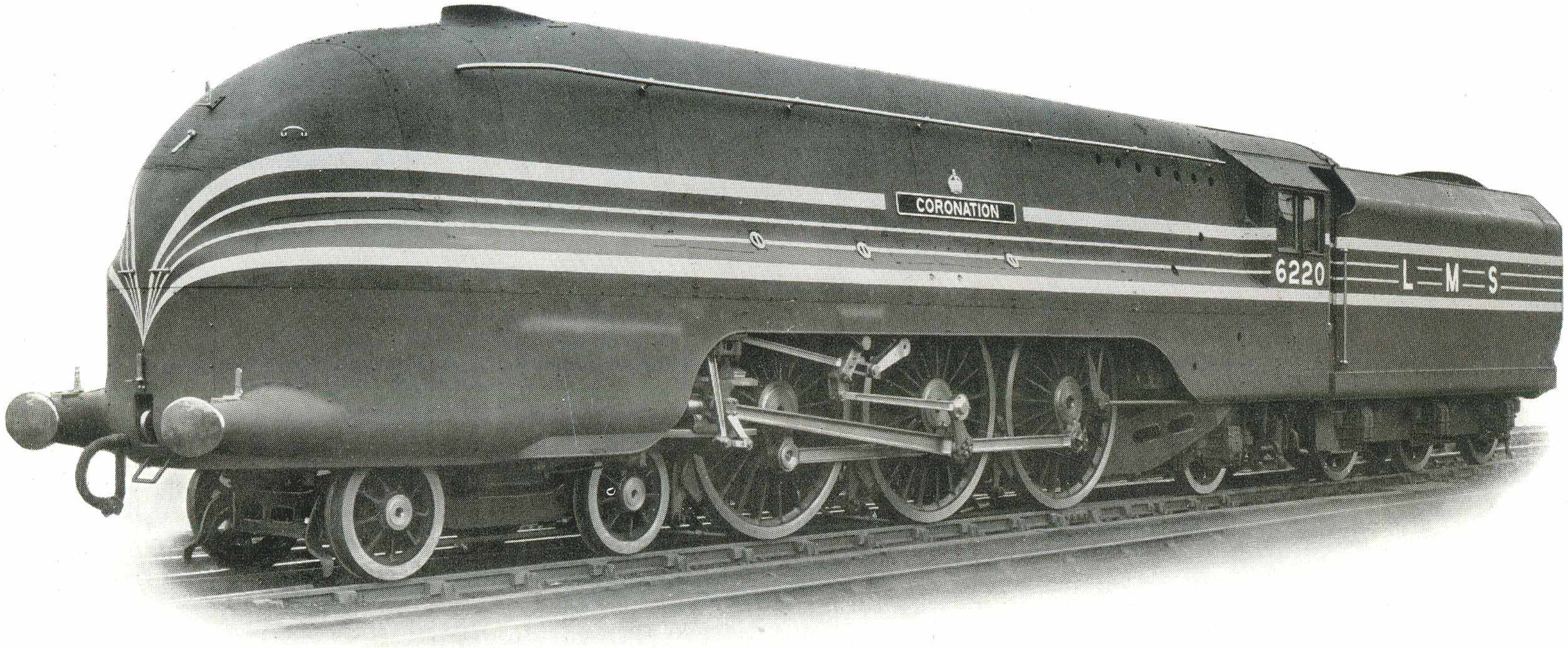
THE EXHAUST STEAM INJECTOR



CLASS
J

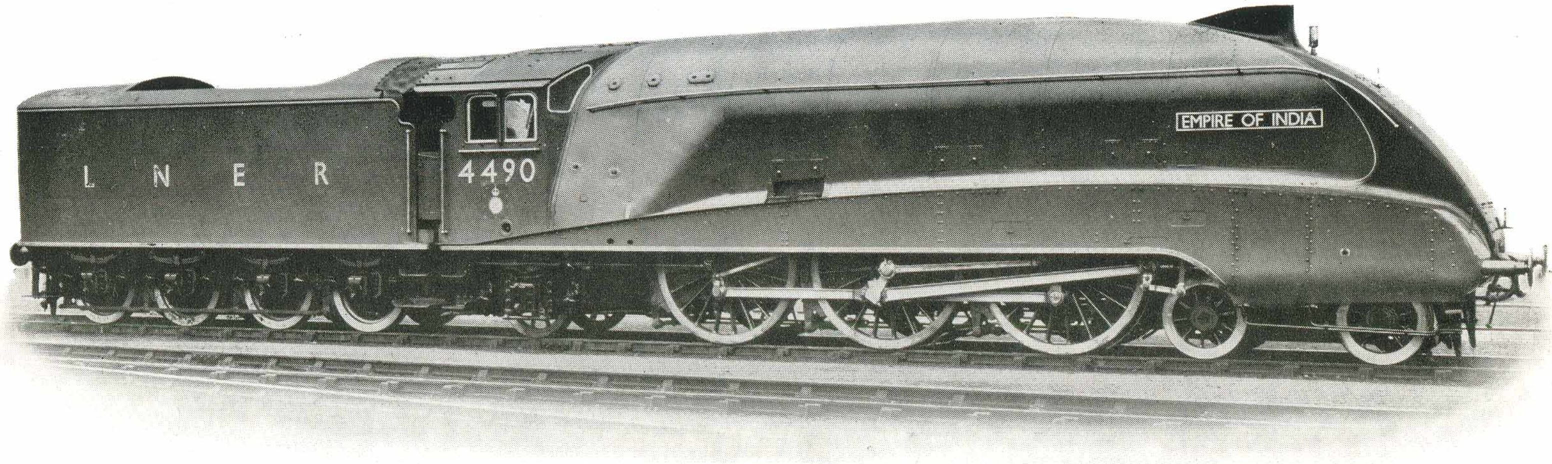
METCALFE'S
PATENTS



4 - 6 - 2 "Coronation" Locomotive.
London, Midland & Scottish Railway.

Designed by Sir William Stanier,
Chief Mechanical Engineer.

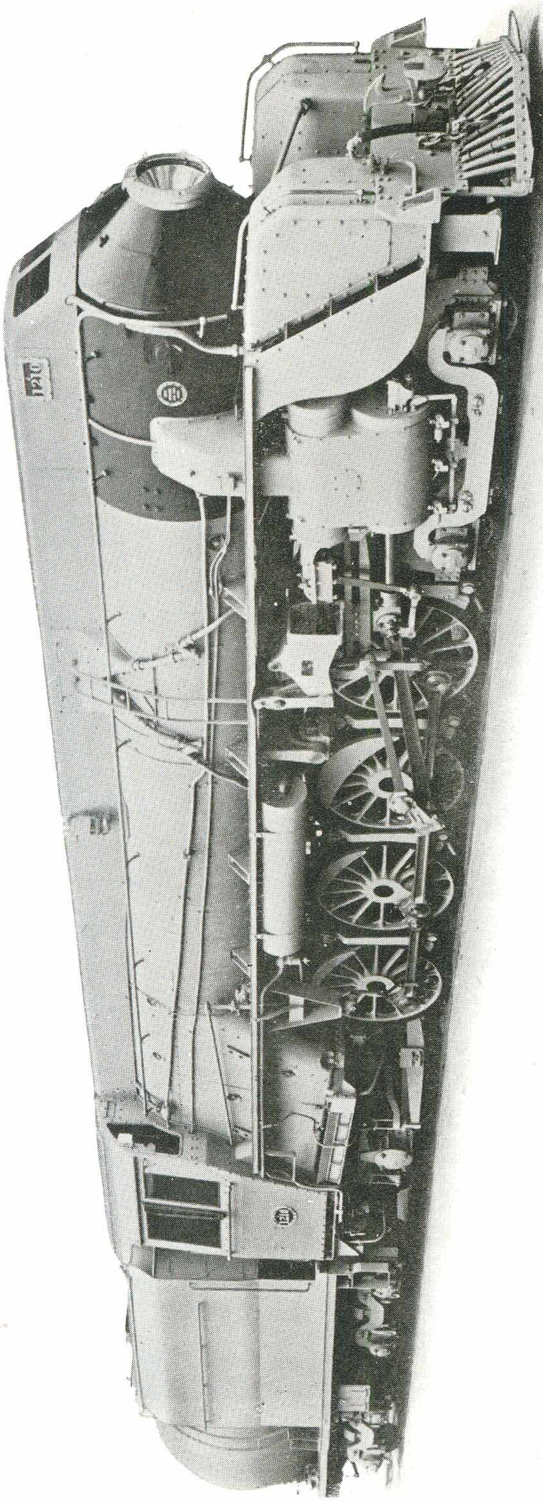
Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.



4-6-2 A4 Class Locomotive.
London & North Eastern Railway.

Designed by the late Sir Nigel Gresley, C.B.E.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR, and VACUUM BRAKE EJECTOR.



4-8-2 Type Mixed Traffic Locomotive.
New Zealand Government Railway.

*Built by the North British
Locomotive Co. Ltd., Glasgow.*

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Class "J" Exhaust Steam Injector

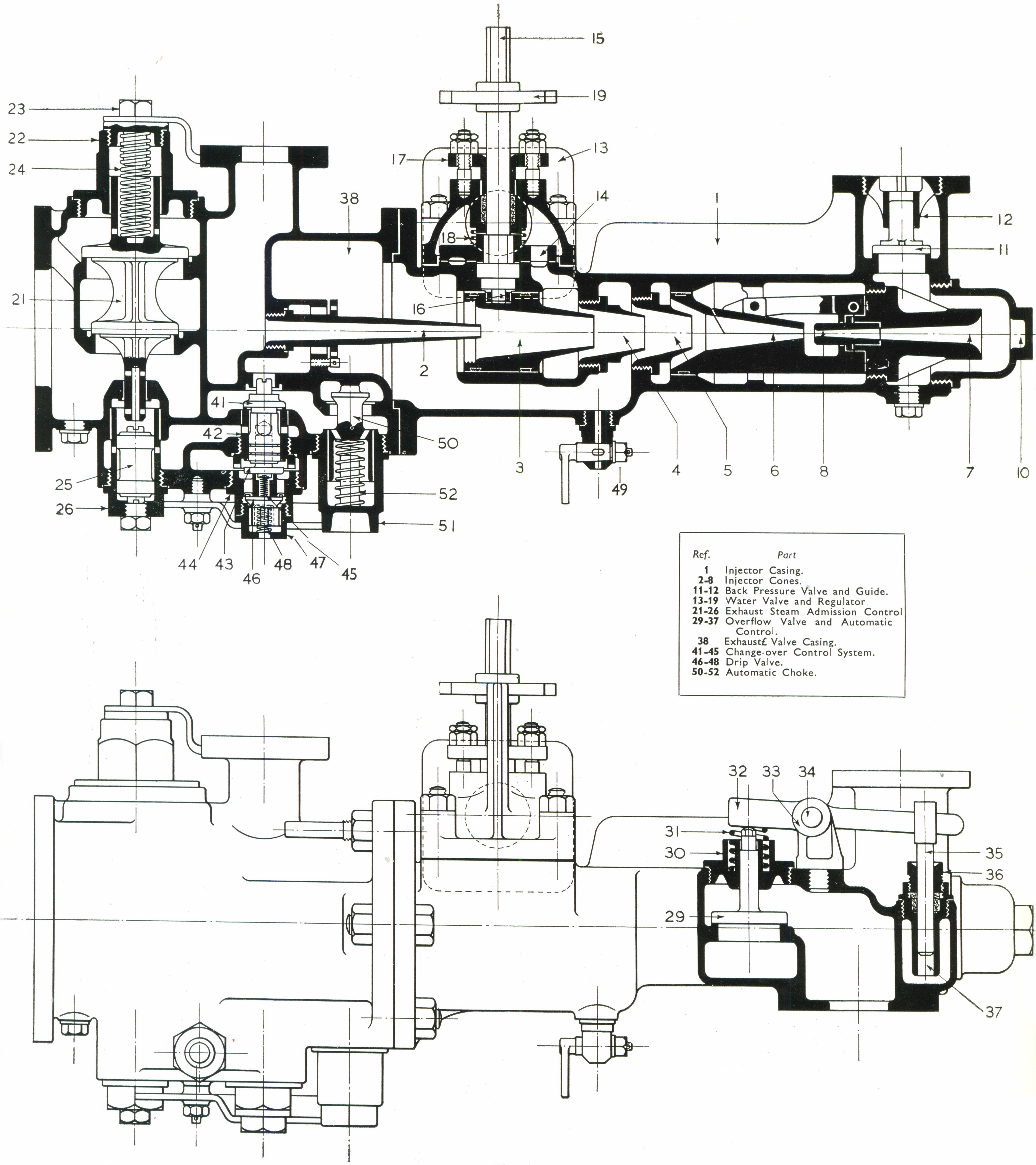
THE Class "J" Exhaust Steam Injector represents a considerable improvement on all former types. The automatic control system has been much simplified and the injector is now operated in a similar manner to an ordinary non-lifting live steam injector.

Two operations are necessary to start the injector, namely, the opening of the combined water regulator valve and the injector steam valve. The only other manipulation necessary is the adjustment (when required) to running conditions of the water regulator to vary the quantity of feed water supplied to the boiler. Compared with previous types of Exhaust Injectors the main feature of the latest development is a far-reaching simplification in design without eliminating any of the advantages of previous types and the addition of the automatic choke which improves the feeding at very low boiler pressures, an important feature particularly when lighting up at the sheds. It should further be noted that unlike its predecessor, the Class "H" Injector, which has an automatic water valve controlled by live steam from the boiler, the Class "J" Injector has a manually operated water valve of the disc pattern combined in the water regulator.

The injector functions as a feed water heater so long as the locomotive is using steam, but when the engine regulator valve is closed it operates with live steam, automatically changing from exhaust to live steam working, and back again to exhaust steam working when the regulator is opened. The automatic change-over is controlled by the steam pressure in the steam chest acting on an automatic valve which shuts off the auxiliary live steam supply when exhaust steam becomes available.

Principle of the Exhaust Steam Injector

The principle of the Exhaust Steam Injector is the same as that of the live steam injector, namely, the utilisation of the heat and the velocity obtained by the expansion of steam and the imparting of them to the water, though, of course, the proportions of the cones are different, being designed to utilise low-pressure steam. As the working of the exhaust injector depends upon the fact that exhaust steam flowing into a vacuum attains a very high velocity, the cones are designed so that at the point of contact of the steam and water the condensation of the steam shall be as efficient as possible, thus obtaining a high vacuum.



Ref.	Part
1	Injector Casing.
2-8	Injector Cones.
11-12	Back Pressure Valve and Guide.
13-19	Water Valve and Regulator.
21-26	Exhaust Steam Admission Control
29-37	Overflow Valve and Automatic Control.
38	Exhaust£ Valve Casing.
41-45	Change-over Control System.
46-48	Drip Valve.
50-52	Automatic Choke.

Fig. 1

The Casings.

The Class " J " Exhaust Injector (Fig. 1) consists of two portions, namely, the injector casing (1) and the exhaust valve casing (38) which are bolted together to form one unit. The injector casing contains the injector cones (3)—(8), the combined water valve and regulator (13)—(19), the overflow valve and its automatic control (29)—(37), the back pressure valve and guide (11)—(12), and the water and delivery connections. The exhaust valve casing contains the exhaust steam admission control (21)—(26), the supplementary live steam cone (2), the auxiliary live steam nozzle, the change-over control system (41)—(45), the drip valve (46)—(48), the automatic choke (50)—(52) the exhaust steam inlet, the inlet connection for live steam, and the connection to the locomotive steam chest. Drain cocks and drain plugs are fitted to empty the casings during frosty weather.

Cones or Nozzles.

The complete set of the injector cones consists of the following cones or nozzles (Fig. 2) :—

(1) **Supplementary Steam Cone** (2), which admits a small supply of live steam for the purpose of increasing the delivery pressure up to present-day boiler pressures.

(2) **Auxiliary Live Steam Nozzle,** which is combined with the supplementary steam cone, and admits live steam to take the place of exhaust steam to work the injector when the regulator is shut and exhaust steam not available.

(3) **Exhaust Steam Cone** (3), which admits the primary supply of exhaust steam. This cone guides and steadies the incoming jet of steam, and regulates, by its bore, the quantity admitted.

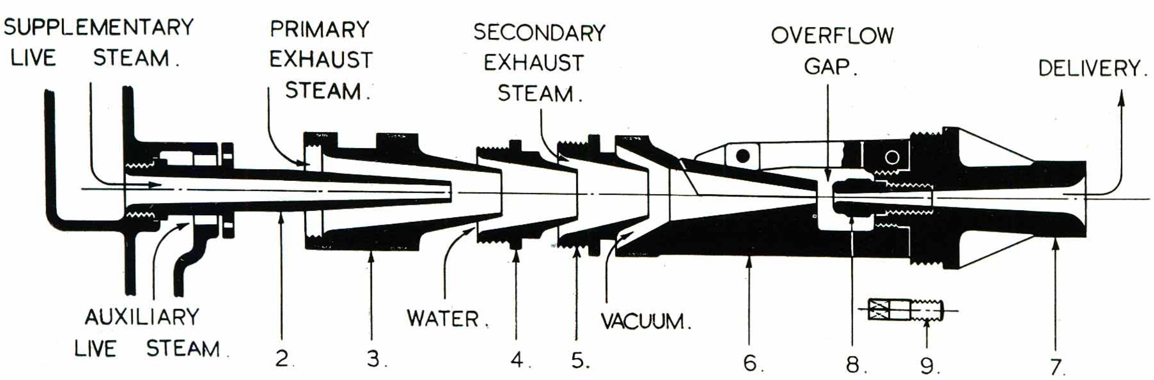


Fig. 2

Ref.	Part	Ref.	Part
2	Supplementary Steam Cone.	5	Vacuum Tube.
3	Exhaust Steam Cone.	6	Combining Cone.
4	Draft Tube.	7-9	Delivery Cone.

(4) **Draft Tube** (4), which admits and guides the supply of water to meet the primary exhaust steam supply at the mouth of the exhaust steam cone.

(5) **Vacuum Tube** (5), which admits the secondary supply of exhaust steam to meet the mixture flowing out of the draft tube.

(6) **Combining Cone** (6), which receives the mixture of steam and water flowing out of the vacuum tube. Its function is to bring the steam and water into as intimate contact as possible so that complete condensation shall take place with the minimum of loss thus ensuring a high value for both the thermal and kinetic energies of the combined jet.

(7) **Delivery Cone** (7), (8). The jet leaving the combining cone passes into the delivery cone whose function is to change the kinetic energy or energy of motion of the combined jet into pressure energy so that the feed water may enter the boiler.

Action of the Cones.

A small quantity of supplementary live steam which enables the injector to feed against higher pressures than would be possible by the use of the exhaust steam alone is admitted to the injector in the form of a solid jet through the supplementary steam cone.

The quantity of steam admitted is determined by the bore of the supplementary steam cone and is therefore, a constant quantity, amounting to about $2\frac{1}{2}\%$ of the normal amount of water delivered. The whole of this live steam is condensed by the feed water and directly returned to the boiler so that there is no thermal loss.

When the engine is standing, or running with the regulator shut, it is necessary to work the injector as a live steam injector. By the action of the change-over valve, an equivalent supply of live steam to replace the exhaust steam is introduced through the auxiliary steam nozzle, entering the injector through the annular space, surrounding the supplementary steam cone. This steam flowing into the exhaust steam cone, replaces the exhaust steam, and the injector works exactly as when exhaust steam is used.

Exhaust steam from the cylinders is fed into the injector through the exhaust steam pipe, and, entering the exhaust valve casing, passes into the injector cones. It is admitted in two stages, the primary supply being admitted through the exhaust steam cone, impinging, at the end of this cone on to the water entering through the annular passage formed by the outside of the exhaust steam cone and the inside of the draft tube, in the form of an annular jet surrounding the end of the exhaust steam cone. The steam is condensed by the water jet and imparts its momentum to it, the mixture flowing forward at a high velocity, the proportion of steam to water being such that a high degree of vacuum is created thus ensuring a high steam velocity. Around the outside of the draft tube (4) the secondary supply of exhaust steam is admitted in the form of an annular jet surrounding the mixture leaving the draft tube at its entrance to the vacuum tube (5), adding further impetus to the water jet. The mixture of steam and water flowing out of the vacuum tube then passes into the combining cone (6), the function of which is to ensure as complete condensation as possible.

The internal bore of the combining cone is convergent, *i.e.*, the bore gradually decreases so as to support the jet which, owing to the reduction in volume as condensation becomes more complete, decreases in size.

The combining cone is constructed on the " flap " principle, being split longitudinally at its middle section up to a point where the bore is sufficiently large to permit the whole mixture of water and steam to escape freely to the overflow, and so ensure the prompt starting and automatic working of the injector. The top portion or " flap " is hinged on to the lower one so that it opens freely to allow the mixture to escape.

When starting, the steam and water admitted enter the cones, the pressure of the steam in the combining cone lifts the hinged flap so allowing the mixture of steam and water to pass freely into the overflow. As soon as condensation takes place a vacuum is created within the combining cone, the flap closes, and so forms a solid wall cone. Thus a continuous and steady jet is created which is supported throughout its length by the wall of the combining cone. Should the jet be broken in any way the vacuum is destroyed and the pressure of the steam opens the flap so allowing the steam and water to escape freely into the overflow, until the vacuum is again created and the continuity of the jet re-established.

The jet, on leaving the combining cone, passes into the delivery cone (7)—(8). Between the combining and delivery cones is a small space or gap, termed the " overflow " gap, which is necessary for starting purposes. The delivery cone consists of two parts—a short parallel portion known as the throat, followed by a diverging cone. The function of the diverging cone is to change the kinetic energy of the jet into pressure energy to overcome the boiler pressure, the velocity of the jet being gradually reduced and its pressure increased to that of the boiler. After leaving the delivery cone the water flows past the back pressure valve (11) into the delivery pipe and so to the boiler.

The point of maximum wear in the injector cones occurs in the throat portion of the delivery cone, the wear being due to two causes :—

(1) Wear caused by erosion due to the high velocity of the jet at this point, and also the presence of solid matter in the water.

(2) Wear caused by cavitation due to the impact of particles of uncondensed steam on the surface of the throat wall.

The throat portion of the delivery cone is, therefore, made in the form of a renewable end of special steel which has been found very effective in withstanding the wear due to the erosive action of the jet. By the adoption of this renewable end, the worn portion of the delivery cone can be replaced easily and cheaply.

Exhaust Steam Admission Control (Fig. 3).

There are three working parts in the Exhaust Steam Admission Control, namely the Exhaust Steam Valve, its Control Piston and the Exhaust Valve Spring.

(1) **The Exhaust Steam Valve** (21). This is a double beat valve moving vertically in the exhaust valve casing and having upper and lower stems to form guides in the body. Its movements are controlled by the exhaust steam valve control piston (25), acting on the lower stem to open it, and by the exhaust valve spring (24) on the upper stem to shut it. The lower seating of the exhaust steam valve is only slightly smaller than the upper one so that the steam pressures acting on the valve are practically balanced. These pressures vary not only in magnitude but also in direction, according as the regulator is open or shut. When the regulator is open exhaust steam tends to keep the valve closed, but as the valve is practically balanced, a comparatively small control piston is sufficient to lift the exhaust steam valve against the exhaust steam pressure, however high the latter may be.

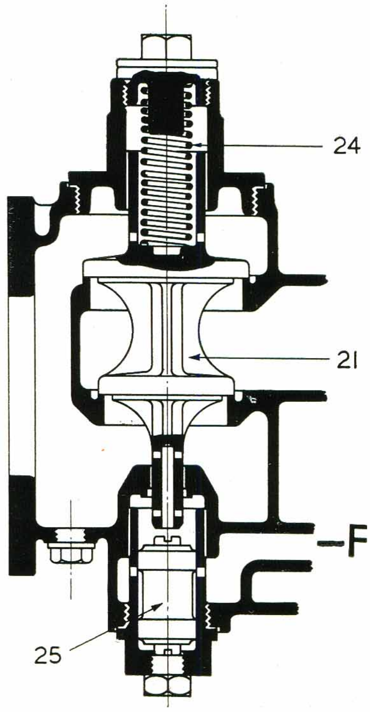


Fig. 3

Ref.	Part
21	Exhaust Steam Valve.
24	Exhaust Valve Spring.
25	Exhaust Valve Control Piston.

When the regulator is closed, the auxiliary live steam inside the casing tends to open the exhaust steam valve. Here again, as the valve is almost balanced a comparatively weak spring suffices to keep the valve on its seating. To free any steam which may accumulate above the exhaust valve piston, a vent hole drilled in the lower stem of the exhaust valve allows any such steam to escape into the exhaust steam chamber.

(2) **The Exhaust Valve Control Piston** (25) is fitted axially below the exhaust valve. This piston is operated by the live steam supply to the injector and its upward movement opens the exhaust valve, the upper face of the piston bearing against the lower stem of the exhaust valve.

(3) **Exhaust Valve Spring** (24), which is fitted inside the upper stem of the exhaust valve. As the exhaust valve opens, this spring is compressed and so always tends to close the exhaust valve.

When the injector is set to work while the engine is running with the regulator open (so that the exhaust steam is available), the operating live steam is admitted by the action of the change-over valve (41) to the underside of the exhaust valve piston (25) thus forcing this upwards on to the seating at the top end of the piston guide chamber. As the upper side of the piston bears on the lower stem of the exhaust steam valve (21) the latter is opened so admitting the exhaust steam to the injector, and at the same time compressing the exhaust valve spring (24). When the injector is set to work with the regulator closed or when it changes over from exhaust steam to live steam working on closing the regulator, the action of the change-over valve (41) shuts off the supply of live steam to the underside of the control piston which then falls and so the spring (24) closes the exhaust valve, cutting off all communication between the exhaust valve casing and the exhaust steam supply pipe.

Change-over Control (Fig. 4).

The change-over control consists of three parts: the change-over valve (41), the liner (42), and the automatic check valve (43), and its working is controlled by the steam from the steam chest.

The Change-over Valve (41) consists of a double-seated valve with a lower stem forming a piston which moves in and is guided by the liner. Its upper seating controls the admission of auxiliary steam into the injector and the lower seating the admission of live steam to operate the exhaust valve control piston.

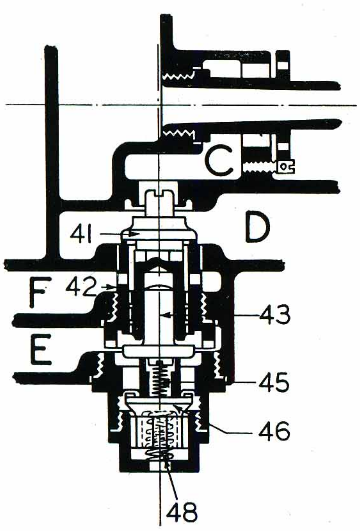


Fig. 4

Ref.	*Part*
41	Change-over Valve.
42	The Liner.
43	Automatic Check Valve.
45	Automatic Check Valve Spring.
46	Drain or Drip Valve.
48	Drip Valve Spring.

The Liner (42) is a steel bush screwed into the exhaust valve casing, and acts as a guide in which the piston portion of the change-over valve slides. The two ends of the liner form two seatings; the upper end forms the seat for the lower seating of the change-over valve, and the lower end a seating for the automatic check valve. The upper outside plain part of the liner makes a steam-tight joint in the exhaust valve casing, and for this reason the liner should only be removed when absolutely necessary, that is, when it becomes necessary to grind in the change-over valve. A special key (58) and guide nut (59) are supplied for removing this liner (see page 29).

The Automatic Check Valve (43) is a non-return valve which works in conjunction with the change-over valve, and seats itself on the lower end of the liner. Underneath the check valve is a small spring (45) which is just sufficient to support the weight of the valve. The function of the automatic check valve is simply to prevent steam from the steam chest entering the injector cones when the regulator is open and the injector not working. The steam chest is connected with the injector by a $\frac{3}{4}$-inch pipe through which steam from the steam chest enters underneath the check valve, raising this valve up on to its seating, thus cutting off any flow of steam from the steam chest into the injector cones. If the injector is put to work, the automatic check valve is free to follow the movements of the change-over valve.

Drip Valve.

A drain or drip valve (46) is fitted in the control portion of the injector, to drain water condensed in the steam chest pipe.

This valve is spring-loaded and remains in the open position until the engine regulator is opened, thus allowing any condensate to escape to atmosphere. When the regulator is opened, steam passes from the steam chest to the injector, and when the pressure reaches 20 lb. per square inch, it closes the drip valve.

So long as the steam chest pressure remains above 20 lb. per square inch, the drip valve remains closed.

It should be noted that this drip valve does not affect in any way the pressure at which the injector changes over, but is merely, as its name implies, a drain valve.

Automatic Choke (Fig. 5).

This consists of the Choke Valve (50) and the Spring (52), and its function is to regulate the quantity of auxiliary steam supplied to the injector when the regulator is shut, increasing the area for the admission of steam to the injector as the boiler pressure is reduced, so that at low boiler pressures sufficient live steam is admitted to work the injector. The auxiliary steam passes from Chamber A to Chamber D through a cylindrical hole in which the choke valve moves vertically so that the steam inlet area will vary according to the position of the choke valve.

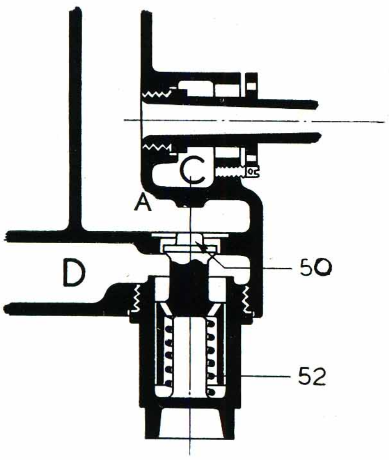


Fig. 5

Ref.	Part
50	Choke Valve.
52	Spring.

The choke valve consists of a cylindrical valve head which is slightly smaller in diameter than the corresponding hole connecting Chamber A to Chamber D. The lower portion of the choke valve forms a guide for the control spring and is connected to the valve head by a stem which is considerably smaller in diameter than the valve head.

The choke valve is subjected to two forces :—

(1) The pressure of the spring tending to force the valve upwards.

(2) The pressure of the live steam in Chamber A acting on the choke valve head

and tending to force the valve downwards so that the position of the valve will depend upon the difference between these two pressures.

The Choke Valve has two working positions :—

(1) At low boiler pressures, less than about half the standard working pressure of the locomotive, the upward pressure of the spring is greater than the downward pressure exerted on the valve head by the steam in Chamber A. The valve is therefore moved upwards by the spring until the valve head is outside the connecting hole between Chamber A and Chamber D. This results in an increased inlet area for the steam and therefore increases the supply of auxiliary steam to the injector.

(2) When the boiler pressure is at or near its normal working pressure, the pressure exerted by the steam on the Choke Valve head in Chamber A is greater than the upward pressure exerted by the spring so that the spring is compressed and the choke valve forced downwards to its lower position, where the valve head is inside the bore of the connecting hole and the inlet area for auxiliary steam reduced. The clearance between the valve head and the bore of the connecting hole is designed to be just sufficient to allow the necessary quantity of live steam to pass when the boiler is at its normal working pressure. This device allows the injector to function over a wide range of steam pressures and by increasing the quantity of auxiliary steam supplied to the injector makes it possible to work the exhaust injector at pressures as low as the live steam injector.

These three control systems, viz.: Exhaust Steam Admission Control, Change-over Control and Automatic Choke, comprise the steam control system (Fig. 6) of the injector and control the automatic action in the following manner, under all conditions of working :

The Change-over Valve (41) automatically controls the admission of live steam to the auxiliary steam nozzle, when exhaust steam is not available, or to the exhaust control piston controlling the opening of the exhaust steam valve when exhaust steam is available. The live steam to work the injector passes from the boiler steam valve through the steam pipe which is connected to the inlet flange on Chamber A, enters Chamber D, past the choke valve (which regulates the quantity of auxiliary live steam) and passes into Chamber F or Chamber C, according to the locomotive regulator being open or shut. The movement of the change-over valve is governed by the pressures in Chamber D and Chamber E, *i.e.*, by the boiler pressure and the steam chest pressure. When the injector is working with the regulator shut the steam in Chamber D keeps the change-over valve on its lower seating and so shuts off the supply of live steam to Chamber F, but allows steam to pass to Chamber C—in other words, allows the auxiliary live steam to pass into the injector, replacing the exhaust steam.

As soon as the regulator is opened, steam from the steam chest enters Chamber E, tending to lift the change-over valve against the downward pressure of steam in Chamber D. The proportions of the valve seatings and the piston of the change-over valve are so designed that the change-over takes place when the pressure in the steam

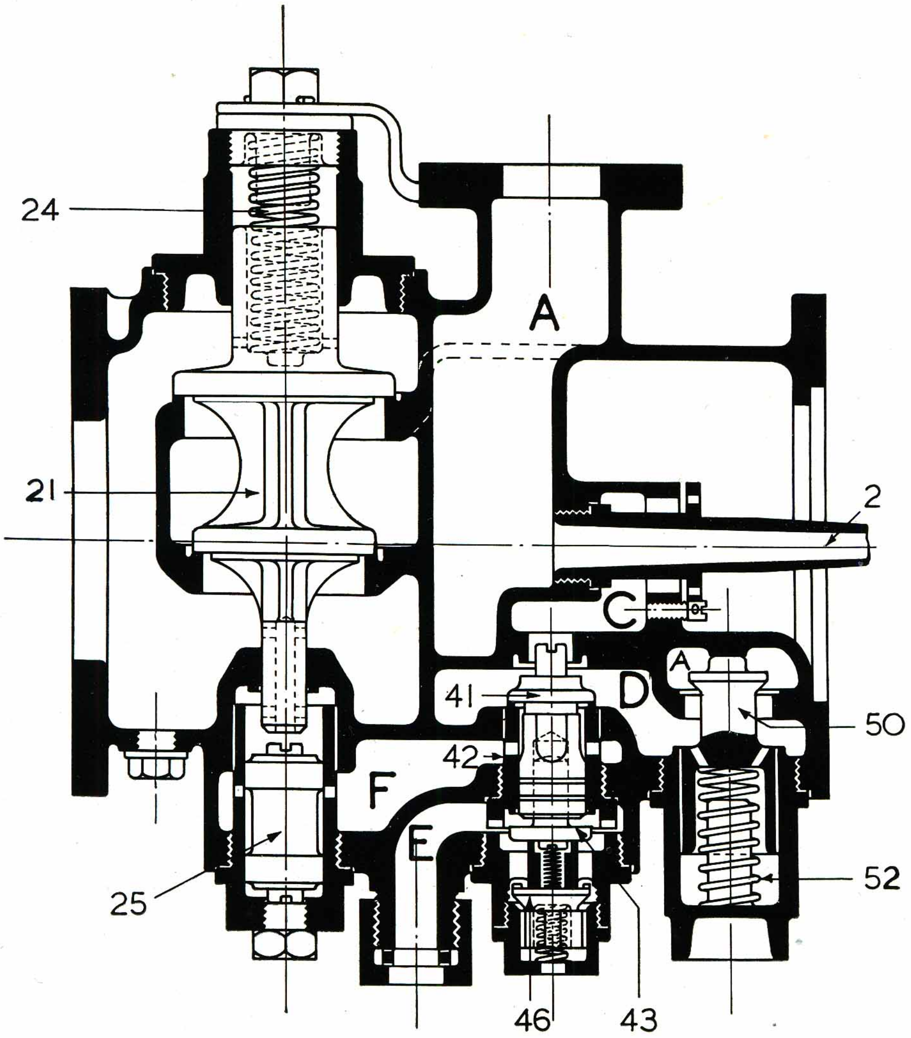


Fig. 6

Ref.	Part	Ref.	Part
21	Exhaust Steam Valve.	43	Automatic Check Valve.
24	Exhaust Valve Spring.	46	Drain or Drip Valve.
25	Exhaust Valve Control Piston.	50	Choke Valve.
41	Change-over Valve.	52	Spring.
42	Liner.		

chest is about one-third of the boiler pressure. When that pressure is reached in Chamber E the downward pressure in Chamber D is overcome and the change-over valve is forced up on to its upper seating, so cutting off the communication to Chamber C, *i.e.*, the flow of auxiliary live steam is stopped. As the regulator has been opened and the exhaust steam is available, no further auxiliary live steam is necessary to work the injector. The change-over valve, being forced on to its upper seating, opens the passage to Chamber F, and allows steam to pass to the underside of the exhaust valve control piston (25), forcing it up on to its seating and lifting the exhaust steam valve (21) to admit exhaust steam to the injector.

It should be noted that there is **no consumption of steam from the steam chest;** its pressure is utilised solely to control the movements of the change-over valve (41).

As soon as the regulator is shut again, the pressure falls in Chamber E and steam flows from Chamber D to Chamber E by way of the clearance between the change-over valve (41) and the liner (42). When the pressure in Chamber E falls below one-third of the boiler pressure the steam-flow past the change-over valve reaches a velocity at which the change-over valve is pulled off the upper seating and forced down to its lower seating by the pressure in Chamber D, thus shutting the passage to Chamber F. The steam from this chamber escapes into Chamber E along the piston clearance and from there to the steam chest pipe, so that as there is no pressure underneath the exhaust valve control piston, the spring on top closes the exhaust valve. The supply of auxiliary steam which now passes from Chamber D into Chamber C and so into the auxiliary steam nozzle has to pass the choke valve before reaching the Chamber D. If the boiler is at its normal working pressure the spring underneath the choke valve is compressed by the steam pressure on the top of it and the head of the choke valve is inside the corresponding opening of the body whereby it leaves just enough clearance to allow for the necessary quantity of auxiliary steam to work the injector.

Water Control System

(Fig. 7).

Inside the Engine Cab is the Water Regulator Sector Handle (20) on the top end of a rod, the bottom end of which is coupled to the Water Regulator Spindle (15) which controls both the supply of water to the injector, and the regulation of the quantity of water. The water supplied to the injector passes through the water valve (14) which consists of a circular disc valve fitted on the water regulator spindle (15) and rotated by it. The valve beds on a seating formed on the injector body, and is forced down on the seating by the water valve spring (18).

The disc valve (14) merely acts as water admission valve and does not regulate the quantity of water admitted to the injector cones. The movement of the sector handle (20) from the " shut " to " minimum " position rotates the disc valve, uncovering the water ports on the injector sufficiently to admit the full supply of water necessary to work the injector. The movement of the sector handle to the " shut " position closes the water ports so cutting off the water admission.

The regulation of water admitted is made by the exhaust steam cone which moves longitudinally. On the outside of the exhaust steam cone a transverse slot is cut into which a hardened steel die (16) is fitted to slide freely but without side play. The lower end of the water regulator spindle (15) is turned in the form of an eccentric pin which fits into a hole drilled in the water regulator die (16). The turning of the water regulator spindle results, therefore, in a longitudinal movement of the exhaust steam cone (3) this movement varying the annular area between the end of the exhaust steam cone (3) and the draft tube (4) through which the water enters. The variation of this area regulates the quantity of water admitted to the injector and is achieved by moving the water regulator sector handle between the " minimum " and " maximum " positions. By this means a large range of capacity is obtained, the minimum capacity being 50% of the maximum, allowing for a constant feed under all conditions of working.

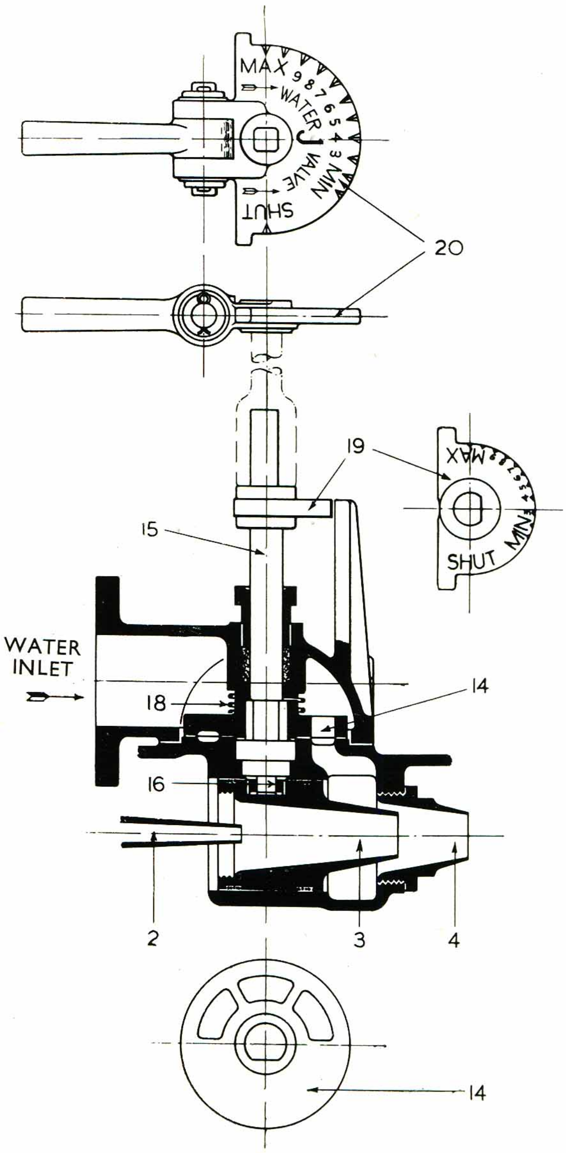


Fig. 7

Ref.	Part
2	Supplementary Steam Cone.
3	Exhaust Steam Cone.
4	Draft Tube.
14	Water Valve.
15	Regulator Spindle.
16	Regulator Die.
18	Water Valve Spring.
19	Water Regulator Sector.
20	Water Regulator Sector Handle.

Overflow and Delivery Valves

A special type of overflow valve (Fig. 8) is fitted, consisting of a valve (29) of the ordinary drop type positively controlled by a piston (35) which is fitted into the delivery chamber of the injector.

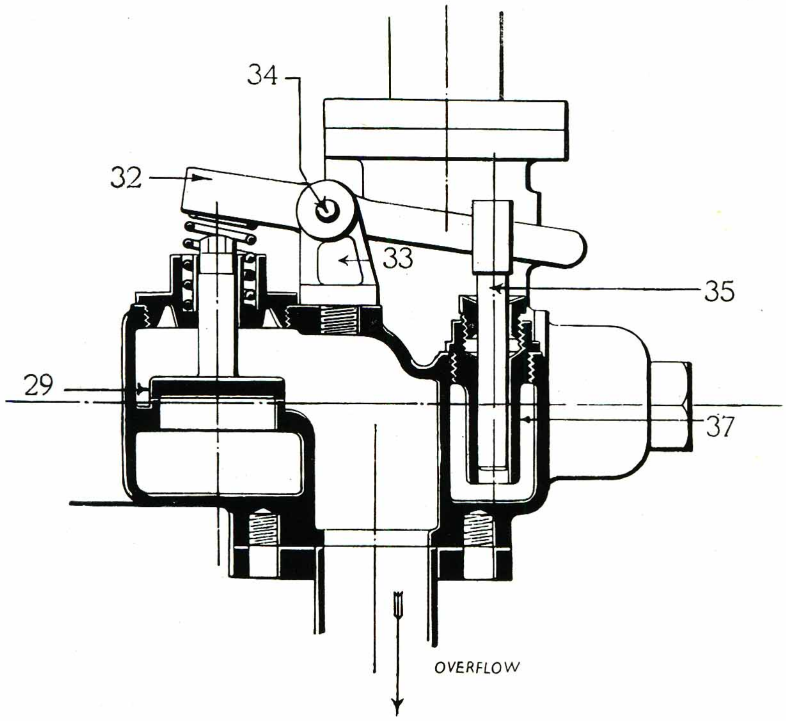


Fig. 8

Ref.	Part	Ref.	Part
29	Overflow Valve.	34	Overflow Control Fulcrum Pin.
32	Lever.	35	Piston.
33	Fulcrum.	37	Overflow Control Cylinder.

This piston (35) is coupled through a lever (32) pivoted on a fulcrum (33) on the casing so that the other end of the lever bears against the upper stem of the overflow valve (29). When the injector is working, the delivery pressure under the piston (35) forces up the lever (32) and so holds the overflow valve (29) on to its seating, thus sealing the overflow chamber.

Should the injector break off, the pressure under the piston immediately drops and the overflow valve is free to open, allowing the steam and water to escape through the overflow until the injector restarts, the increasing delivery pressure building up under the piston and again closing the overflow valve.

This is a safe and positive method of closing the overflow chamber, being perfectly automatic in action and preventing any waste or any leakage of air back into the injector.

The last valve which the water has to pass before leaving the injector is the delivery check or back pressure valve (11) (Fig. 1) which is a non-return valve to prevent the delivery pipe being emptied when the injector is shut off, and is also an additional safeguard in case of a defective boiler check valve.

Action of the Control System

(a) Injector working with exhaust steam (Fig. 9.)

The water valve (14) in the injector is opened and also the steam valve on the boiler so admitting water and live steam to the injector. Steam enters by the passage "A" and flows through the supplementary steam cone (2) into the injector, at the same

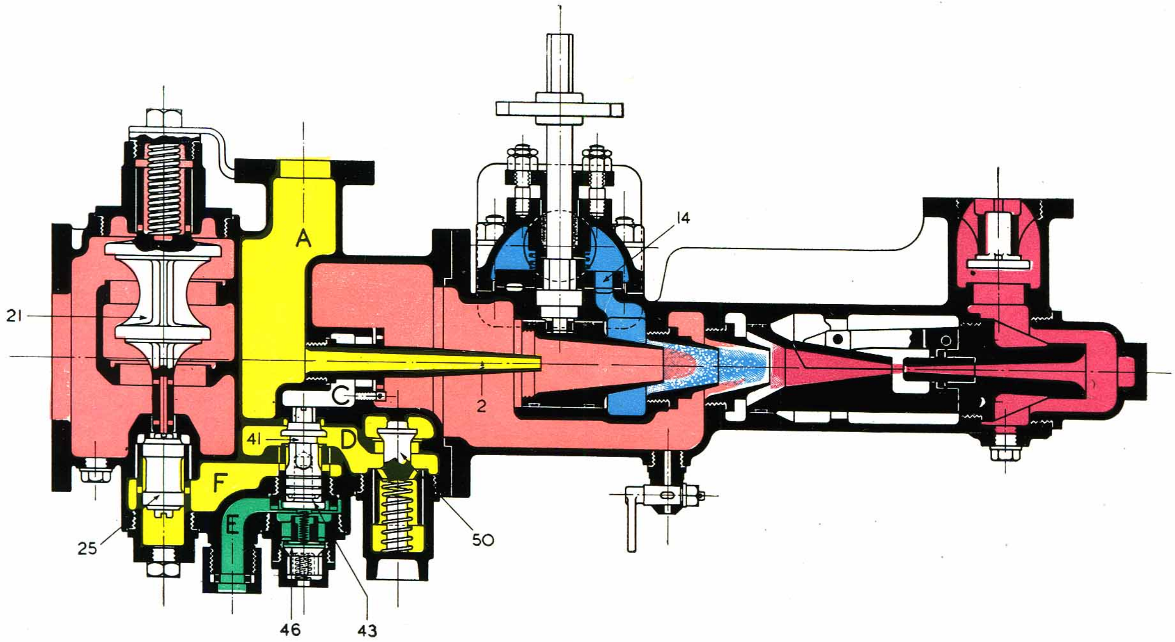


Fig. 9

Ref.	Part
2	Supplementary Steam Cone.
14	Water Valve.
21	Exhaust Steam Valve.
25	Exhaust Steam Valve Control Piston.
41	Change-over Valve.
43	Automatic Check Valve.
46	Drip Valve.
50	Choke Valve.

time passing through the choke valve (50) into the change-over chamber "D." The engine regulator being open, steam from the engine steam chest enters chamber "E" lifting both the automatic check valve (43) and the change-over valve (41). The latter closes the passage to chamber "C," thus preventing the flow of auxiliary steam into the injector.

The passage for the live steam to the chamber "F" is open, so steam passes to the underside of the exhaust valve control piston (25) which is forced upward on to its seat, whereby the exhaust steam valve (21) is opened.

Thus the injector works with exhaust steam as long as the regulator is open and the pressure in the steam chest is not less than one-third of the boiler pressure.

The positions of the various valves when the regulator is open and the *injector working with exhaust steam are*:—

(1) Exhaust Steam Valve (21) is open.
(2) Water Valve (14) is open.
(3) Change-over Valve (41) is on its upper seating.
(4) Automatic Check Valve (43) is on its seating.
(5) Drip Valve (46) is shut.

(b) **Injector working with live steam (engine standing or drifting with closed regulator).** (Fig. 10.)

The water valve in the injector and the steam valve on the boiler are open admitting water and live steam to the injector. Steam enters by passage " A " and flows through the supplementary steam cone into the injector at the same time through the choke valve (50) into the change-over chamber " D."

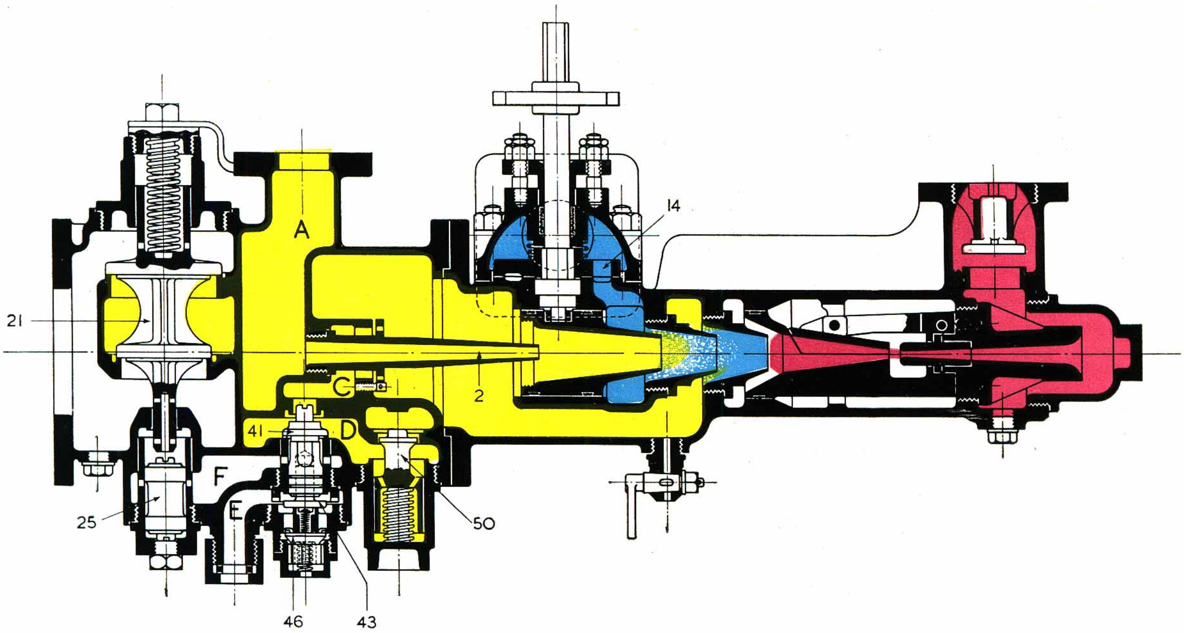


Fig. 10

Ref.	Part	Ref.	Part
2	Supplementary Steam Cone.	**41**	Change-over Valve.
14	Water Valve.	**43**	Automatic Check Valve.
21	Exhaust Steam Valve.	**46**	Drip Valve.
25	Exhaust Steam Valve Control Piston.	**50**	Choke Valve.

The engine regulator being shut, steam is cut off from the steam chest, and there is no pressure in the chamber " E." The pressure of the steam in chamber " D " forces the change-over valve on to its lower seating. This cuts off the supply of steam to the passage " F," which leads to the exhaust valve control piston (25) so that the exhaust valve is closed, shutting off communication between the exhaust steam supply pipe and the injector. At the same time steam passes from chamber " D " into passage " C " leading to the auxiliary steam nozzle and so into the injector, replacing the exhaust steam, the quantity being regulated by the choke valve.

The positions of the valves when the *regulator is shut* and the *injector is working with live steam* are :—

(1) Exhaust Steam Valve (21) is closed.
(2) Water Valve (14) is open.
(3) Change-over Valve (41) is on its lower seating.
(4) Automatic Check Valve (43) is off its seating.
(5) Drip Valve (46) is open.

Grease Separator

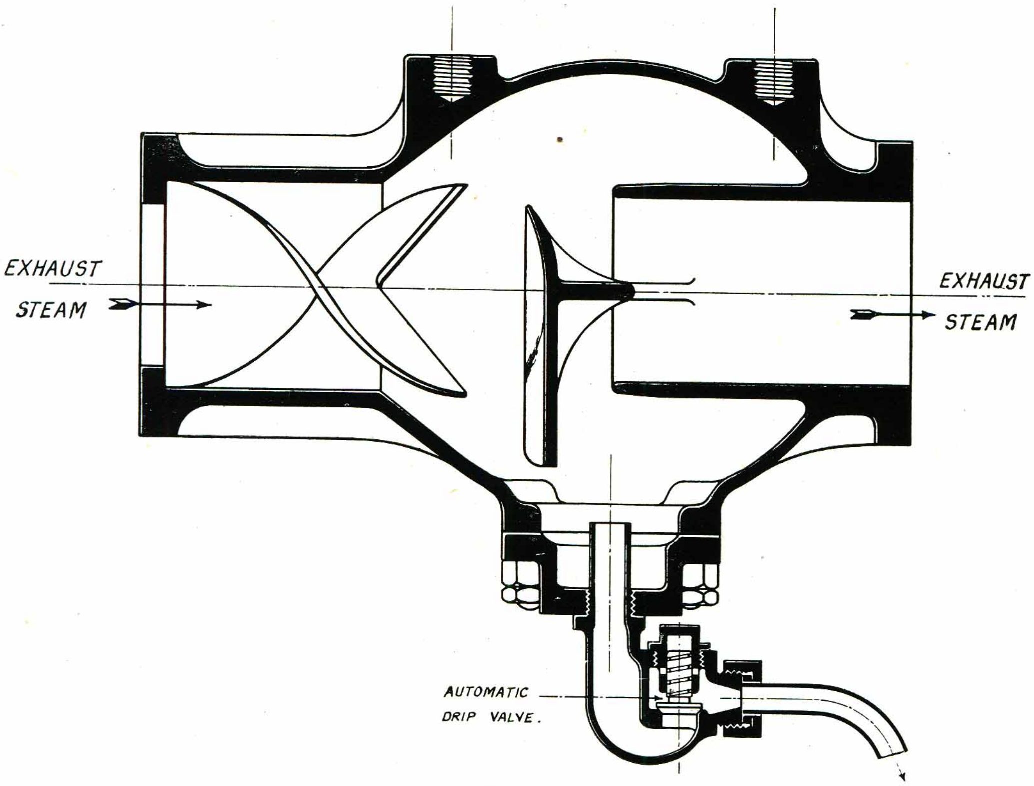


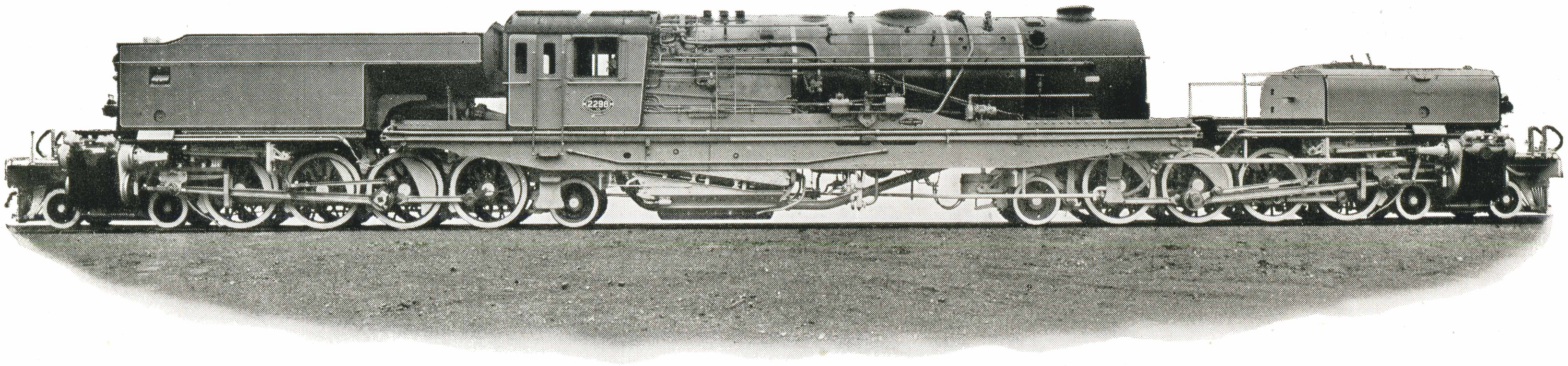
Fig. 11

The Class "H.M." Patent Grease Separator is fitted in the exhaust pipe line and consists of a spherical casing with flanged inlet and outlet branches for the exhaust steam—an arrow on the outside of the casing showing the direction of the flow of the exhaust steam.

In the inlet passage is fitted a helical vane which gives the incoming steam a rotary or centrifugal motion, so that the heavier particles of water, ash, oil, etc., are directed outwards to strike against the separator wall and then drop down into the well below.

A circular disc, or baffle plate, with a channel leading to the well below is fitted between the helical vane and the outlet passage so that any particles of grease or ash which may be carried forward by the steam will strike the baffle and pass down the channel into the well. The purified steam passes around the baffle plate and then through the outlet passage to the injector.

At the bottom of the spherical casing a well is formed into which is fitted an automatic drip valve. This valve allows a small quantity of exhaust steam to escape continuously to the atmosphere, and so drains away all impurities which may fall into the well during exhaust steam working.



4-8-2 + 2-8-4 Garratt Locomotive.
South African Railways.

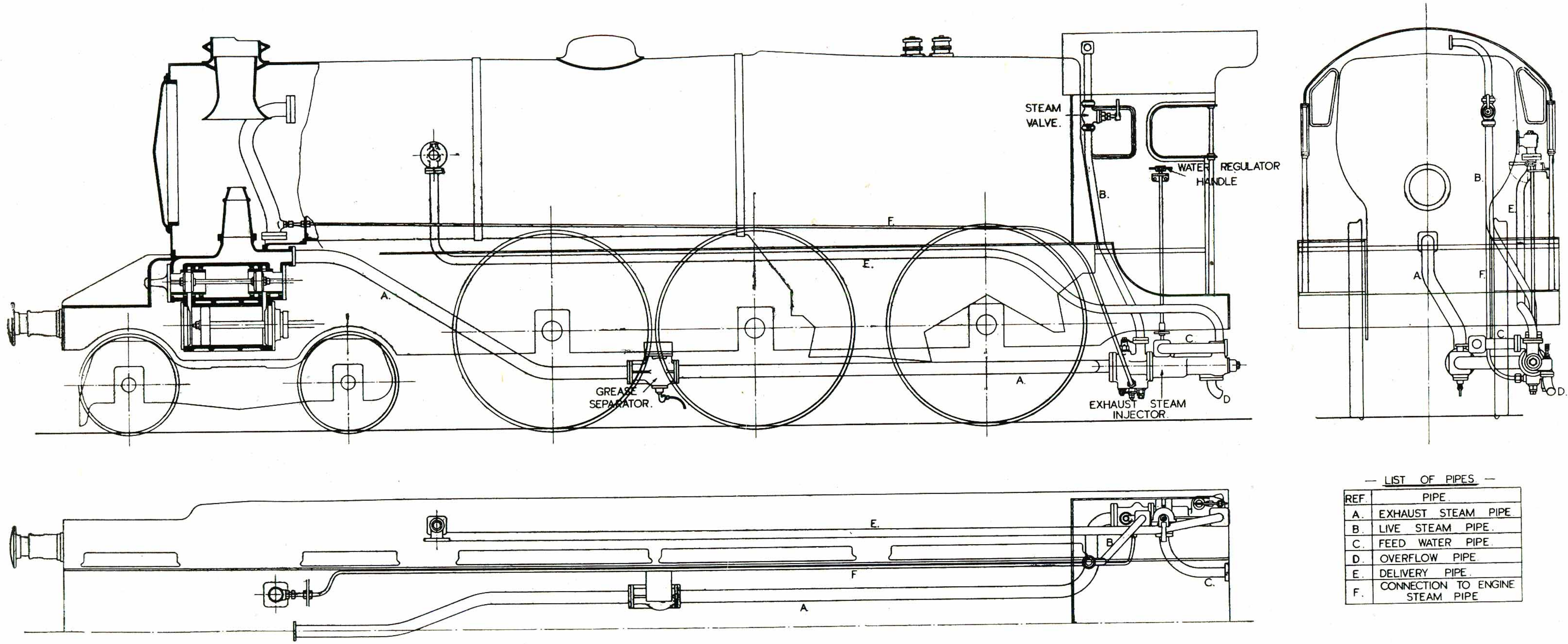
Built by Messrs. Beyer, Peacock & Co. Ltd.,
Gorton, Manchester.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

FIXING ARRANGEMENT OF

METCALFE'S PATENT EXHAUST STEAM INJECTOR — CLASS "J"

WITH GREASE SEPARATOR, STEAM VALVE, PIPING, ETC.



— LIST OF PIPES —

REF.	PIPE.
A.	EXHAUST STEAM PIPE
B.	LIVE STEAM PIPE.
C.	FEED WATER PIPE.
D.	OVERFLOW PIPE
E.	DELIVERY PIPE.
F.	CONNECTION TO ENGINE STEAM PIPE

Fig. 12

Installation

Diagrams of the installation and pipe arrangement are shown in Fig. 12.
A table of pipe sizes and injector capacities is shown on page 28.

The Exhaust Injector is of the non-lifting type, *i.e.*, it must be fixed lower than the bottom of the tender so that the water from the tender will flow to it. It is usually fitted below the footplate on the fireman's side and attached by a fixing bracket to either the frame or the foot step.

Accessories.

Besides the fixing brackets for the injector and the grease separator a rod connection is necessary between the water regulator spindle (15) on the injector and the water regulator sector handle (20) inside the cab. If the handle cannot be placed vertically above the regulator spindle one or two universal joints may be inserted in the connecting rod.

When fitting the water regulator sector handle (20) in the cab care must be taken that its "shut" position coincides with the "shut" position of the water regulator sector (19) on the injector itself, in other words that the water valve is really shut.

The following pipes are necessary :—

- Exhaust Steam Pipe (A) from cylinders to grease separator and from there to injector.
- Steam Pipe (B) from boiler to injector.
- Delivery Pipe (E) from injector to boiler.
- Feed Water Pipe (C) from tender to injector, including hose pipes between engine and tender.
- Steam Pipe (F) between engine steam pipe or steam chest and injector.
- A short Overflow Pipe (D).

The following valves are necessary :—

- Injector Steam Valve in the cab.
- Tender Feed Cock.
- Boiler Check Valve.

Care must be taken that all these pipes and valves are of *full bore throughout* and not less internally than shown in table (page 28). The *valves must have sufficient lift* to give full bore area.

A fitting often adopted is the combined steam and delivery valve in which the steam valve is combined with the boiler check valve in one casing fitted by a flange on to the firebox back plate, with steam and delivery pipes inside the boiler.

Pipes should be as free as possible from pockets, sharp bends and elbows.

All joints in the exhaust steam pipe and water supply pipe must be perfectly tight, so that there can be no air leakage. Rubber jointing should not be used.

The exhaust steam connection should be made into the exhaust passages as near to the cylinders as possible. We do not recommend making the connection into the blast pipe.

Tank Strainer.

A fine mesh sieve should be fitted into the tender so as to prevent dirt, etc., passing over with the feed water. It is imperative that the area of the strainer should be large so as to admit an ample supply of water, as it is always liable to become partially choked with dirt (leaves, coal, etc.).

A small tender strainer is a very frequent cause of Injector failures.

Working Instructions

To start the injector, open the water valve by means of the water regulator sector handle in the cab. Then open *fully* the injector steam valve on boiler. The injector then commences to work and the amount of feed can be regulated by the water regulator sector handle. The steam valve must always be *kept fully open* and *not* regulated. The injector then works with exhaust steam or live steam according as the regulator is open or shut.

To stop the injector, shut the injector steam valve on boiler, then shut the water valve by turning the water regulator sector handle to mark " *shut*."

Note 1.—The water regulator when in the " shut " position cuts off the injector water supply, so that the tender feed cock need not be touched, and should be left in the open position.

Note 2.—So far as is possible the injector should be kept constantly at work while the engine is running. A constant water level should be maintained by regulating the water supply. Intermittent feeding should be avoided.

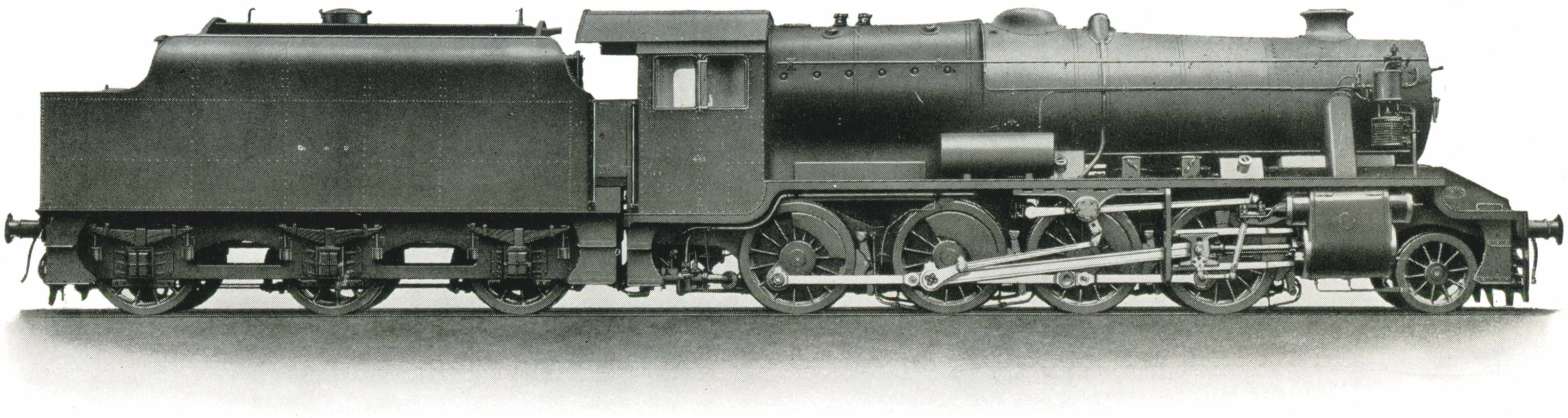
The regulation of capacity of the injector is large, so that a constant feed can be maintained under all conditions, whether the engine is worked heavily or lightly.

Filling the boiler at stops or when running down hill should, if possible, be avoided as the maximum fuel saving is only made while the exhaust injector is working with exhaust steam.

It is necessary, if the best results are to be obtained, that this method of boiler feeding (which is exactly the reverse to that of the live steam injector) should be adopted, otherwise a proportion of the economy will be lost, owing to the boiler being fed with live steam instead of exhaust steam.

Note 3.—During cold weather periods when the engine is not in service the injector and the feed water pipe should be emptied.

To do this—*shut tender feed cock and open injector water valve and drain cocks.*



2 - 8 - 0 Locomotive.
Ministry of Supply.

Built by Messrs. Beyer, Peacock & Co. Ltd.,
Gorton, Manchester.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

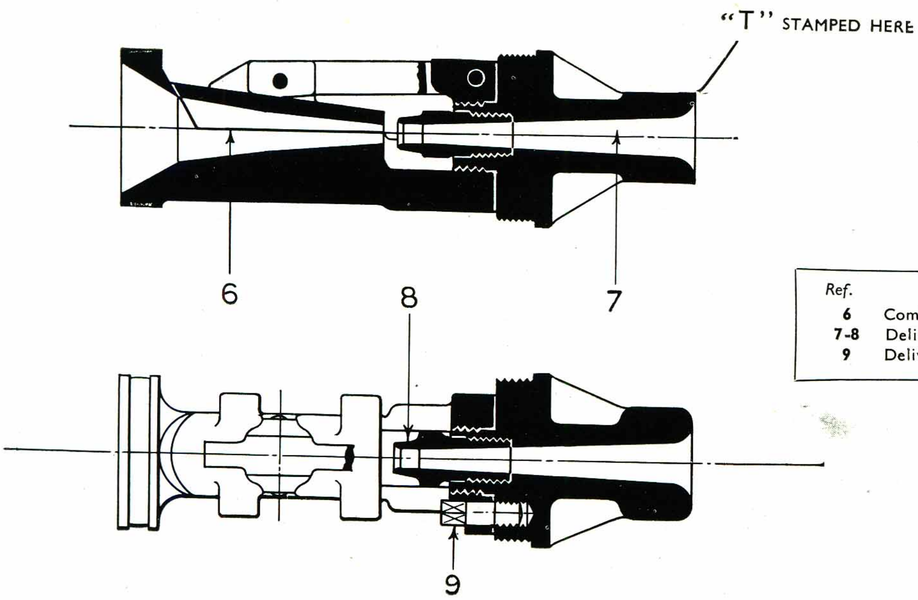
Maintenance

Tank hose and tender sieve should be examined and cleaned frequently; if badly choked there will be erratic action of the injector.

Joints in exhaust steam piping and injector feed pipe should be examined frequently for air leaks, which will affect the proper working of the injector.

The grease separator drip valve (68) Fig. 14, should be examined and cleaned to ensure proper functioning of the device, and the cover should be removed periodically and the separator drained and cleaned.

Removal of Cones.—The combining and delivery cones (6, 7 and 8) Fig. 13, are applied as a unit. To remove them, take off the cap nut (10) at the delivery end of the injector body and screw out the delivery cone, withdrawing the combining cone with it. To remove the renewable end (8) take out the setscrew (9) and separate the combining cone (6) from the delivery cone (7) by unscrewing.



Ref.	*Part*
6	Combining Cone.
7-8	Delivery Cone.
9	Delivery Cone Setscrews.

Fig. 13

When fitting the cones into the injector casing, care must be taken that the flap of the combining cone (6) is always at the top when the delivery cone (7) is screwed home on its seating. To verify the position of the flap the letter "T" is stamped on the outer end of the delivery cone, which letter, too, should be at the top.

For correct working of the injector, the flap should always be as near to the vertical as possible but a 60° variation on either side of the vertical is permissible and still allows the correct working of the injector.

Great care should be taken when removing or replacing the vacuum and draft tubes that the ends of the cones do not become damaged, as the slightest defect to these two cones can cause rapid wear.

The exhaust steam cone (3) Fig. 7, is actuated by an eccentric pin on the end of the water regulator spindle (15), which fits into a sliding die (16) in the cone, and the regulator spindle (15) must be taken out before the cone can be removed. When the parts are re-applied, special care must be taken to ensure that the *eccentric pin enters the hole in the sliding die*, and before applying other cones, the movement of the exhaust steam cone should be tested by moving the regulator spindle (15) from " shut " to " maximum."

The movement of the exhaust steam cone is

$\frac{1}{2}$-inch for the injector size 6 and 7.
$\frac{5}{8}$-inch „ „ „ „ 8, 9 and 10.
$\frac{13}{16}$-inch „ „ „ „ 10 (large body), 11, 12 and 13.

The renewable end (8) in the delivery cone (7) should be examined about every six months and, if worn, should be renewed.

Packing for the Injector.—Special cord packing is supplied for packing the exhaust steam cone (3), combining cone (6), change-over valve liner (42) and control piston guide nut (26). This should be examined and renewed, if necessary, when the engine is undergoing general repairs.

An anti-friction metallic packing is used for the overflow piston gland (36). This should be lubricated periodically to ensure that the piston moves freely.

The water regulator gland (17) for the water regulator spindle (15) should be well packed with greased asbestos and the gland should be screwed down tightly enough to prevent the water regulator spindle from creeping when the injector is working.

Spare Parts.—Spare parts can be supplied. When ordering, give injector size, names of part and reference number shown on Fig. 14, page 29.

Table of Pipe Sizes and Capacities–Class "J" Exhaust Injector

Size of Injector	Capacity Gallons per hour		Internal Diameter of Pipes in Inches					Connection to Engine Steam Chest
	Maximum	Minimum	Exhaust Steam	Live Steam	Water from Tender	Delivery to Boiler	Overflow	
6	920	470	$2\frac{1}{2}$	1	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	3/4
7	1250	630	$2\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	3/4
8	1600	820	3	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	2	3/4
9	2000	1050	$3\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{4}$	3/4
10	2500	1300	4	$1\frac{1}{2}$	2	$1\frac{3}{4}$	$2\frac{1}{4}$	3/4
11	3000	1600	$4\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	3/4
12	3600	1900	5	$1\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{3}{4}$	3/4
13	4100	2200	5	2	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3/4
14	4800	2500	$5\frac{1}{2}$	2	$2\frac{3}{4}$	$2\frac{1}{2}$	3	3/4
15	5500	2800	6	$2\frac{1}{4}$	3	$2\frac{3}{4}$	$3\frac{1}{4}$	3/4
16	6300	3300	6	$2\frac{1}{4}$	$3\frac{1}{4}$	3	$3\frac{1}{2}$	3/4

For slow running goods engines the internal diameter of the exhaust pipe should be $\frac{1}{2}$-inch larger than shown in above table.

LOCOMOTIVE EXHAUST STEAM INJECTOR.

CLASS "J"

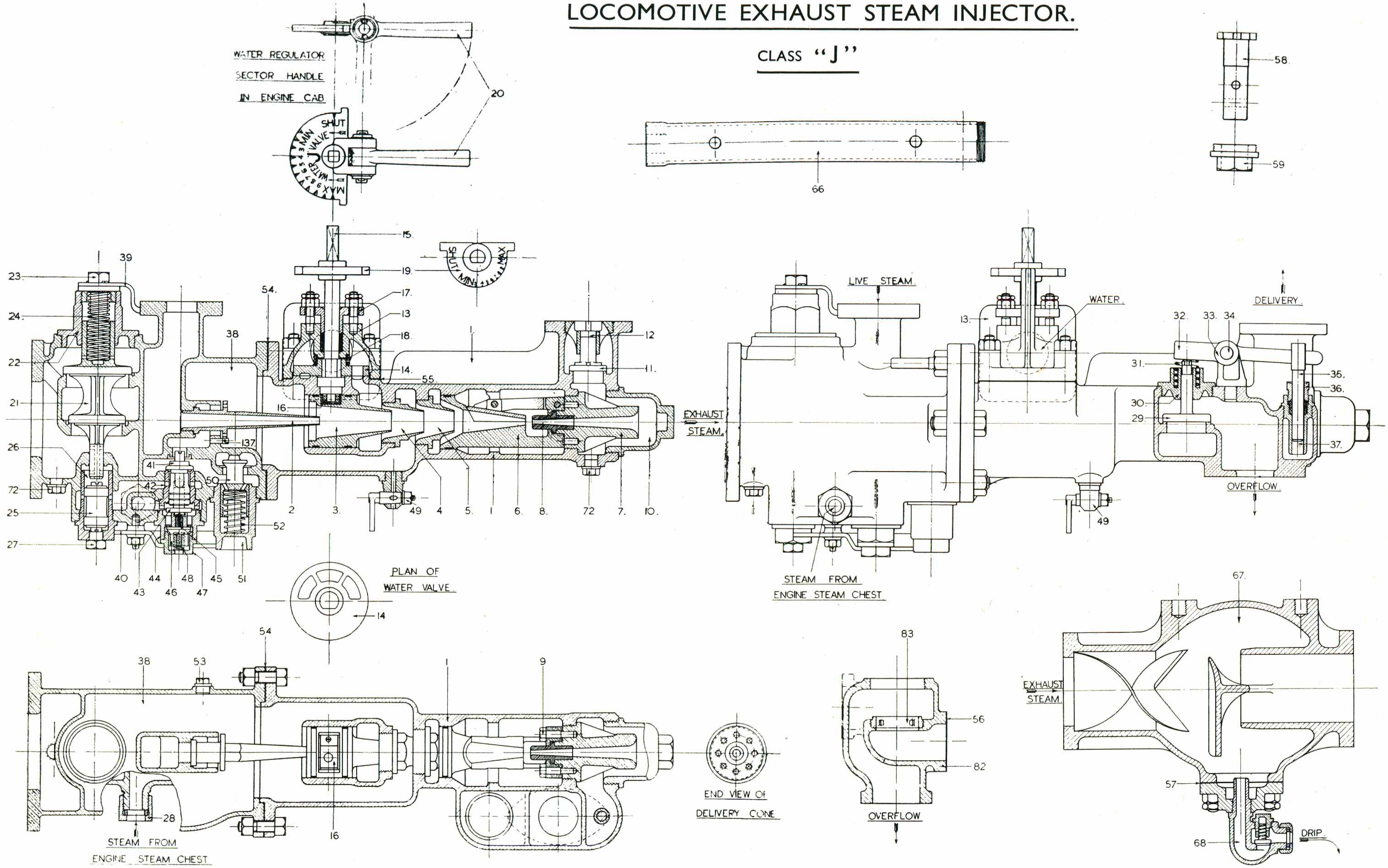


Fig. 14

LIST OF PARTS

Ref.	Part
1	Injector Casing
*2	Supplementary Steam Cone
3	Exhaust Steam Cone
*4	Draft Tube
*5	Vacuum Tube
*6	Combining Cone
*7	Delivery Cone
*8	Delivery Cone Renewable End
*9	Delivery Cone Set-screw
*10	Cone Cap Nut
*11	Back Pressure Valve
*12	Back Pressure Valve Guide
13	Water Valve Casing
14	Water Valve
15	Water Regulator Spindle
16	Water Regulator Die
17	Water Regulator Gland
18	Water Valve Spring
19	Water Regulator Sector
20	Water Regulator Sector Handle
21	Exhaust Steam Valve
22	Exhaust Steam Valve Cap Nut
23	Exhaust Steam Valve Grinding Nut
24	Exhaust Steam Valve Spring
25	Exhaust Steam Valve Control Piston
26	Control Piston Guide Nut
27	Control Piston Grinding Nut
28	Coupling Nut and Ring
*29	Overflow Valve
*30	Overflow Valve Guide Nut
*31	Overflow Valve Spring
*32	Overflow Control Lever
*33	Overflow Control Fulcrum
*34	Overflow Control Fulcrum Pin
*35	Overflow Control Piston
*36	Overflow Control Piston Gland
*37	Overflow Control Cylinder
38	Exhaust Valve Casing
39	Top Locking Plate
40	Bottom Locking Plate
41	Change-over Valve
42	Change-over Valve Liner
43	Automatic Check Valve
44	Change-over Valve Cap Nut
45	Automatic Check Valve Spring
46	Drip Valve
47	Drip Valve Cap Nut
48	Drip Valve Spring
*49	Drain Cock
50	Choke Valve (state boiler pressure)
51	Choke Valve Guide Nut
52	Choke Valve Spring
53	Plug-Test
54	$\frac{1}{32}$" Asbestos Joint for Exhaust and Injector Casings
55	$\frac{1}{32}$" Asbestos Joint for Water Valve Casing
56	$\frac{1}{32}$" Asbestos Joint for Overflow Size 11-13 Body only
57	$\frac{1}{32}$" Asbestos Joint for Grease Separator
58	Key for Item 42
59	Guide Nut for Key
*66	Cone Box Key
*67	Grease Separator
*68	Grease Separator Drip Valve
*72	Plug-Drain
*82	Overflow Valve Casing
*83	Overflow Valve Seat
	Nos. 82 & 83: size 11-13 Body only
*137	Setscrew for Locking Supp. Steam Cone

Note.—Parts marked thus * are interchangeable with Class H Exhaust Steam Injectors of the same size. When Ordering Spare Parts state name of Part. No. of Part, Size of Injector.

Steaming Capacity and Draft

The application of an Exhaust Injector to a locomotive is equivalent to an increase of steaming capacity. As the feed water is heated by the exhaust steam before entering the boiler, waste heat is returned to the boiler, so that for the same amount of coal burnt on the grate there is a definite increase of steam production. This is very noticeable in locomotives which are worked at or near their maximum capacity and is clearly shown by the steadiness of the steam pressure when the engines are working.

From 10% to 12% of the exhaust steam is taken by the injector, so that the quantity of steam passing through the blast pipe orifice is reduced, with a consequent slight reduction of the draft equivalent to about a 5% drop in the smokebox vacuum. The effect of this on the steaming of the boiler is, however, negligible compared with the increase of steam production, and when fitting an exhaust injector to any locomotive no change whatever is necessary in the draft arrangement.

The exhaust steam is directly condensed by and forms part of the boiler feed, so that the amount of exhaust steam taken is the minimum necessary to heat the feed water and force it into the boiler, the effect on the draft being less than with other types of feed water heaters.

An improvement is also found in the quality of the feed water, the condensed exhaust Team being in the form of pure distilled water when returned to the boiler.

there is no possibility, under any circumstances, of delivering cold water into the boiler. When using the injector with live steam (engine standing or drifting with closed regulator) a hot feed is always delivered to the boiler, so that the boiler troubles frequently experienced when using pumps, due to the introduction of cold water into the boiler, are eliminated.

Temperature of Water Delivered to the Boiler

This is a feature of considerable importance, as any increase of feed temperature affects fuel economy, and also reduces the wear and tear of the boiler, with resulting economy in boiler maintenance.

With an exhaust steam injector there are several factors which influence this temperature, namely, the exhaust steam pressure, feed water temperature, the quantity of water delivered to the boiler, etc.

A maximum temperature of 230°F. is obtained when the injector is working at its minimum capacity, *i.e.*, with the water regulator cut down to its lowest working position. During ordinary working when the water regulator is set in approximately the mean position, the delivery temperature ranges from 190° to 200° Fah., so that an extremely hot feed is always delivered to the boiler.

Reduction of Cylinder Back Pressure

A reduction of cylinder back pressure is always found when the exhaust injector is working, owing to the amount of exhaust steam condensed by the injector. This varies with the exhaust steam pressure, being greater as the exhaust pressure increases, so that when the locomotive is being forced, giving the maximum evaporation and maximum exhaust steam pressure, the reduction of cylinder back pressure is also greatest.

The reduction of back pressure is about 10% of the absolute back pressure, and is clearly shown in tests when indicator cards are taken or when pressure gauges are fixed in the blast pipe or in the exhaust steam pipe.

Coal and Water Economy

If the exhaust injector is worked, a definite economy must be obtained under all conditions of working. The exhaust injector cannot feed the boiler under any circumstances without utilising exhaust steam when available. The greater portion of the feeding work and of the heat content of the delivery water are obtained from the exhaust steam, so that waste heat is continually being returned to the boiler so long as the injector is kept at work.

If no fuel economy is shown in the fuel consumption records, then this is being wasted in other directions, for it is clear that if a certain amount of otherwise waste heat is returned into the boiler a corresponding fuel economy must result, and if this is not apparent there must be other conditions preventing it being shown.

The economy obtained by the use of the injector is the result of several factors :—

(1) Economy due to the direct return of heat to the boiler by the condensation of exhaust steam during its passage through the injector. The amount of steam condensed varies slightly with the working conditions, but in normal service 10% is condensed and returned directly to the boiler.

(2) Economy due to the reduction of cylinder back pressure. As previously stated, when the injector is working there is a reduction of cylinder back pressure. This represents a direct increase of effective piston pressure and an increase in the power developed by the locomotive.

(3) Economy due to the high temperature of feed water delivered to the boiler and the lower rate of firing.

The total saving varies, of course, with the locomotive and the class of work which it is doing, but test results show a regular economy of from 8 to 12% in general service. A water saving of 10 to 12% is usually found due to the exhaust steam condensed and returned to the boiler by the injector.

Maintenance Cost of Locomotive Feed Water Heaters

To make any equitable comparison between the economy realised by different systems of Locomotive Feed Water Heating, it is necessary to take into account, in each case, the total maintenance cost of the apparatus employed.

Maintenance costs with the Exhaust Steam Injector are extremely low, averaging about 4¾d. per 1,000 train miles, while the maintenance costs of Pumps and Heaters are about *fifteen times* as great.

These figures are for maintenance only and do not cover interest and depreciation. Further, the initial cost of the exhaust injector is much lower than that of any other system of feed water heating, and, therefore, the total figures, including interest and depreciation charges, enhance this great difference in working costs.

EXTRACT FROM MONTHLY BULLETIN OF THE INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

Page 2101. *October* 1930.

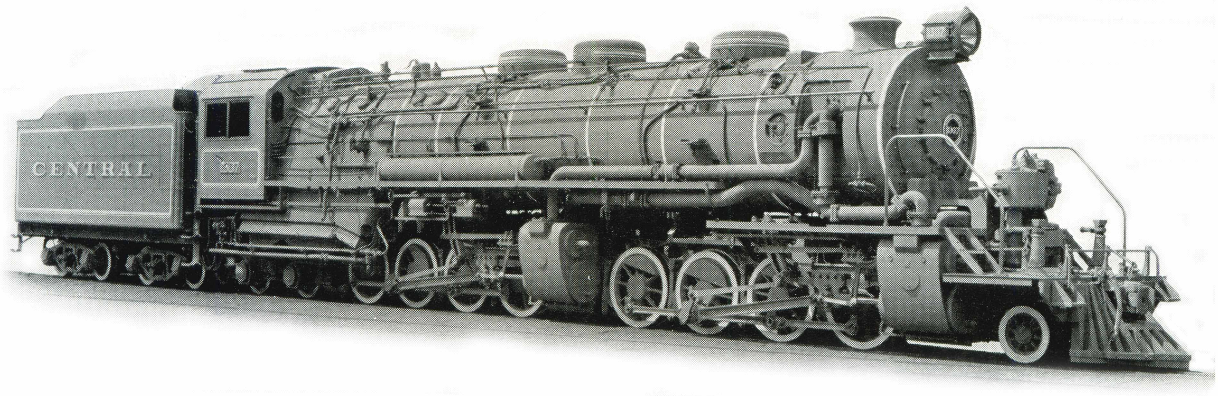
Communication from Mr. R. P. Wagner,
Chief Engineer, German State Railways,
Special Reporter on Question VI, Madrid Session of the International Railway Congress.

MAINTENANCE COSTS OF VARIOUS PRE-HEATERS

1. **Exhaust Steam Injector.**
   1.50 French francs per 1,000 train kilometres.
   4.7 pence per 1,000 train miles.

2. **Surface Heater (Knorr).**
   29.15 French francs per 1,000 train kilometres.
   90.0 pence per 1,000 train miles.

3. **Contact Heater A.C.F.I./R.M.**
   21.90 French francs per 1,000 train kilometres
   67.6 pence per 1,000 train miles.



2 - 8 - 8 - 4 Mallet Type Locomotive.
Central Railway of Brazil.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

The Advantages of the Class "J" Exhaust Steam Injector

May be briefly stated as follows :—

(1) Saves 10% in coal and water, and this saving is regularly maintained in service, due to the fact that the exhaust steam heats the feed water and also forces it into the boiler.

(2) Reduces cylinder back pressure, so increasing the power of the locomotive.

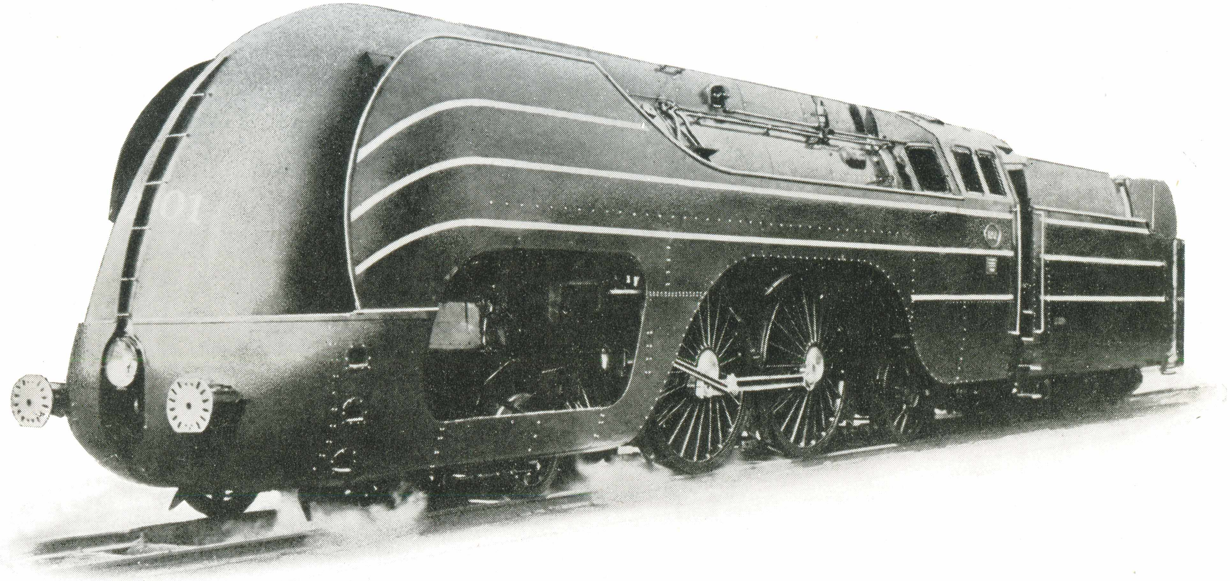
(3) Hot water is delivered to the boiler whether the engine is running or standing, so improving the circulation and reducing the stresses set up by the admission of cold feed water.

(4) Installation and maintenance costs are much lower than those of any other type of locomotive feed water heater.

(5) *Simplicity of working.* The injector is started like an ordinary live steam injector by simply opening the water valve and the steam valve and requires no further attention. It switches over automatically from exhaust steam to live steam working when the engine regulator is shut or *vice versa.*

(6) The steaming power of the boiler is greatly improved, and the injector has a large range of capacity, so that a constant feed can be maintained under all conditions of working.

(7) Simplicity of construction with no moving parts, while feeding and easy access to all parts for examination and cleaning without dismounting the injector.



4-4-2 Type Locomotive. *Belgian State Railway.*

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Possible Causes of Injector Failures

If the Injector primes and then flies off instead of working, the combining nozzle (6) may be choked or the combining nozzle flap may not be seating properly. Air leaks or the sticking of the back pressure valve (11) or the main boiler check valve may also be responsible for trouble of this nature.

If injector works with live steam but will not work with exhaust steam, either the change-over valve (41) does not function or the exhaust valve (21) does **not open.**

If the injector works with exhaust steam but will not work with live steam, the change-over valve (41) may not function, or the exhaust valve (21) may be **stuck open.**

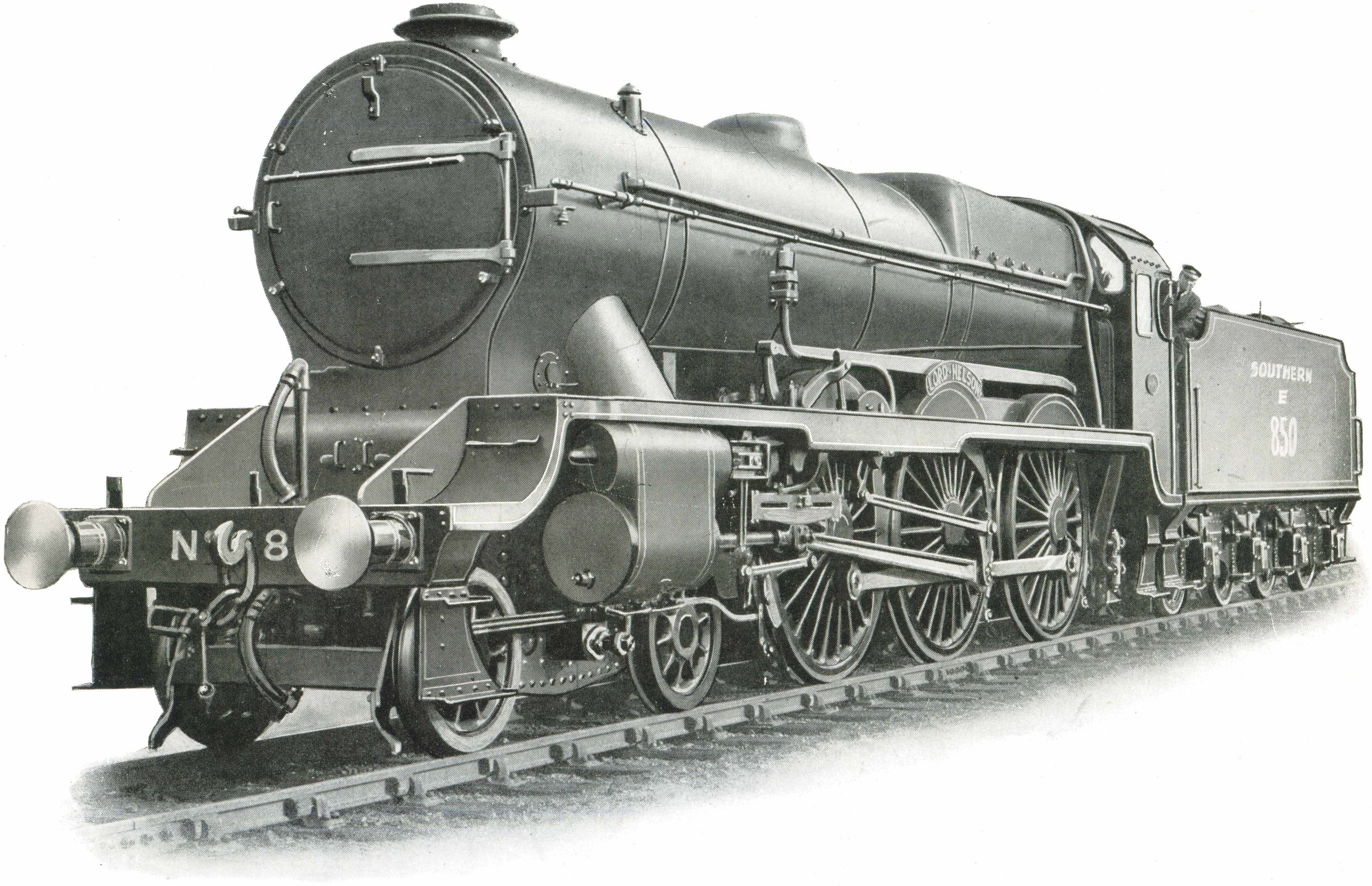
If steam escapes in puffs from the overflow when the injector is **shut off** with engine working, exhaust valve (21) is either stuck open or does not seat properly.

If water escapes at overflow when injector is **not working,** the water valve (14) does not shut properly or may need grinding in.

If steam escapes from the overflow when the injector is **not working,** the boiler steam valve does not seat properly or may need grinding in.

If water escapes at overflow when injector is **working** and cannot be corrected by adjustment of the water regulator, the overflow control piston (25) may be sticking or the overflow valve (29) may need grinding in or some of the injector nozzles may have become loose in the injector body.

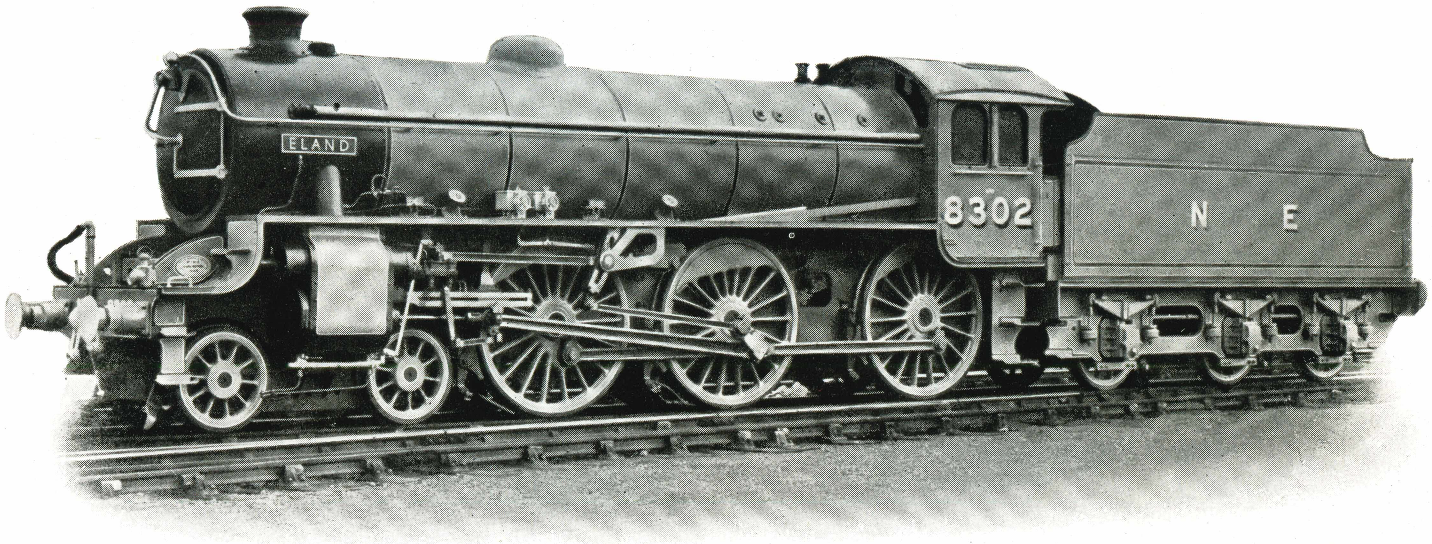
To test the automatic change-over from live steam to exhaust steam and *vice versa*, apply engine brake with engine standing, start injector working, and then open the engine regulator. If the change-over valve (41) functions properly, the injector will stop working and water will run out of the overflow. Then close the regulator and open cylinder cocks. When the pressure has escaped from the engine cylinders, the injector will immediately go to work. If the injector does not operate as outlined above and continues to work with the regulator open, the change-over valve does not function. Either a restriction will be found in the steam pipe leading from the steam chest of the locomotive to the injector, or the change-over valve is sticking.



4-6-0 4-Cylinder Express Locomotive.
Southern Railway.

Designed by the late R. E. L. Maunsell, C.B.E.,
Chief Mechanical Engineer.

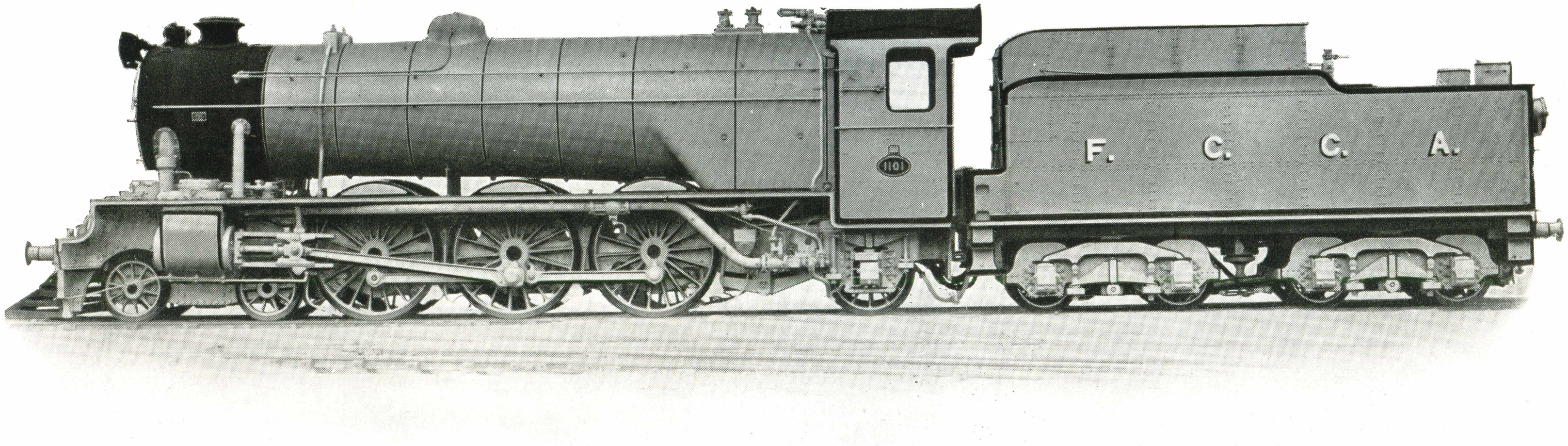
Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.



4 - 6 - 0 B 1 Class Locomotive
London & North Eastern Railway

By kind permission
of A. H. Peppercorn, C.M.E.

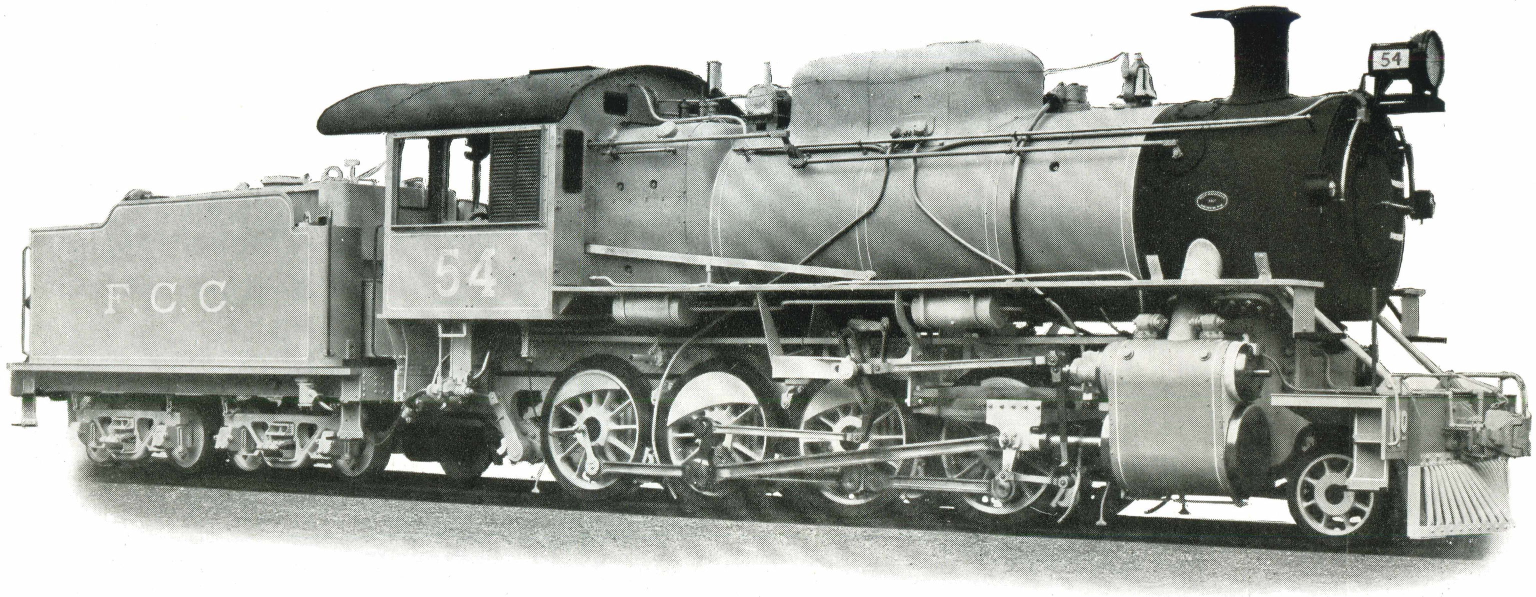
Fitted with **METCALFE'S PATENT EXHAUST STEAM INJECTOR.**



4 - 6 - 2 Locomotive.
Central Argentine Railway.

Built by Sir W. G. Armstrong Whitworth & Co. Ltd.,
Newcastle-upon-Tyne.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.



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