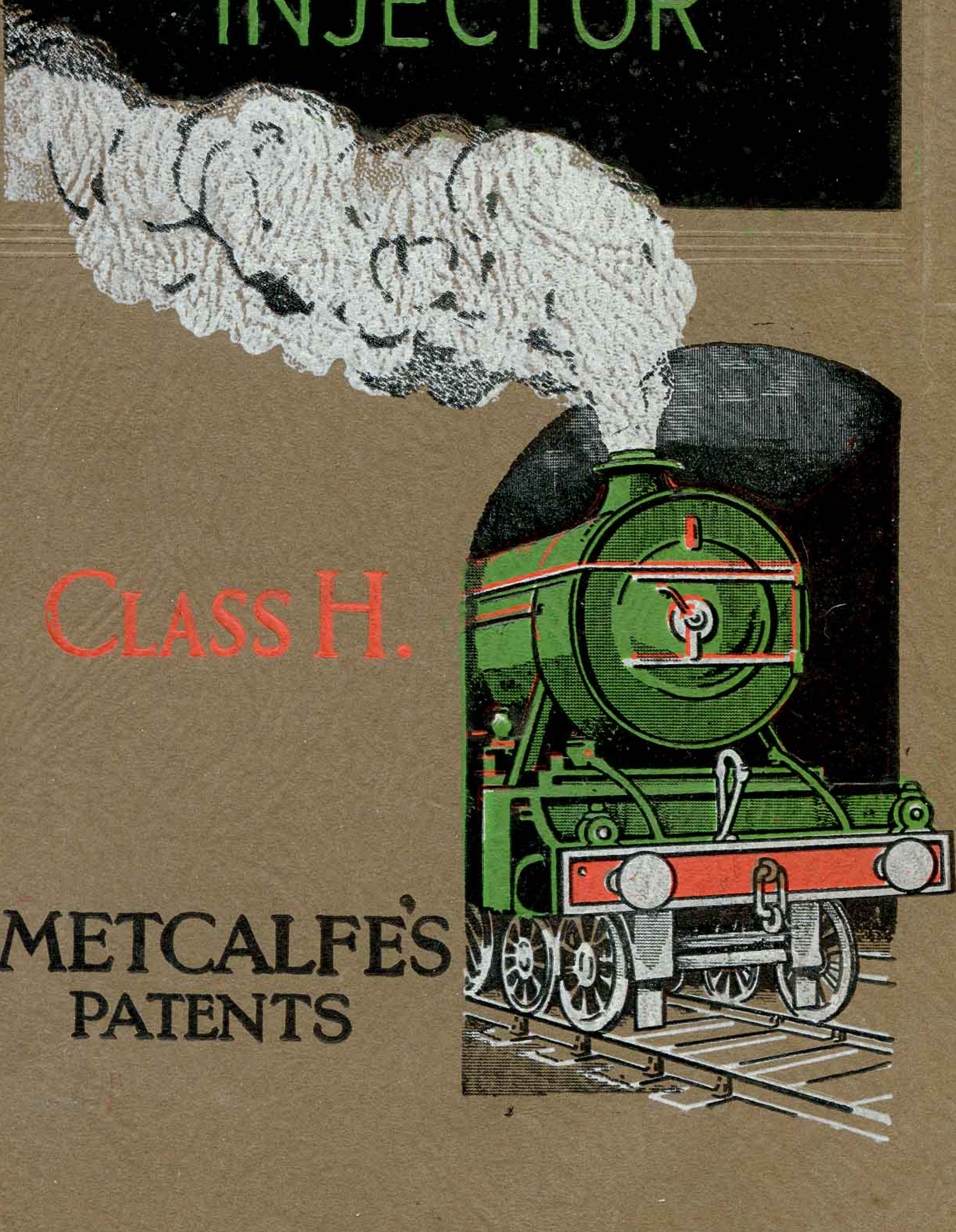
THE EXHAUST STEAM INJECTOR



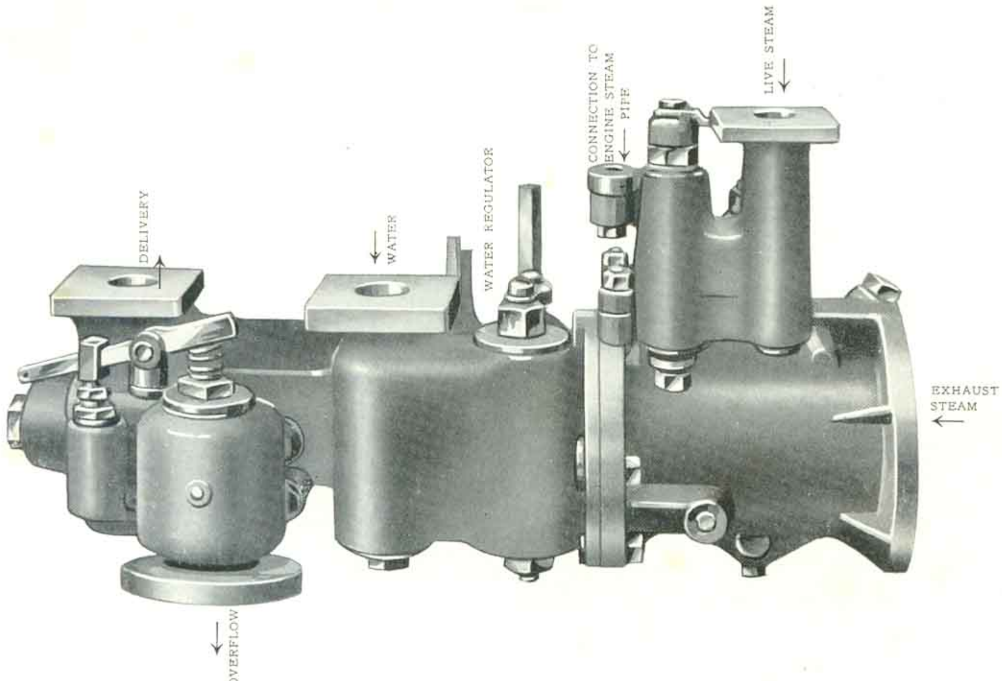
CLASS H.

METCALFE'S
PATENTS

THE EXHAUST STEAM INJECTOR

CLASS "H"

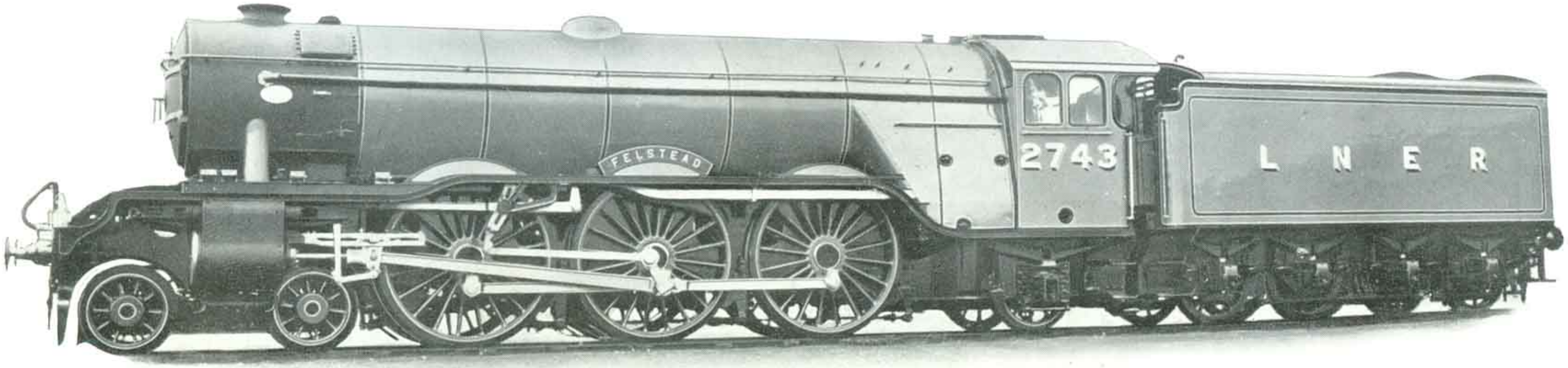
METCALFE'S PATENTS



THE SIMPLEST AND MOST RELIABLE
LOCOMOTIVE FEED WATER HEATER

8 to 12% Coal and Water Economy

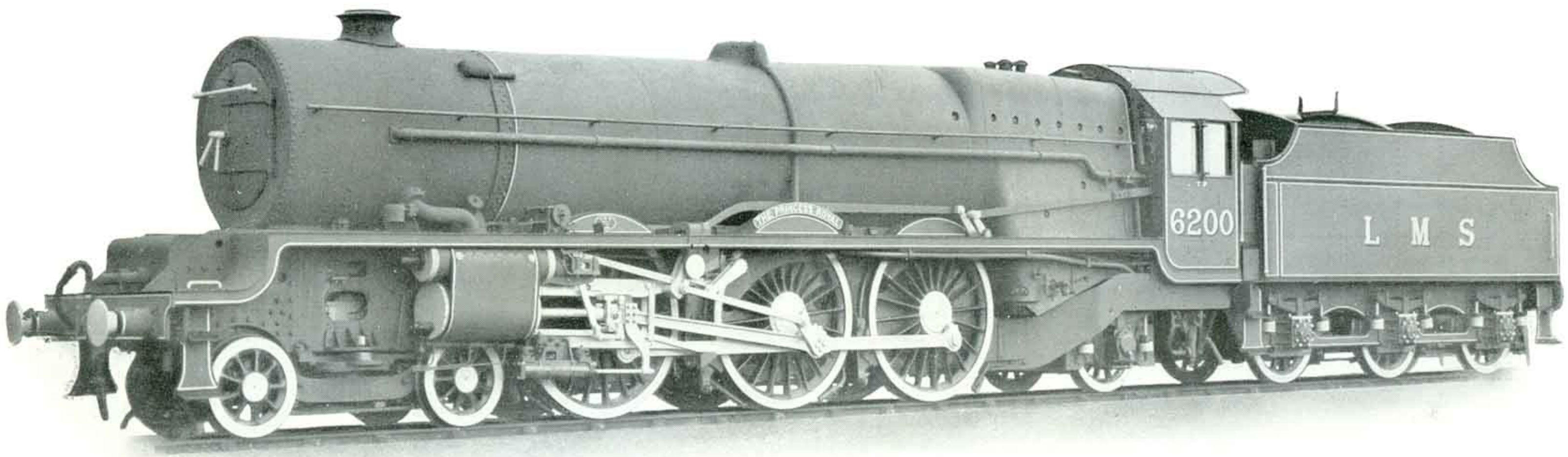
OVER 20,000 LOCOMOTIVES FITTED



4 - 6 - 2 Pacific Type Locomotive.
London & North Eastern Railway.

By the courtesy of H. N. Gresley, Esq., C.B.E.,
Chief Mechanical Engineer.

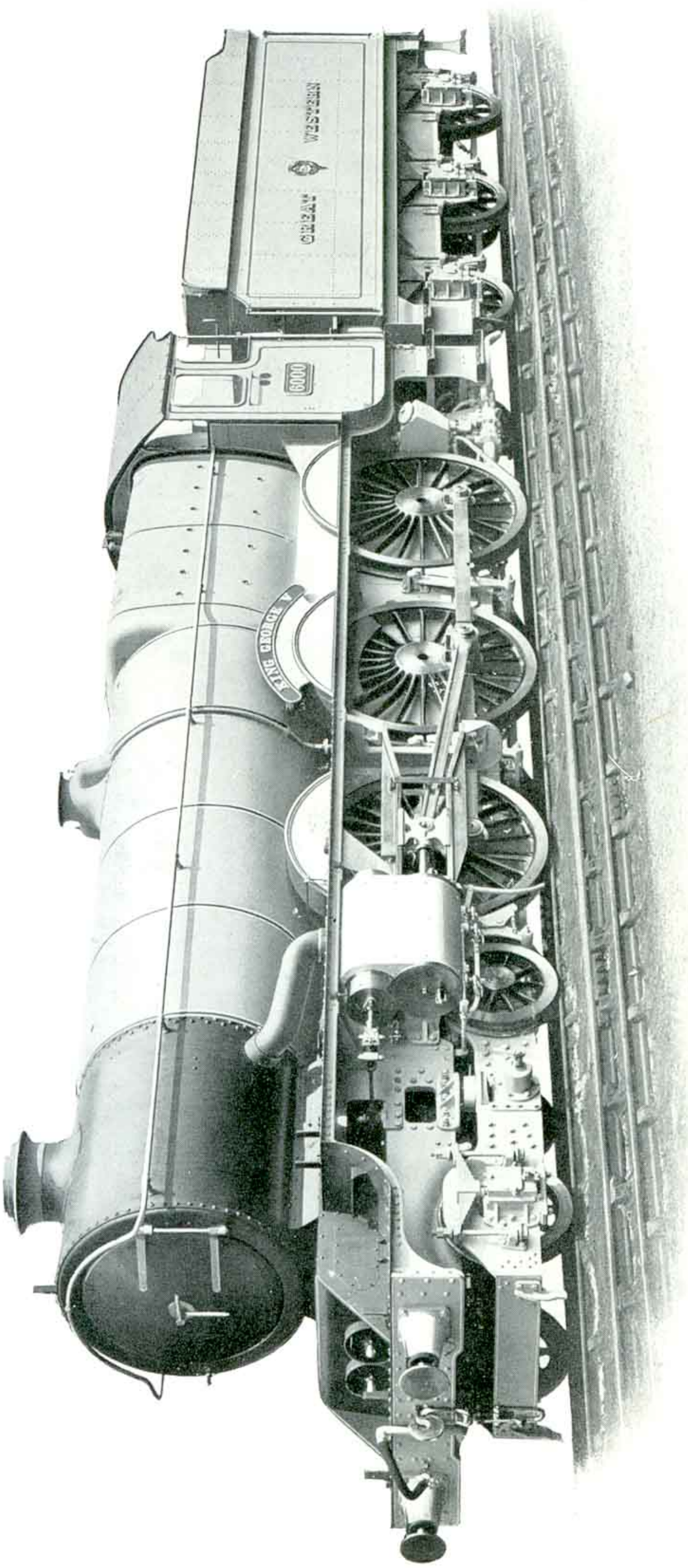
Fitted with DAVIES & METCALFE'S PATENT EXHAUST STEAM INJECTOR, and VACUUM BRAKE EJECTOR.



4 - 6 - 2 Pacific Type Locomotive.
London Midland & Scottish Railway.

By the courtesy of W. A. Stanier, Esq.
Chief Mechanical Engineer.

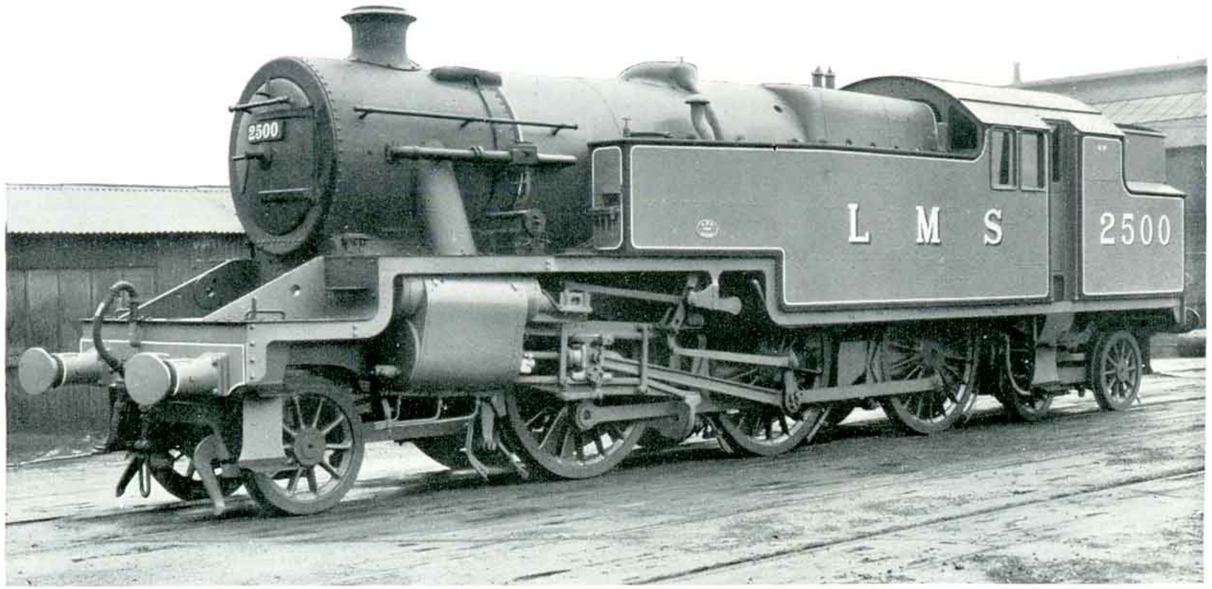
Fitted with DAVIES & METCALFE'S PATENT EXHAUST STEAM INJECTOR.

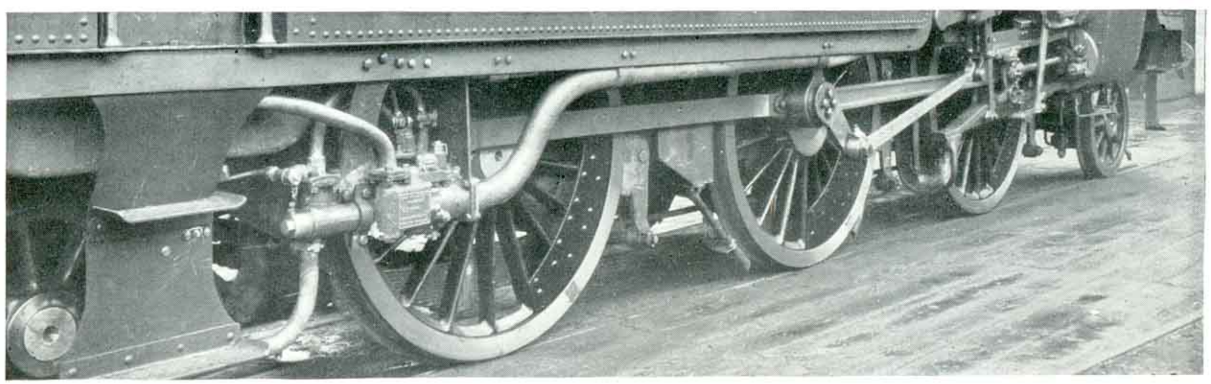


4-6-0 4-Cylinder Express Locomotive.
Great Western Railway.

Designed by C. B. Collett, O.B.E.,
Chief Mechanical Engineer.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

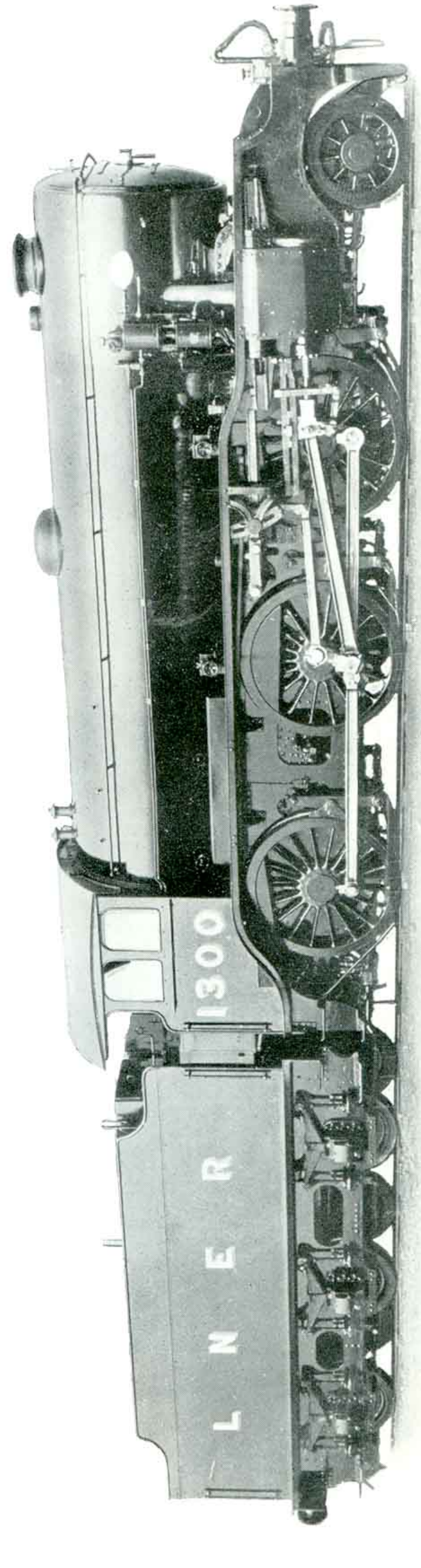




2-6-4 3-Cylinder Tank Engines.
London Midland & Scottish Railway.

By the courtesy of W. A. Stanier, Esq.
Chief Mechanical Engineer.

Fitted with DAVIES & METCALFE'S PATENT EXHAUST STEAM INJECTOR.



By the courtesy of H. N. Gresley, Esq., C.B.E., Chief Mechanical Engineer.

2 - 6 - 0 Locomotive.
London & North Eastern Railway.
Fitted with DAVIES & METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Class "H" Exhaust Steam Injector

THE Exhaust Steam Injector is a feed water heater which is, in principle, similar to the ordinary live steam injector, except that it utilizes exhaust steam from the cylinders to heat the feed water and also to force it into the boiler.

The class "H" Exhaust Steam Injector represents a considerable improvement on all former types. Automatic control valves are fitted which eliminate the hand controls necessary with previous types, and the injector is as simple to operate and requires no more attention than an ordinary live steam injector.

The injector is fitted with self-contained exhaust steam admission valves, water inlet valve, auxiliary live steam valve and overflow valve, which function automatically and require no attention.

The injector is started by one operation only, viz., the opening of the valve to admit live steam to the injector. The only other manipulation necessary is the adjustment (when required) of the water regulator to vary the quantity of feed water supplied to the boiler.

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

The exhaust injector consists of three sections, viz., the injector, the exhaust valve and the automatic valve casings which are bolted together to form one unit. The injector casing contains the injector cones, the overflow valve, the back pressure valve and the water and delivery connections. The exhaust valve casing contains the exhaust steam inlet, the automatic exhaust valves, the supplementary live steam cone and the auxiliary live steam nozzle. The automatic valve casing contains the automatic shuttle valve, the exhaust valve control piston and the inlet connection for live steam to operate the injector.

The working parts of the injector portion consist of the following nozzles or cones :—

(1) **Supplementary Live Steam Cone,** which admits a small supply of live steam for the purpose of increasing the delivery pressure.

(2) **Auxiliary Nozzle,** which admits live steam to work the injector when the regulator is shut and the exhaust steam not available.

Locomotive Exhaust Steam Injector. Class "H"

METCALFE'S PATENT

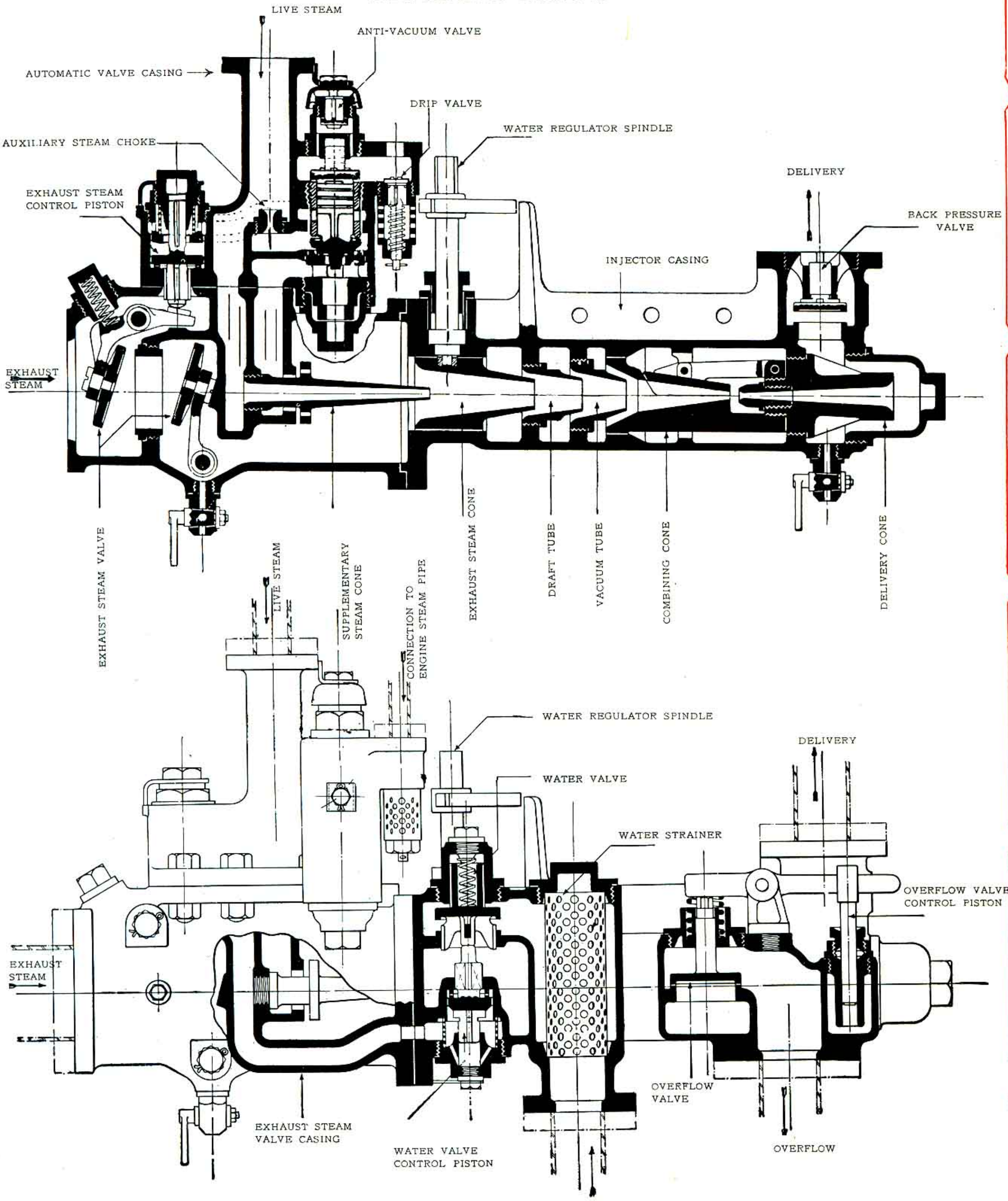


Fig. 1

(3) **Exhaust Steam Cone,** 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.

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

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

(6) **Combining Cone.** The mixture of steam and water passes out of the vacuum tube into the combining cone where condensation is completed.

(7) **Delivery Cone.** The jet leaving the combining cone passes into the delivery cone where its kinetic energy is changed into pressure energy.

Exhaust Injector.

The principle of the Exhaust Steam Injector is the same as that of the live steam injector, viz., utilizing the velocity obtained by the expansion of steam, though, of course, the proportions of the cones are different, being designed to utilize 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 steam and water the condensation of steam may be as efficient and rapid as possible, thus obtaining a high vacuum with a resultant high steam velocity.

The exhaust steam from the blast pipe is led to the injector by the exhaust steam pipe, and entering the exhaust valve casing, passes into the injector cones. It is admitted in two stages, the first stage being the steam admitted through the main exhaust steam cone, and at the end of this cone the incoming steam meets the condensing water, which is in the form of an annular jet surrounding the end of the steam cone, the water entering through the annular passage formed by the outside of the steam cone and the inside of the draft tube. The steam is condensed by the water jet and imparts its momentum to it, and the mixture of steam and water flows forward at a high velocity. The proportion of steam to water is such that a high degree of vacuum is created, and at the end of the draft tube the second supply of exhaust steam is admitted through the vacuum tube in the form of an annular jet of steam surrounding the mixture leaving the draft tube. This gives a further impetus to the mixture, which then flows along the vacuum tube into the combining nozzle where complete condensation takes place, and the available energy of the steam is transferred into work imparting velocity to the water jet.

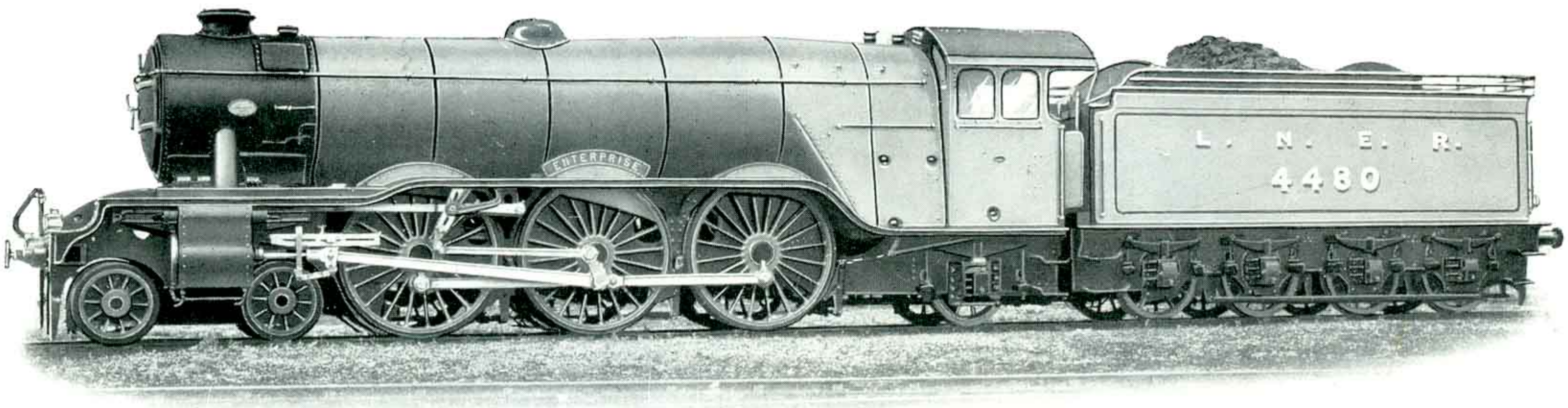
The combining cone is constructed on the flap system, being split longitudinally at its middle section up to a point near the vacuum tube, where the bore is sufficiently large to permit the mixture of water and steam to escape freely to the overflow. This ensures the prompt starting and automatic working of the injector.

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

The combining cone receives the mixture of steam and water flowing out of the vacuum tube, and its function is to ensure as complete condensation as possible.

The internal bore of the combining cone is convergent, that is, the bore gradually decreases so as to support and guide the varying form of the jet as condensation becomes more complete. The whole process of condensation of the steam and the transfer of its energy to the water jet takes place in this cone. The jet, leaving the combining cone, passes into the delivery cone. Between the combining and delivery cones is a small space or gap, termed the overflow space, which is necessary for starting purposes. The delivery cone consists of a parallel portion known as the throat, followed by a diverging cone. Its function is to change the kinetic energy of the jet into pressure energy with as little loss as possible. When the jet leaves the combining cone it is moving with a very high velocity, but at a very low pressure, and to overcome the boiler pressure a certain amount of its kinetic energy must be changed into pressure. In the diverging cone the velocity of the jet is gradually reduced and its pressure increased.

The jet leaves the delivery cone at a pressure higher than the boiler pressure. It then flows past the back pressure valve into the delivery pipe and so to the boiler.



4-6-2 3-Cylinder Express Locomotive.
London and North Eastern Railway.

Designed by H. N. Gresley, C.B.E.,
Chief Mechanical Engineer.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Injector Control System

The control portion of the class " H " Injector automatically governs the admission to the injector of :—

(1) Exhaust steam,

(2) Water,

(3) Auxiliary live steam (to work the injector when the regulator is shut and exhaust steam not available).

It consists of the following elements :—

(1) Steam-controlled Exhaust Steam Valve. (Fig. 2).

When the injector is at work (Engine running with the regulator open so that exhaust steam is available) the exhaust valve is open, admitting exhaust steam to the injector ; but if the injector is not in use, then the exhaust valve is automatically closed and there can be no leakage of exhaust steam through the injector.

(2) Auxiliary Shuttle Valve. (Fig 3).

This valve automatically controls the admission of steam to the injector—either exhaust steam or auxiliary live steam—(according as the regulator is open or shut).

When the regulator is open and exhaust steam is available, the auxiliary live steam is shut off, but when the regulator is shut and no exhaust steam available, this is automatically replaced by a supply of live steam by the action of the shuttle valve.

(3) Steam-controlled Water Valve. (Fig. 4).

The water valve is always in the shut position when the injector is not in use, but automatically opens immediately the injector is set to work.

The action of these valves is shown in Figs. 5A, 5B and 5C, which illustrate the positions of the valves and the flow of exhaust and live steam under the following conditions, viz :—

Fig. 5A. Injector shut off.

Fig. 5B. Injector working with exhaust steam.

Fig. 5C. Injector working with live steam (engine standing, or drifting with closed regulator).

The Automatic Exhaust Steam Admission Valves

Two valves (the inner and outer exhaust valves) (Fig. 2) are fitted to control the admission of exhaust steam into the injector, the outer valve being operated by the live steam supply to the injector. Both valves are circular disc valves, the outer valve being carried on the lower end of a crank lever, the other end of which is controlled by the control piston. The inner valve is carried by a hanger, which swings on a hinge pin at its lower end, so that the valve is free to swing open or shut under the action of the steam. A spring is fitted on the back of the crank lever, which is compressed as the exhaust valve opens, so that the pressure tends to close the outer exhaust valve. When the injector is not working the pressure of the spring closes the outer exhaust valve, so that no exhaust steam can pass into the injector.

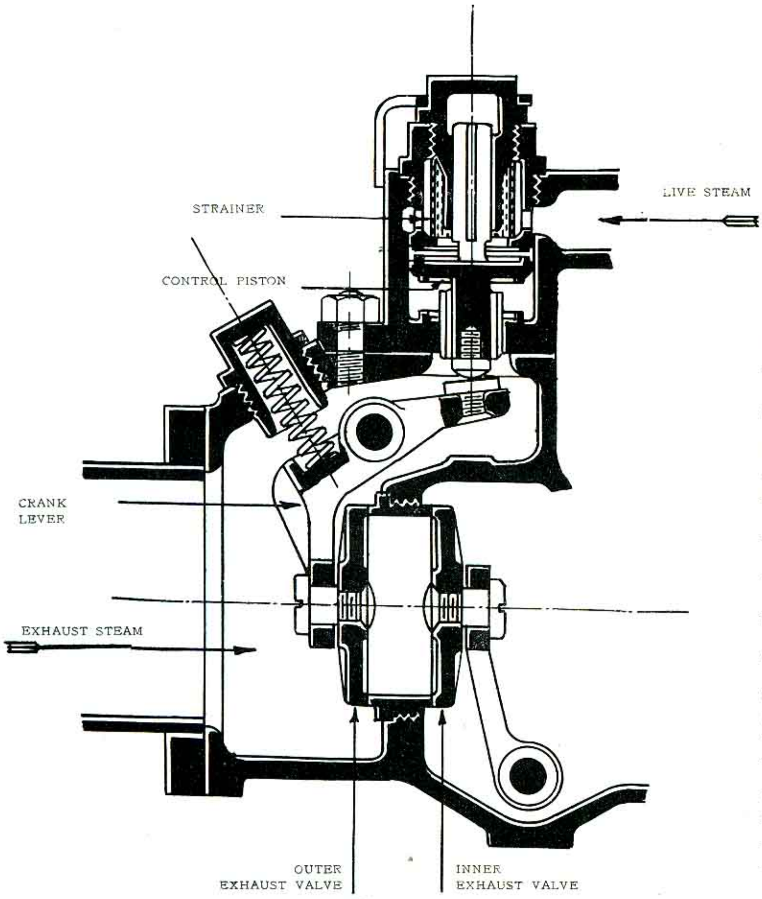


Fig. 2

When the injector is set to work with the regulator open, the operating live steam is admitted to the upper side of the control piston, forcing it down on to its seating, and the lower stem of the control piston, acting on the crank lever, opens the outer exhaust valve, so admitting the exhaust steam which passes through the seating and opens the inner exhaust valve and so enters the injector cones.

When the regulator is closed the injector changes over to live steam working. The live steam above the control piston is shut off and the pressure of the spring closes the outer exhaust valve. The auxiliary live steam replacing the exhaust steam enters the exhaust valve casing and its pressure closes the inner exhaust valve, so that no steam can escape from the injector into the exhaust pipe.

A strainer is fitted in the steam inlet and surrounds the control piston to prevent any dirt, grit, etc., entering the piston chamber. This strainer should be cleaned periodically and the piston ground to its seating.

Auxiliary Check Valve and Shuttle Valve

These valves (Fig. 3) control the automatic action of the injector (*i.e.*, the change over from exhaust steam to live steam working when the regulator is closed and *vice versa*).

The auxiliary check valve is a non-return valve which, when on its seating, cuts off communication between chamber E and chamber D. When the regulator is open the auxiliary check valve is forced on to its seating by the pressure of the steam from the engine steam pipe which enters chamber E through the auxiliary control pipe, but when the engine regulator is closed the steam pressure in chamber E is released and the auxiliary check valve is free to lift under the action of the steam in chamber D.

The automatic shuttle valve consists of a double-seated valve, the upper stem of which is a piston which slides in a cylinder formed in the valve casing, the upper end of the cylinder being closed by the auxiliary check valve.

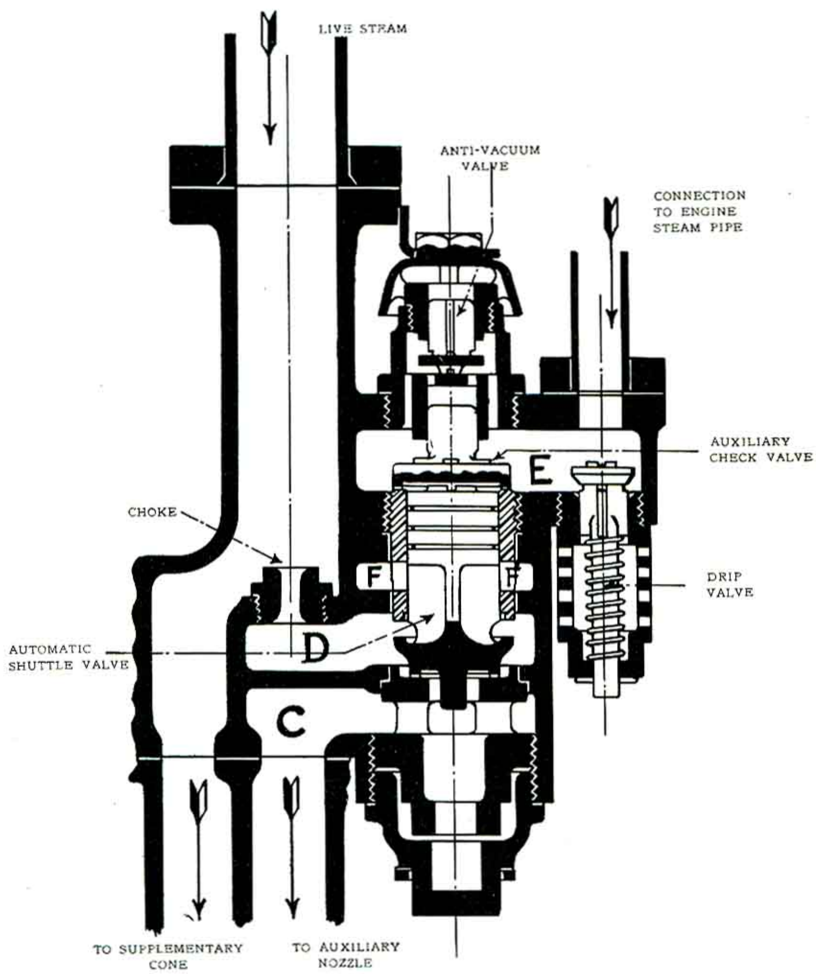


Fig. 3

The function of the shuttle valve is to automatically control the admission of live steam to the auxiliary nozzle (to work the injector when exhaust steam is not available) and to the exhaust valve control piston (to control the opening and closing of the exhaust valve). The live steam operating the injector enters chamber D through the choke tube (which regulates the quantity of steam admitted) and passes into either chamber F or chamber C according as the shuttle valve is on the lower or upper seating.

The shuttle valve, when on its lower seating, shuts off communication between chamber D and chamber C, so shutting off the supply of live steam to the auxiliary nozzle of the injector. When on its upper seating the shuttle valve shuts off communication between chamber D and chamber F, which leads to the exhaust valve control piston.

The movement of the shuttle valve is governed by the steam pressures in chambers D and E. The proportions of the valves and piston are designed so that the change over takes place at a steam chest pressure of 45 lbs.

The action of the shuttle valve is as follows: —

(1) Regulator open, engine working with exhaust steam.

The steam from the engine steam pipe enters chamber E and forces the auxiliary check valve on to its seating. The steam operating the injector enters chamber D and forces the shuttle valve on to its lower seating. This cuts off the flow of steam from chamber D to chamber C, but allows a free passage for steam from chamber D into chamber F. The pressure of this steam in chamber F, acting on the exhaust valve control piston, opens the exhaust valve to admit the exhaust steam to the injector.

(2) Regulator shut, Injector working with live steam.

As soon as the engine regulator is shut the pressure falls in chamber E and the pressure of steam in chamber D lifts open the auxiliary check valve. When the pressure in chamber E falls to 45 lbs. the pressure below the piston end of the shuttle valve lifts it on to its upper seating. This allows steam to flow from chamber D to chamber C and so to the auxiliary nozzle, and at the same time cuts off the steam supply to chamber F, so that the exhaust valve closes and the injector works with the live steam admitted through the auxiliary nozzle.

The injector will continue working with live steam so long as the pressure in chamber E is below 45 lbs. If the regulator is again opened, then when the steam pressure in chamber E reaches 45 lbs., it closes the auxiliary check valve and the shuttle valve falls to its lower seating, so cutting off the flow of steam to the auxiliary nozzle and admitting steam through chamber F to open the exhaust valve and admit exhaust steam to the injector.

An anti-vacuum valve is fitted in the chamber E, which admits air when the regulator is shut, and so prevents any chattering and consequent wear of the auxiliary check and shuttle valves when the engine is drifting. This valve is automatically closed by the steam pressure in chamber E when the regulator is open.

A **drip valve** is also fitted to chamber E to prevent any accumulation of water in the chamber or in the auxiliary control pipe.

Water Inlet Valve

A self-closing water valve (Fig. 4) is fitted, which automatically opens when the injector is set to work and closes when injector is shut off, so relieving the fireman of the necessity of operating the water valve.

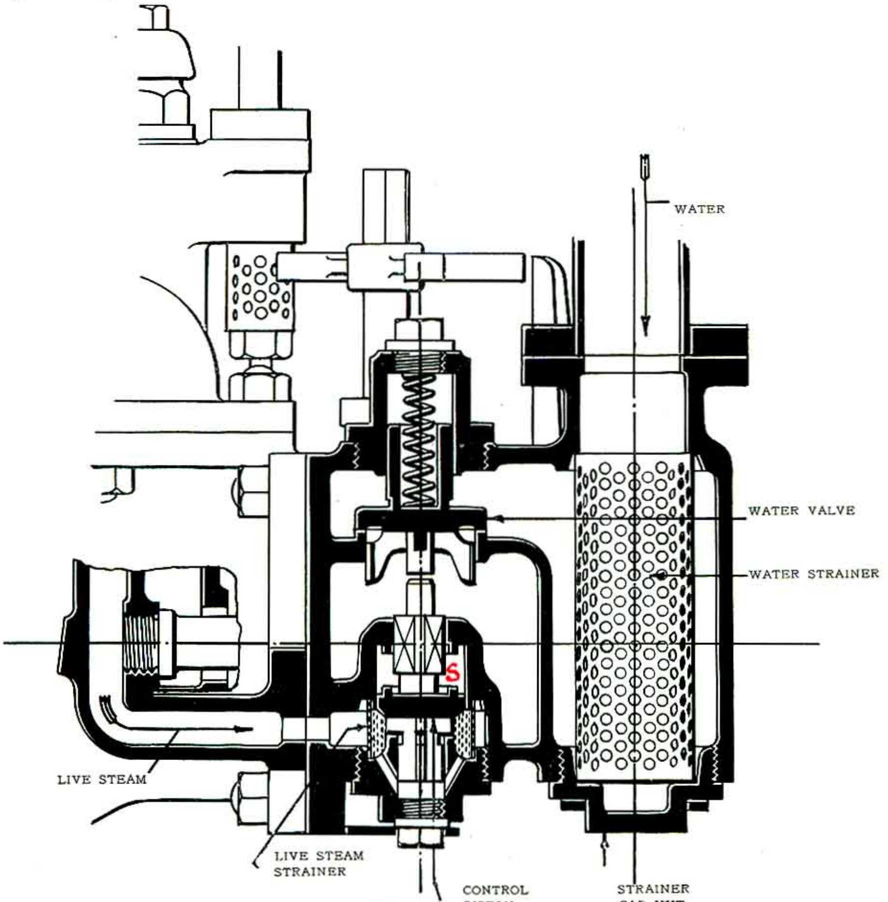


Fig. 4

The feed water from the tender enters through the strainer, which prevents any dirt, etc., being carried into the cones, and then passes to the upper side of the water valve. This consists of a drop valve actuated by a live steam operated control piston. A spring is fitted above the valve which forces it on to its seating until the injector is started. When the steam valve is opened to work the injector, steam passes to the under side of the control piston, forcing this up, and so opening the water valve and admitting water to the injector.

The steam piston seats itself on the seating S, so preventing any leakage of steam into the incoming water.

When steam is shut off the pressure below the piston drops, and the water valve falls on to its seating, so shutting off the water supply.

A strainer is fitted around the control piston to prevent the entrance of grit into the piston chamber.

The control piston should be removed periodically and ground to its seating.

Water Strainer.

A fine mesh circular strainer is fitted in the water inlet chamber to prevent any dirt in the feed water from entering the injector. This strainer is removed by simply unscrewing the strainer cap nut, and should be taken out and cleaned periodically.

Action of the Control System

Injector shut off. (Fig 5A).

The supply of exhaust steam and water is automatically cut off, so that there can be no entry of either into the injector and no waste through the overflow.

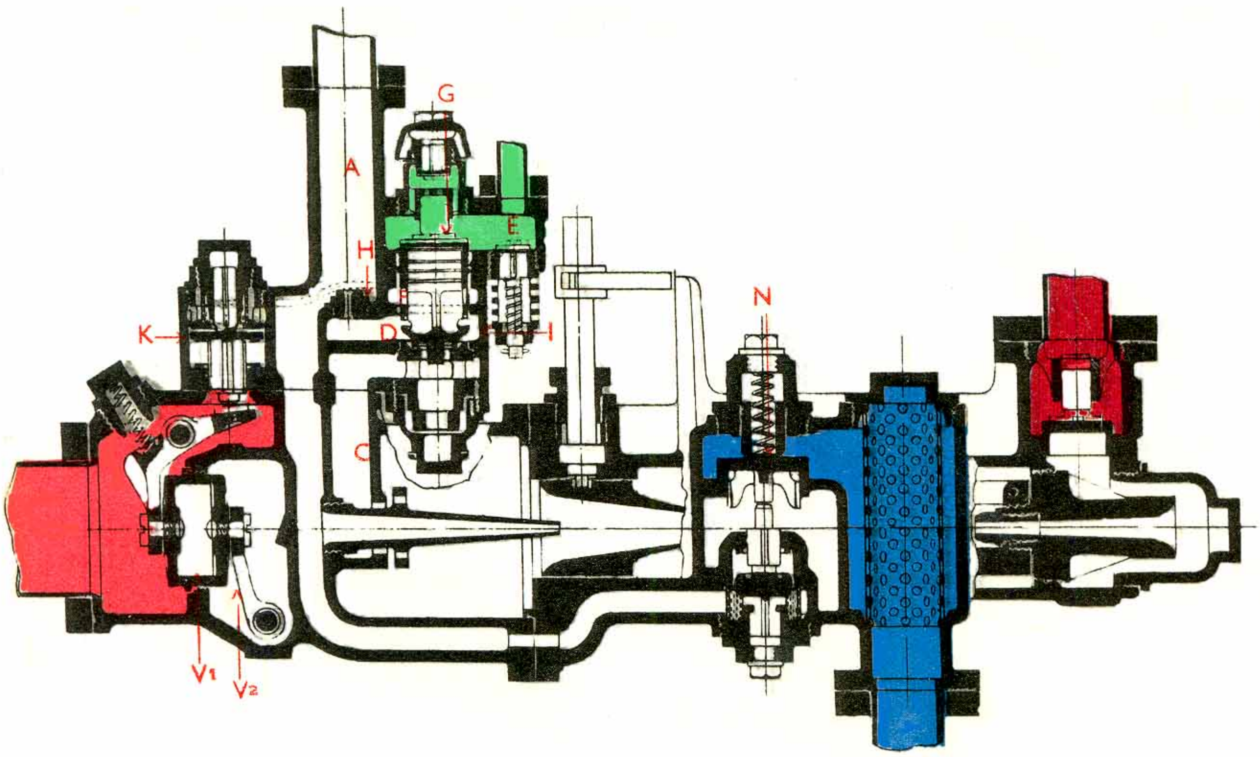


Fig. 5A

The positions of the various valves *when the injector is not working* are as follows :—

(1) Exhaust Steam Valves V1 and V2 shut.

(2) Water Valve N is shut.

(3) Shuttle Valve I is on its lower seating.

(4) Auxiliary Check Valve G is on its seating.

Injector working with exhaust steam (engine regulator open). (Fig. 5B)

The steam valve on the boiler is open, admitting live steam to the injector.

Steam enters by the passage A and flows through the supplementary cone into the injector.

The steam also passes at the same time to the lower side of the water valve control piston, forces this piston upwards on to its seating, and so opens the water valve N, admitting the feed water to the injector.

At the same time steam passes through the auxiliary steam choke H into the shuttle valve chamber D.

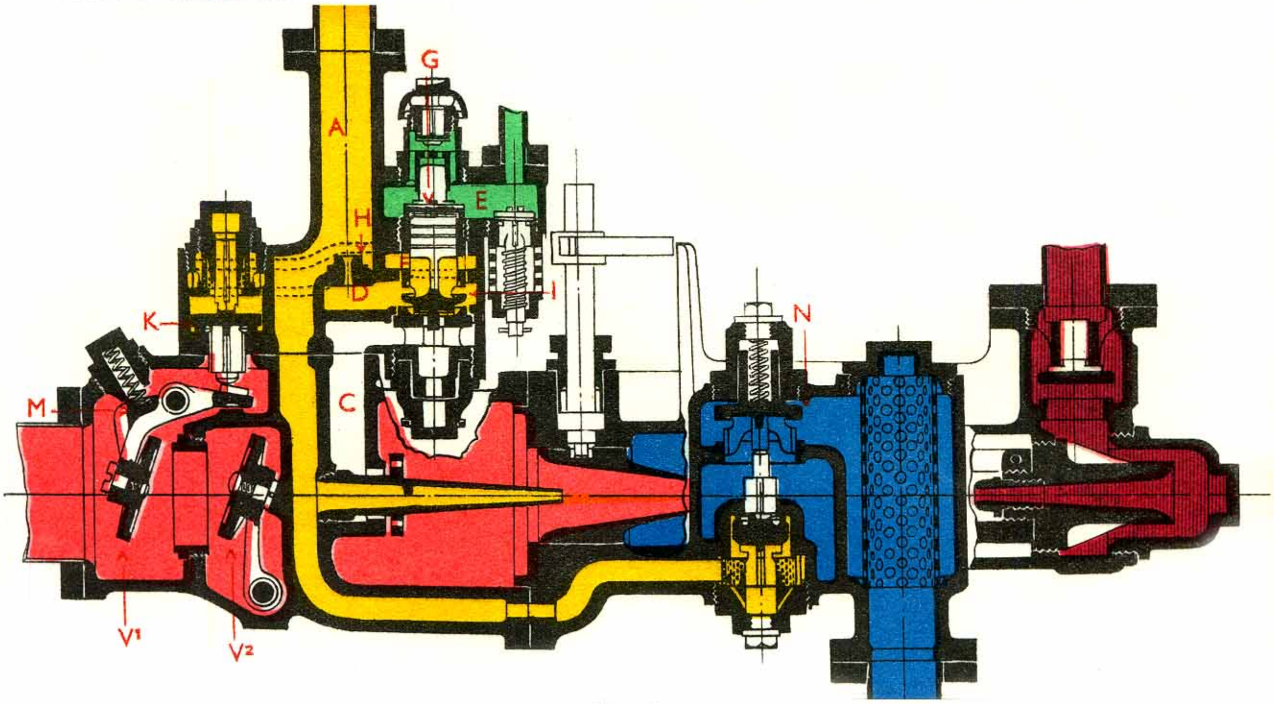


Fig. 5B

The engine regulator being open, live steam from the engine steam pipe enters through the auxiliary control pipe and forces the auxiliary check valve G on to its seat. The shuttle valve I remains on its lower seating, so that the live steam in chamber D is allowed to flow along the passage F to the upper side of the exhaust valve control piston K, but is prevented from flowing down the auxiliary steam passage C into the injector.

The exhaust valve control piston K is forced down, and by its action on the crank lever M, opens the exhaust steam valve V1. The exhaust steam then opens the exhaust steam valve V2 and enters the injector.

Thus the injector works with exhaust steam as long as the regulator is open and the engine running.

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

(1) Exhaust Steam Valves V1 and V2 are open.
(2) Water Valve N is open.
(3) Shuttle Valve I is on its lower seating.
(4) Auxiliary Check Valve G is on its seating.

Injector working with live steam (engine standing or drifting with closed regulator.) (Fig. 5c).

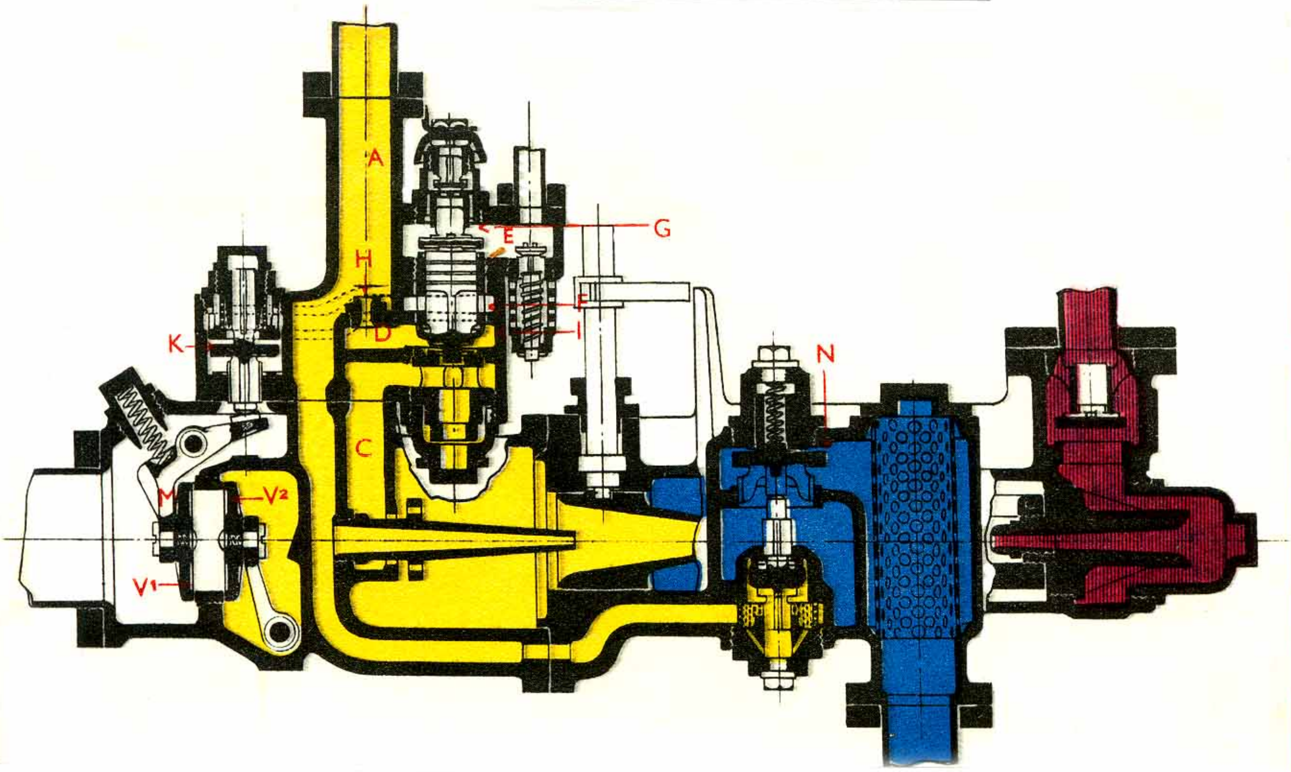


Fig. 5c

The regulator being shut, steam is cut off from the steam chest, there will be no pressure in the chamber E above the auxiliary check valve G. Then the pressure of the steam in chamber D lifts the auxiliary check valve and forces the shuttle valve I on to its upper seating. This cuts off the supply of steam to the passage F, which leads to the exhaust valve control piston K, so that the exhaust valve V1 closes, shutting off communication between the exhaust steam supply pipe and the injector. At the same time steam passes from chamber D into the passage C leading to the auxiliary nozzle and so into the injector, replacing the exhaust steam, so that the injector continues to work with live steam. The quantity of auxiliary steam entering is determined by the bore of the auxiliary choke tube H.

The action of the control is perfectly automatic and almost instantaneous, so that the injector continues steadily at work without any waste at the overflow.

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

(1) Exhaust Steam Valves V1 and V2 are closed.
(2) Water Valve N is open.
(3) Auxiliary Shuttle Valve I is on its upper seating.
(4) Auxiliary Check Valve G is off its seating.

Water Regulator

The capacity of the injector is regulated by varying the quantity of water admitted to the cones. This is done by moving the exhaust steam cone, thus varying the surrounding area between the end of the exhaust cone (Fig. 6) and the draft tube through which the water enters, so regulating the quantity of water entering the injector.

The exhaust steam cone can move to and fro in the casing, its movement being regulated by the water regulator spindle. On the end of this spindle is an eccentric pin which fits in a steel die, moving in a slot which is cut on the outside of the exhaust steam cone.

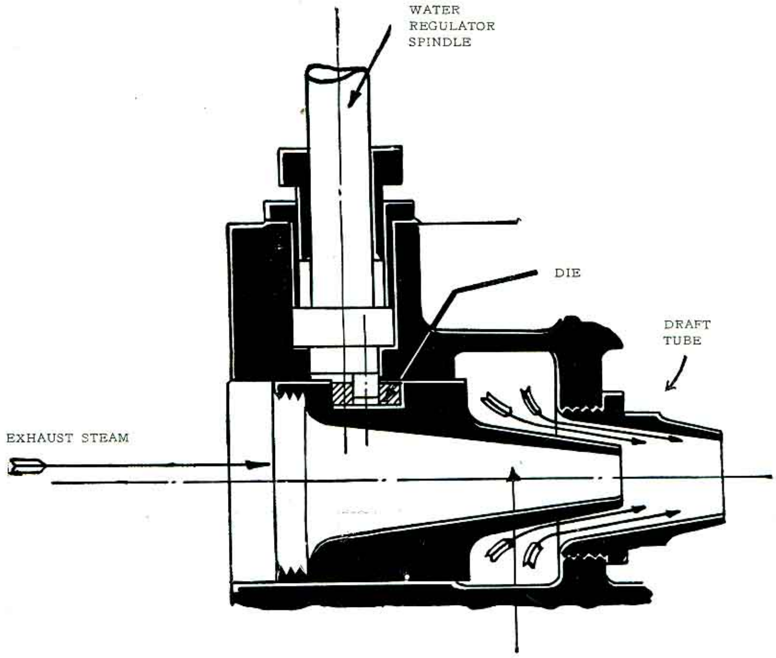


Fig. 6

By turning the water regulator spindle, the exhaust steam cone is moved longitudinally in the casing, so regulating the quantity of water admitted to the injector. By this means an extremely large range of capacity is obtained, the minimum capacity of the injector being 50% of the maximum, so that the injector can be set to give a constant feed under all conditions of working.

Supplementary Live Steam

A small quantity of live steam is admitted to the injector through the supplementary live steam cone (Fig. 7) to give the additional force required to feed against pressures higher than is possible by the use of exhaust steam alone.

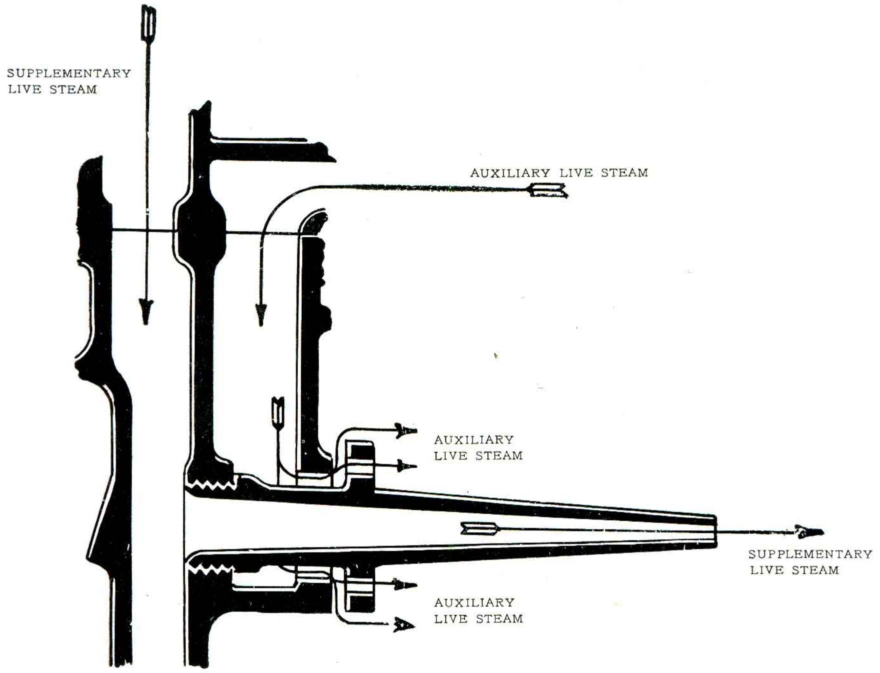


Fig. 7

The quantity of steam admitted is determined by the bore of the supplementary 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 used is condensed by the feed water and directly returned to the boiler, so that there is no thermal loss.

Auxiliary Live Steam

It is necessary at times to work the injector as a live steam injector (when the engine is standing, or running with the regulator shut). By the action of the shuttle valve, a supply of live steam to replace the exhaust steam is introduced through the auxiliary steam branch, entering the injector through the annular auxiliary nozzle, which surrounds the supplementary steam cone (Fig. 7). The steam flows into the exhaust steam cone, replacing the exhaust steam and the injector works exactly as when exhaust steam is used. When working in this manner with live steam, the pressure of the steam closes the inner exhaust valve, so preventing any escape of steam into the exhaust supply pipe. The quantity of live steam admitted is determined by the bore of the auxiliary choke.

Overflow Valve

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

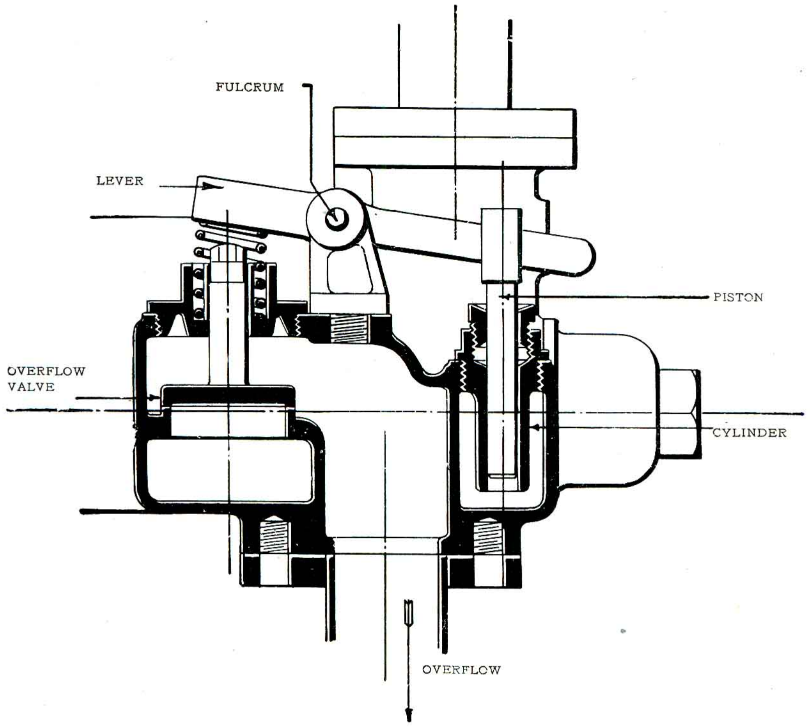


Fig. 8

This piston is coupled to a lever pivoted on a fulcrum on the casing, the other end of the lever bearing against the upper stem of the overflow valve. When the injector is working, the delivery pressure under the piston forces up the lever and so holds the overflow valve on to its seating, thus sealing the overflow chamber.

If the injector breaks off from any cause, the delivery pressure under the piston immediately falls, and the overflow valve is free to open, allowing the steam and water to escape through the overflow pipe until the injector restarts, when the delivery pressure increases, and acting on the piston again closes the overflow valve.

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

Grease Separator

CLASS "H.M." PATENT

This is fitted in the exhaust pipe line, preferably near the injector.

The Class H.M. Patent Grease Separator consists of a spherical casing (Fig. 9) with inlet and outlet branches for the exhaust steam.

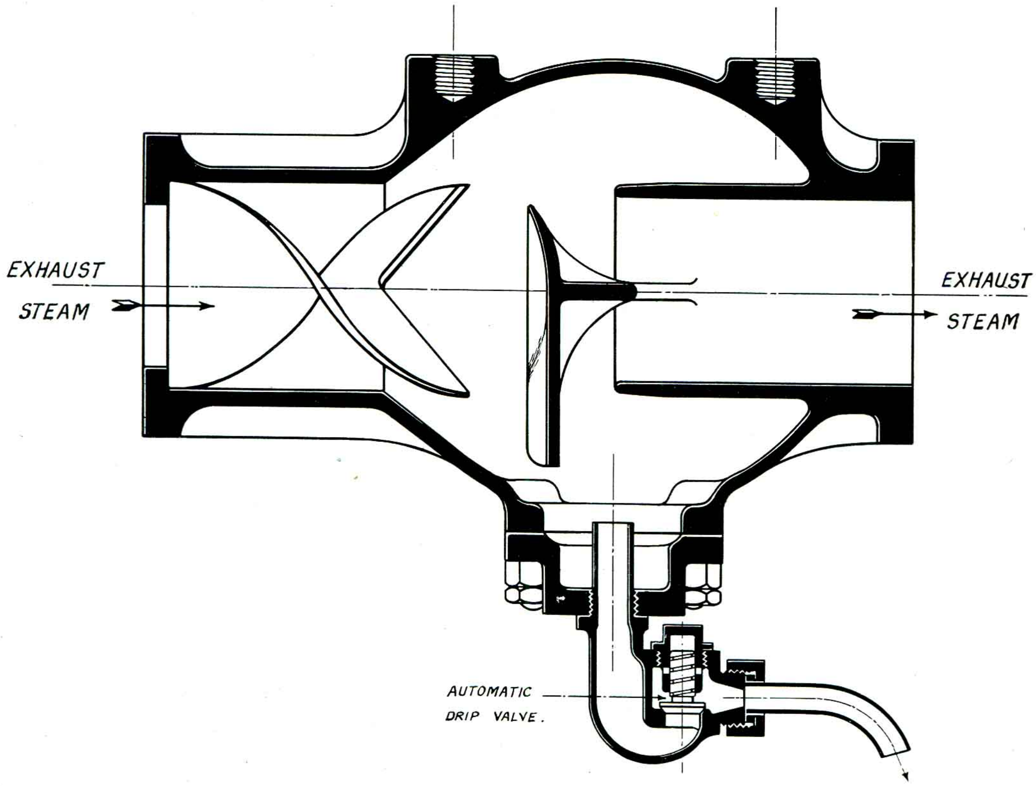
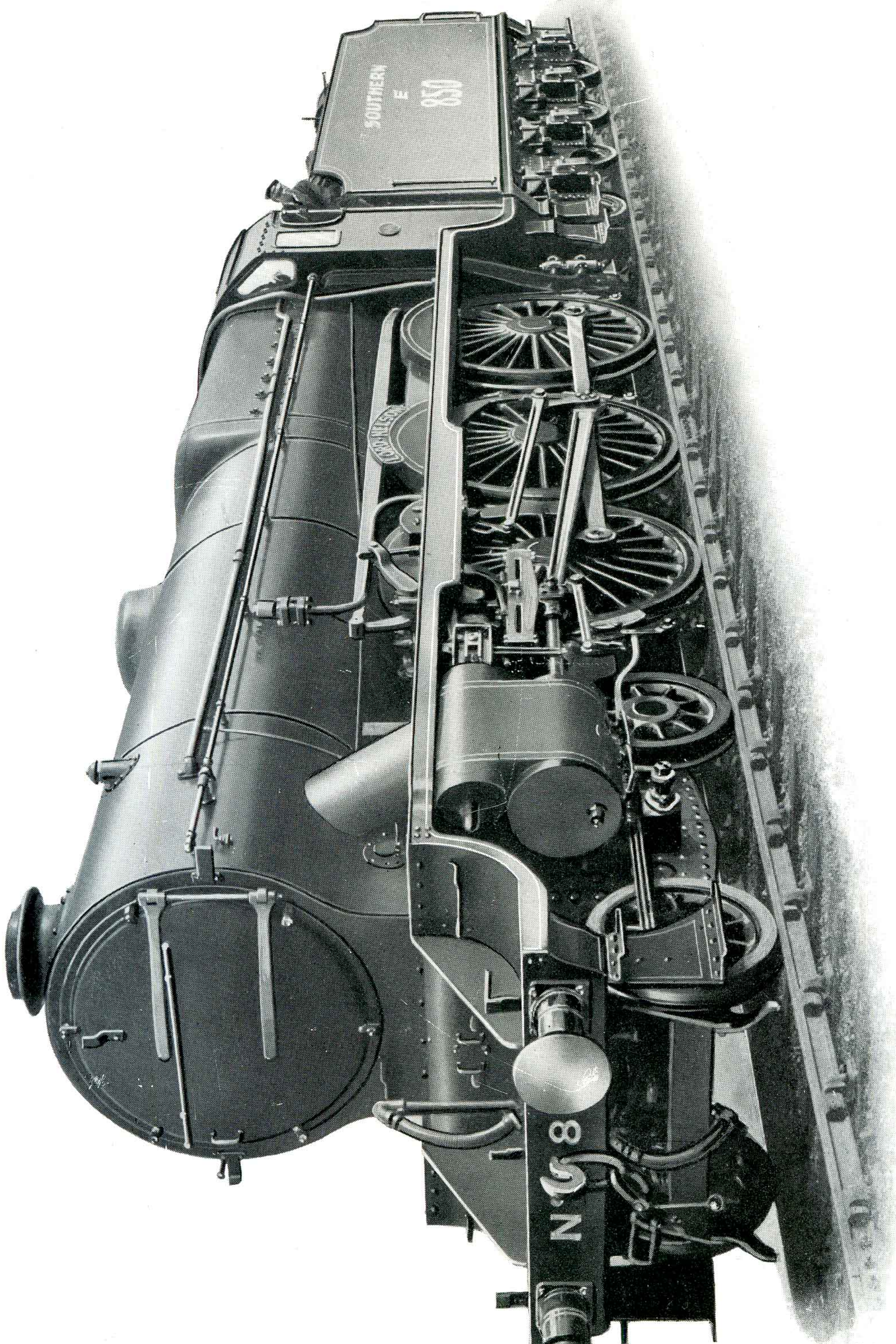


Fig. 9

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, cinders, etc., are directed outwardly to strike against the separator wall and then drop 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 lighter 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, which is fitted with an automatic drip valve. This allows a small quantity of steam to escape to the atmosphere, and so drain away all impurities which fall into the well.



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

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

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Steaming Capacity and Draft

The application of the 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, a certain amount of 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 the maximum capacity and is clearly shown by the steadiness of the steam pressure when the engine is 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 ever found 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, so that the effect on the draft is less than with the ordinary type of feed water heaters.

An improvement will also be found in the quality of the feed water, the condensed exhaust steam being pure distilled water returned to the boiler.

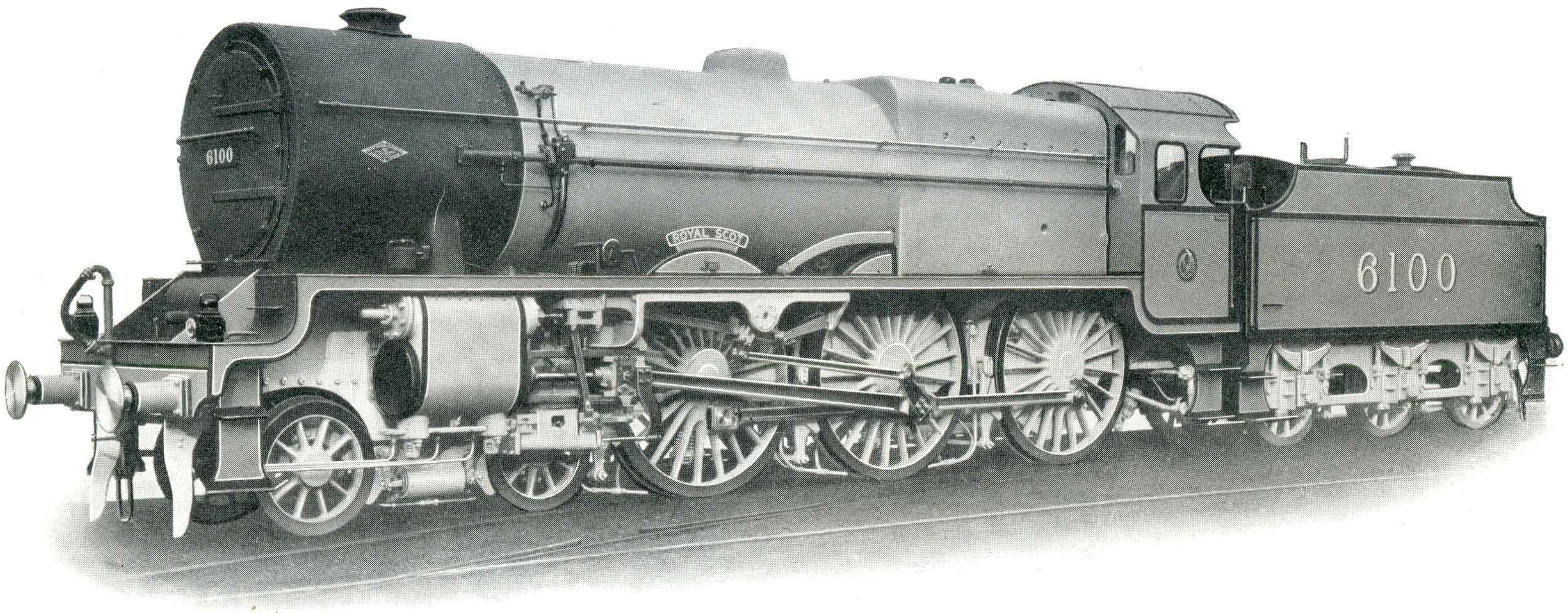
There is no possibility, under any circumstances, of delivering cold water into the boiler. When using the injector with live steam (engine standing or drifting with closed regulator) a hot feed is always delivered to the boiler, so that the boiler troubles frequently experienced when using pumps, due 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 position. In ordinary workings, where the water regulator is set about the mean position, the delivery temperature ranges from 190° to 200° F, so that an extremely hot feed is always delivered to the boiler.



4-6-0 3-Cylinder Express Locomotive.
London Midland and Scottish Railway.

Designed by Sir Henry Fowler, K.B.E.,
Built by The North British Locomotive Co., Glasgow.

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

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 this 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 pressure is clearly shown in tests where indicator cards are taken or where pressure gauges are fixed in the blast pipe or in the exhaust steam pipe, the reduction of pressure being about 10% of the **absolute** back pressure.

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 work done and the heat content of the delivery water are obtained from the exhaust steam, so that a definite amount of waste heat is continually being returned to the boiler so long as the injector is kept at work.

If fuel economy is not shown in the fuel consumption records, then this is being wasted in other directions, for it is clear that if the feed water shows a definite increase of temperature, 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 :—

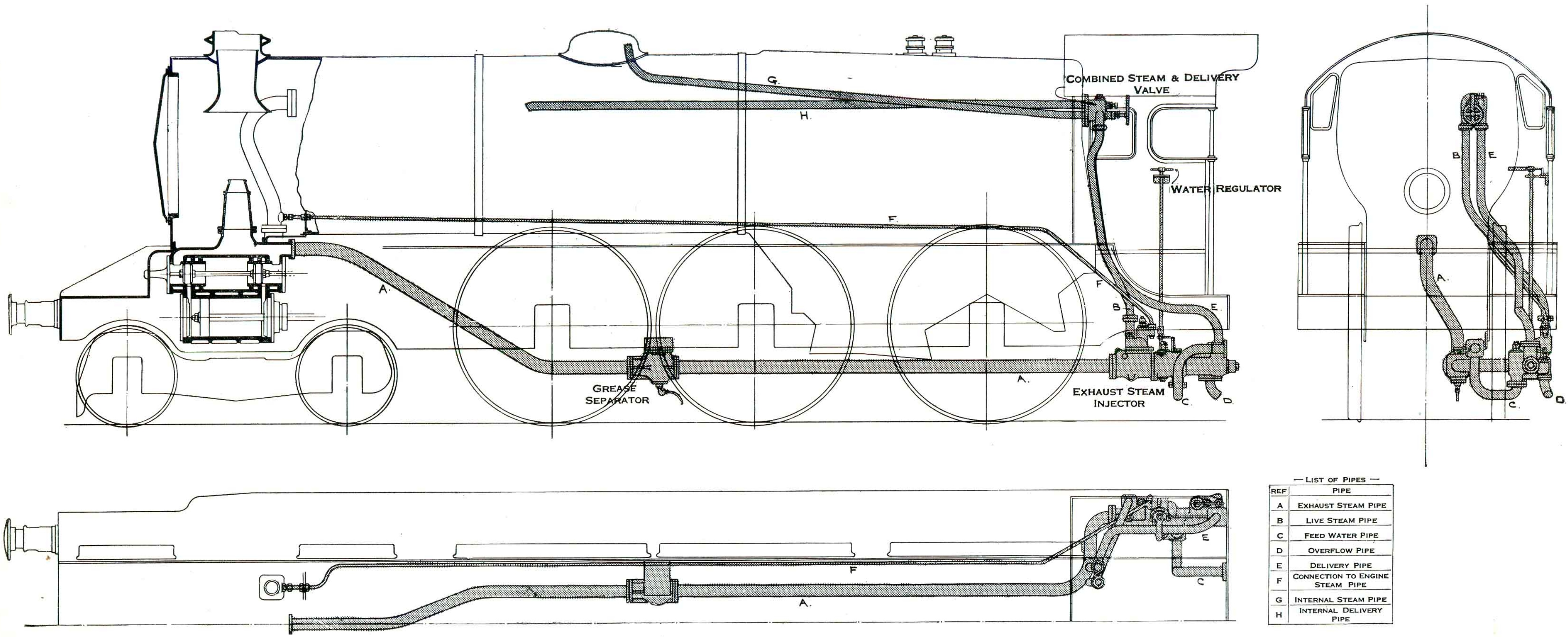
(1) Economy due to the direct return of heat to the boiler by the condensation of exhaust steam by the feed water in its passage through the injector. The amount of steam condensed varies slightly with the working conditions, but in normal service at least 10% is condensed and returned directly to the 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, so increasing the power developed by the locomotive. This increase in pressure varies from 1 to 3 lbs., depending on the exhaust steam pressure in the blast pipe.

(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% on general service.

A water saving of 10 to 12% is usually found. This is due to the exhaust steam condensed and returned to the boiler by the injector. This being pure distilled water forms a considerable improvement in the quality of feed water.



— 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
G	INTERNAL STEAM PIPE
H	INTERNAL DELIVERY PIPE

Fig. 10

Arrangement of Class " H " Exhaust Injector and Combined Steam and Delivery Valve on Locomotive.

Working Instructions

To start the injector, open steam valve on boiler. The injector then commences to work and the amount of feed can be regulated by the water regulator control handle. The injector then works with exhaust steam or live steam according as the regulator is open or shut.

Note.—So far as is possible the injector should be kept constantly at work while the engine is running, the feed being regulated to maintain a constant water level, and 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 very heavily or lightly.

Filling the boiler at station stops or when running down hill should if possible be avoided as 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.

Installation

Diagrams of the installation and pipe arrangement are shown in Figs. 10 and 11.

The Exhaust Injector is of the non-lifting type, *i.e.*, it must be fixed 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.

A control rod is connected to the water regulator spindle and carried up into the cab, the control handle being fixed in a position where it can be easily operated. A pipe is connected to the injector from the steam valve, fitted in a convenient position in the cab.

Pipe Connections.

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

All joints in the exhaust steam pipe and in the water supply pipe must be perfectly tight, so that there can be no air leakage, and the joints should preferably be made by flanged connections, not union coupling nuts. Rubber jointing should not be used.

Grease Separator.

The Grease Separator is fixed at any convenient point in the exhaust pipe line, preferably at its lowest position, and near the injector, so as to drain all water out of the pipe line.

Tank Strainer.

A fine mesh sieve should be fitted in the tender so as to prevent dirt, etc., entering with the feed water.

Steam Valve.

A Steam Valve must be fitted in the cab for supplying the live steam to the injector. A fitting often adopted is the combined steam and delivery valve (Fig. 10), in which the steam valve is combined with the boiler check valve in one casing and fitted by a flange on to the firebox back, with internal steam and delivery pipes to the boiler.

A table of pipe sizes and injector capacities is shown on page ~~28~~.32

Maintenance

Tank hose and injector strainers 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 oil separator drain valve 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 are applied as a unit. To remove them, take off the cap nut at the delivery end of the injector body and screw out the cones. Then the vacuum and draft tubes may be screwed out. To remove the renewable tip, take out the set screw in the centre and screw off the combining cone from the delivery end. The main steam cone may be pushed out after the regulator spindle has been removed.

All the injector cones, except the main steam cone, bear hard against a seat in the injector body, and, when applied, should be screwed up tightly against the seat. When applying the combining and delivery cones, make sure that the " T " mark on the end of the delivery cone comes near the top when the nozzle is against the seat.

The main steam cone is actuated by an eccentric pin on the end of the water regulator spindle, which fits into a sliding die in the cone, and before removing the nozzle, the regulator spindle must be taken out. When the parts are re-applied, special attention must be given to insure that the *eccentric pin enters the hole in the sliding die*, and before applying other cones, the movement of the main steam cone should be tested by moving the regulator spindle from minimum to maximum. The steam cone should move approximately ½ inch.

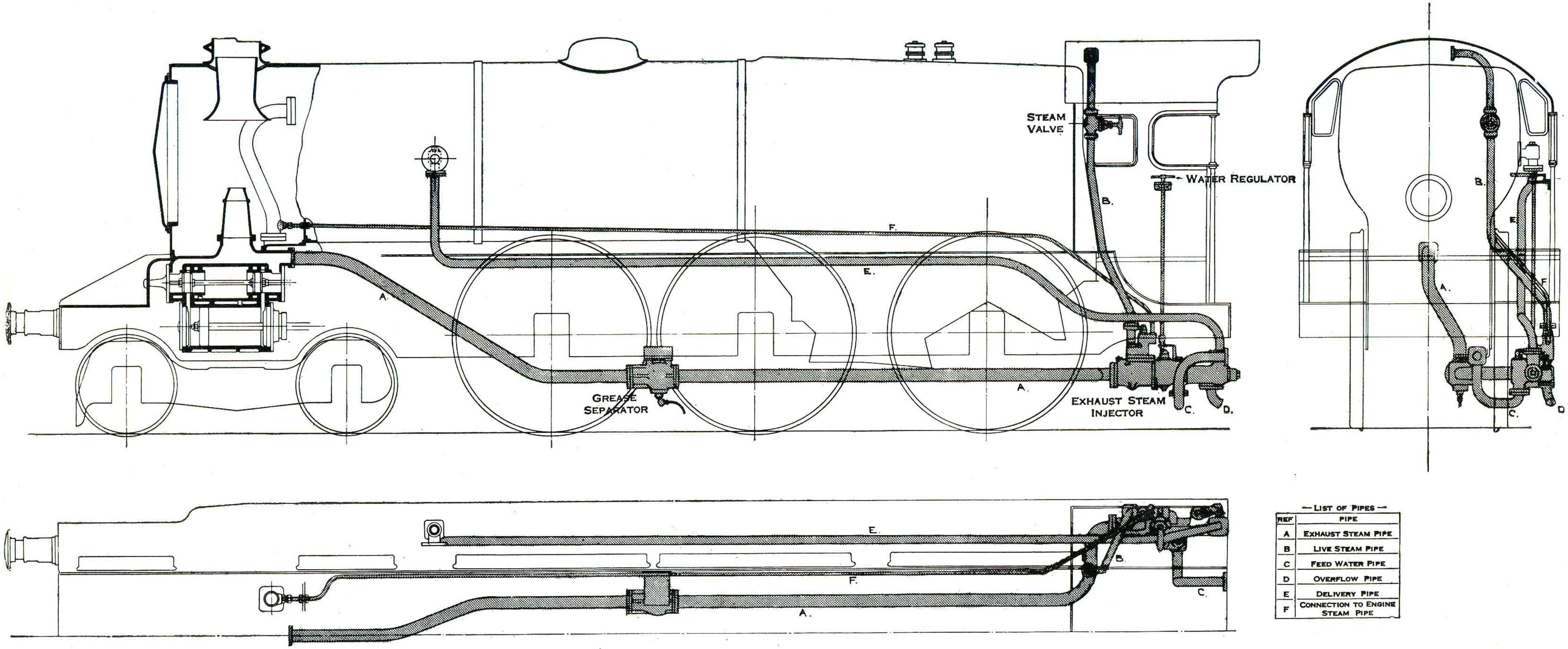
The renewable end in delivery cone should be examined about every six months and, if worn, should be renewed.

Packing for the Injector.—Special cord packing is supplied for packing the exhaust steam cone and the combining cone. 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. This should be lubricated periodically to ensure that the piston moves freely.

The packing gland for the water regulator spindle should be well packed with greased asbestos and the gland should be screwed down tight enough to prevent the water regulator spindle from creeping when the injector is working.

Spare Parts.—All spare parts can be supplied. When ordering, give injector size, name of part and reference number as shown on page ~~29~~.33.



— 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. 11

Arrangement of Class " H " Exhaust Injector with Indepentent Check and Steam Valves on Locomotive.

Table of Pipe Sizes and Capacities—Class "H" Exhaust Injector

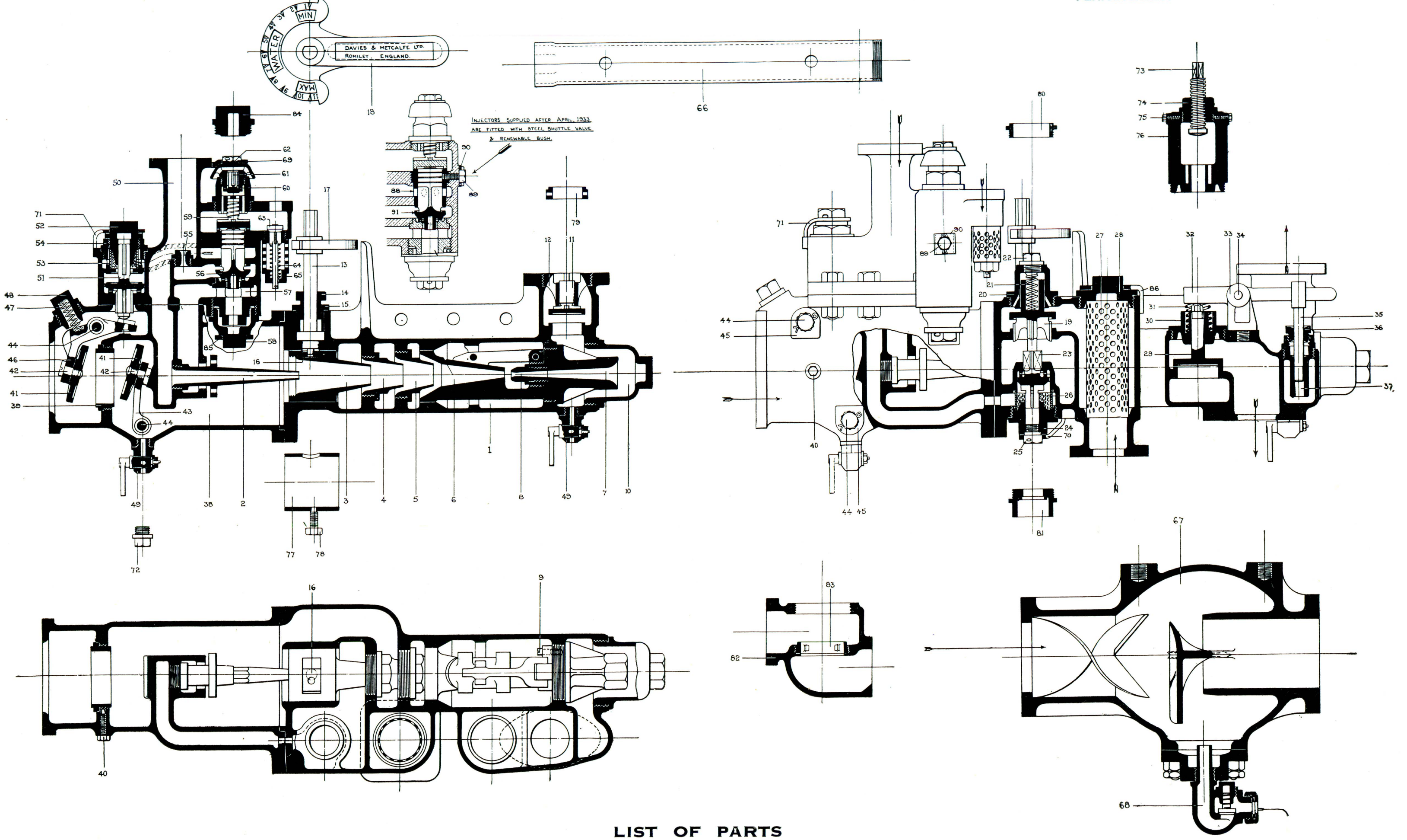
Size of Injector	Capacity Gallons per hour		Internal Diameter of Pipes in Inches					Connection to Engine Steam Pipe
	Maximum	Minimum	Exhaust Steam	Live Steam	Water from Tender	Delivery to Boiler	Overflow	
4	400	210	2	3/4	1	1	$1\frac{1}{2}$	1/2
5	640	330	$2\frac{1}{4}$	3/4	1	1	$1\frac{1}{2}$	1/2
6	920	470	$2\frac{1}{2}$	1	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	5/8
7	1250	630	$2\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	5/8
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	$2\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{3}{4}$	1
14	4800	2500	$5\frac{1}{2}$	2	$2\frac{3}{4}$	$2\frac{1}{2}$	3	1
15	5500	2800	6	$2\frac{1}{4}$	3	$2\frac{3}{4}$	$3\frac{1}{4}$	1
16	6300	3300	6	$2\frac{1}{4}$	$3\frac{1}{4}$	3	$3\frac{1}{2}$	1

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

LOCOMOTIVE EXHAUST STEAM INJECTOR—CLASS "H"

METCALFE'S PATENT

NOTE: CARE TO BE TAKEN TO ENSURE THAT ALL STRAINERS (PARTS NO. 26, 27 & 53) ARE CLEANED PERIODICALLY.



LIST OF PARTS

Ref.	Part
1	Exhaust Steam 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 Regulator Spindle
14	Water Regulator Gland
15	Water Regulator Stuffing Box
16	Water Regulator Die
17	Water Regulator Sector
18	Water Regulator Sector Handle
19	Water Valve
20	Water Valve Guide Nut
21	Water Valve Spring
22	Water Valve Grinding Nut
23	Water Control Piston Valve
24	Water Control Piston Guide Nut
25	Water Control Piston Grinding Nut
26	Water Control Piston Strainer
27	Feed Water Strainer
28	Feed Water Strainer Cap Nut
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 Steam Valve Casing
39	Exhaust Steam Valve Seating
40	Seating Set Screw
41	Exhaust Steam Valve
42	Exhaust Steam Valve Pin
43	Inner Exhaust Steam Valve Hanger
44	Exhaust Steam Valve Hinge Pin
45	Hinge Pin Locking Plate
46	Exhaust Steam Valve Crank Hanger
47	Exhaust Steam Valve Spring
48	Exhaust Steam Valve Spring Cap Nut
49	Drain Cock
50	Control Valve Casing
51	Exhaust Steam Control Piston
52	Exhaust Steam Control Piston Cap Nut
53	Exhaust Steam Control Strainer
54	Exhaust Steam Control Strainer Cap Nut
55	Auxiliary Steam Choke
56	Automatic Shuttle Valve, Gunmetal
57	Automatic Shuttle Valve Seating
58	Automatic Shuttle Valve Cap Nut
59	Automatic Back Pressure Valve
60	Automatic Back Pressure Valve Guide
61	Anti-Vacuum Valve
62	Anti-Vacuum Valve Cap Nut
63	Drip Valve
64	Drip Valve Spring
65	Drip Valve Seating
66	Cone Box Key
67	Grease Separator
68	Grease Separator Drip Valve
69	Locking Plate for Anti-Vacuum Valve Cap Nut
70	Locking Plate for Water Control Piston Grinding Nut
71	Locking Plate for Exhaust Steam Control Piston Cap Nut
72	Plug
73	Warming Screw Spindle
74	Spindle Guide Nut
75	Spindle Guide Nut Setscrew
76	Overflow Valve Guide
77	Steam Nozzle Bush
78	Setscrew for Steam Nozzle Bush
79	Back Pressure Valve Seating
80	Water Valve Seating
81	Water Control Piston Valve Cylinder
82	Overflow Valve Casing
83	Overflow Valve Seating
84	Automatic Back Pressure Valve Guide
85	Locking Plate for Auto. Shuttle Valve Cap Nut
86	Locking Plate for Feed Water Strainer Cap Nut
88	Bush for Renewing Valve Seatings
89	Setscrew for Bush
90	Locking Plate for Setscrew
91	Automatic Shuttle Valve—Steel

WHEN ORDERING SPARE PARTS STATE NUMBER OF PART AND SIZE OF INJECTOR

Maintenance Costs of Locomotive Feed Water Heaters

To make any equitable comparison between the economy realised by different systems of Locomotive Feed Water Heating, it is absolutely 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.

Summarised, the advantages of the exhaust injector are :—
Lower Initial Costs,
Lower Maintenance Charges,
Freedom from Breakdown,
Greater efficiency—giving all round superiority over pumps and heaters.

Over 20,000 locomotives, running in all parts of the world, are fitted with the Exhaust Steam Injector.

Comparison of Exhaust Injector and Heater Systems

EXHAUST STEAM INJECTOR	PUMP AND HEATER
(I.) Low cost of installation.	(I.) High initial cost, the complete installation being at least five times as costly as the Injector.
(II.) Utilises the exhaust steam for both heating the feed water and forcing it into the boiler, and the whole of the heat is returned to the boiler.	(II.) The exhaust steam is used only for heating, and only a portion of the heat is taken up in the heater, a large amount going to waste.
(III.) Supplementary live steam is only required for boiler pressures higher than 150 lbs. per square inch, and all this steam is returned directly to the boiler so that there is no heat loss. The amount of live steam used is only 2½% of the water evaporated.	(III.) The pump uses live steam only, the amount varying from 3 to 5% of the evaporation of the boiler.
(IV.) Extremely low maintenance and repair cost, being practically the same as an ordinary live steam injector, the running shed costs are not increased.	(IV.) The maintenance and repair cost are very high. Practical experience invariably shows that the upkeep costs are greater than the fuel economy realised.
(V.) Coal economy 8-12%, and the maximum economy is regularly maintained in service, due to the fact that the exhaust steam is the motive power as well as the heating medium.	(V.) Economy 10-12% when the heater and pumps are in new condition. The economy rapidly diminishes in service, as it is entirely dependent on the heater being in perfect condition.
(VI.) Water economy 10-12%, due to the exhaust steam being returned to the boiler.	(VI.) No saving of water.
(VII.) Simple, compact and light.	(VII.) Complicated, bulky and heavy.
(VIII.) Easy and immediate access for examination, cleaning and overhauling.	(VIII.) Difficult and lengthy operation to dismantle pump and heater for examination, cleaning or repair.
(IX.) The Cylinder back pressure is **decreased** and not increased (see p. ~~21~~). 25.	

From the foregoing, it will be seen that the Exhaust Steam Injector is greatly superior, having lower installation and maintenance costs, with greatly superior efficiency, and, in addition, is a **proved practical success.**

The Advantages of the Class "H" 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 by simply opening the steam valve and requires no further attention. It switches over automatically from exhaust steam to live steam working when the throttle is shut and *vice versa* without any attention on the part of the fireman.

(6) The steaming power of the boiler is greatly improved, and the injector has a very 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 and easy access to all parts for examination and cleaning without dismounting the injector.

The Exhaust Injector

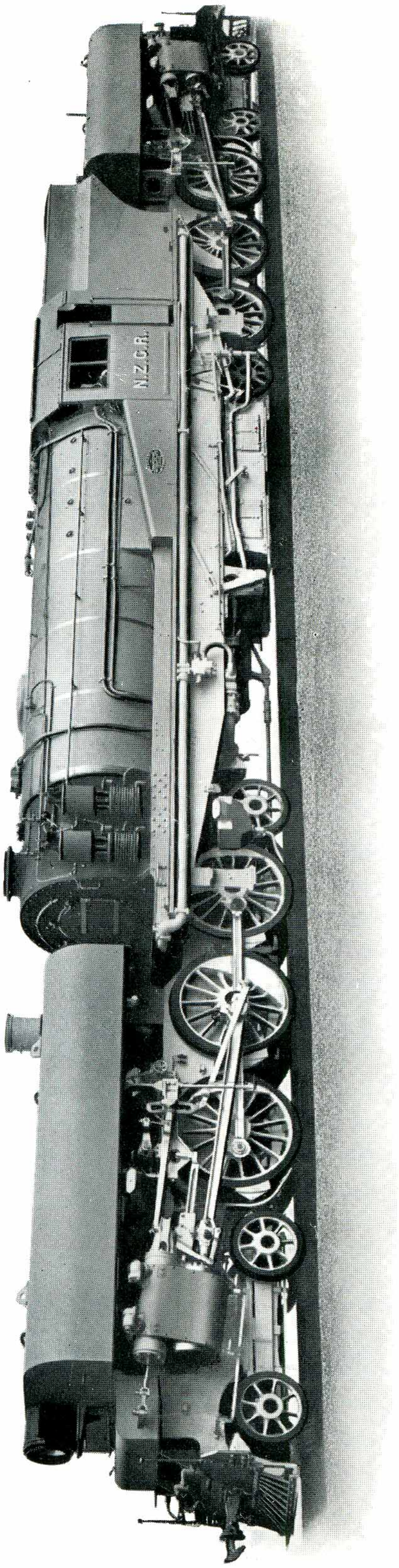
WHAT IT MEANS AS AN INVESTMENT

Example.—Main line locomotive in service 300 days a year burning 3 tons of coal per day at £1 per ton on the tender (£900 per annum).

Coal Saving by exhaust injector based on 10% of total fuel cost of £900	£90 0 0
Less interest, depreciation and maintenance charges being 15% of £130 (cost of injector and application)	£19 10 0
Nett return per year for one locomotive	£70 10 0

Or 54% on capital invested.

The total expenditure is £130, which will be reimbursed in less than two years.



4 - 6 - 2 - 2 - 6 - 4 Garratt Type Locomotive.
New Zealand Government Railway.

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

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

Possible Causes of Injector Failures

If injector fails to prime (*i.e.*, pick up the water) upon opening steam valve and steam escapes from overflow, the trouble may be located in the water valve or the water valve piston.

If the injector primes and then flies off instead of working, the combining nozzle may be choked or the combining nozzle flap not seating properly. Sticking of the injector check valve or the main boiler check may also be responsible for trouble of this nature.

If injector works with live steam but will not work with exhaust steam, either the automatic shuttle valve does not function or the exhaust valve does **not open.**

If injector works with exhaust steam but will not work with live steam, the shuttle valve may not function, or the exhaust valve may be **stuck open.**

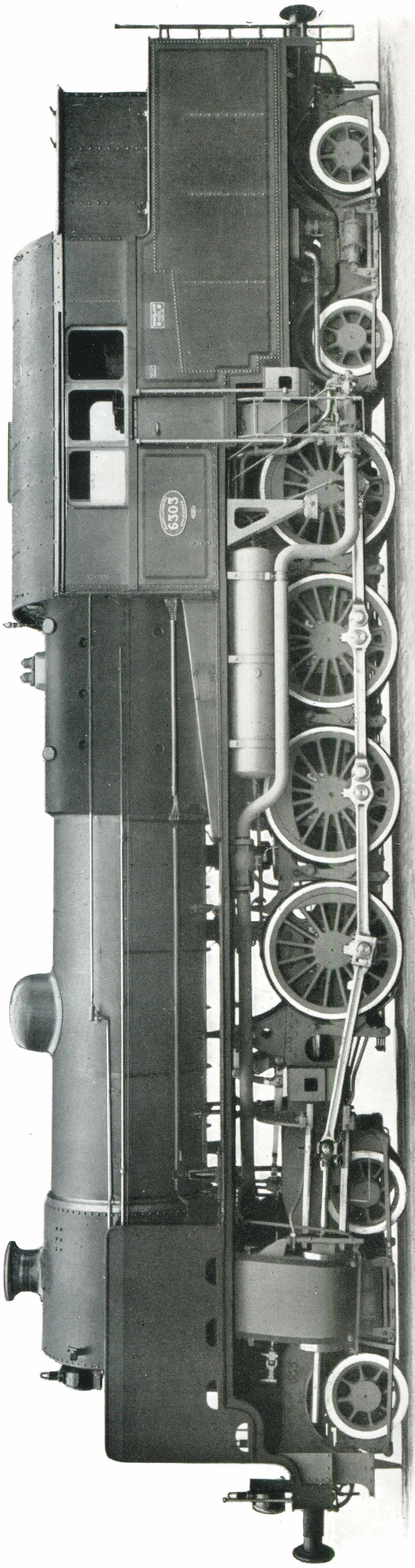
If steam escapes in puffs from the overflow when injector is **shut off** with engine working steam, the exhaust valve is either stuck open or does not seat properly.

If water escapes at overflow when injector is not working, the water valve does not seat properly or may need grinding in.

If water and steam escape 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 valve may need grinding in or some of the injector nozzles may have become loose in the injector body.

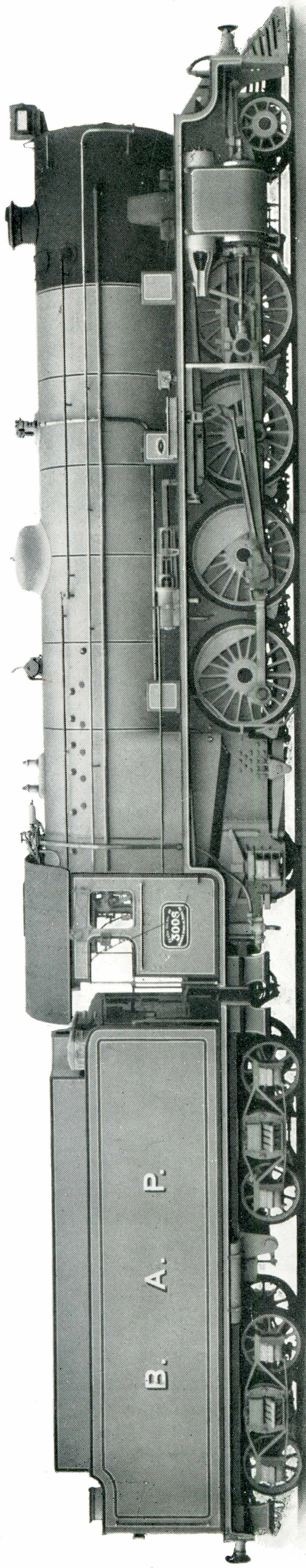
To test the automatic change-over from live steam to exhaust steam and *vice versa*, apply engine brake with engine standing, start injector working, and then open the engine regulator. If the automatic shuttle valve functions properly, the injector will stop working and water will run out of the overflow. Then close the regulator and open cylinder cocks. When 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 automatic shuttle valve does not function. Either a restriction will be found in the steam pipe leading from the main steam pipe of the locomotive to the injector, or the automatic check valve does not seat properly.



Built by Henschel & Sohn,
Cassel.

4 - 8 - 4 4-Cylinder Locomotive.
Netherlands Railway.

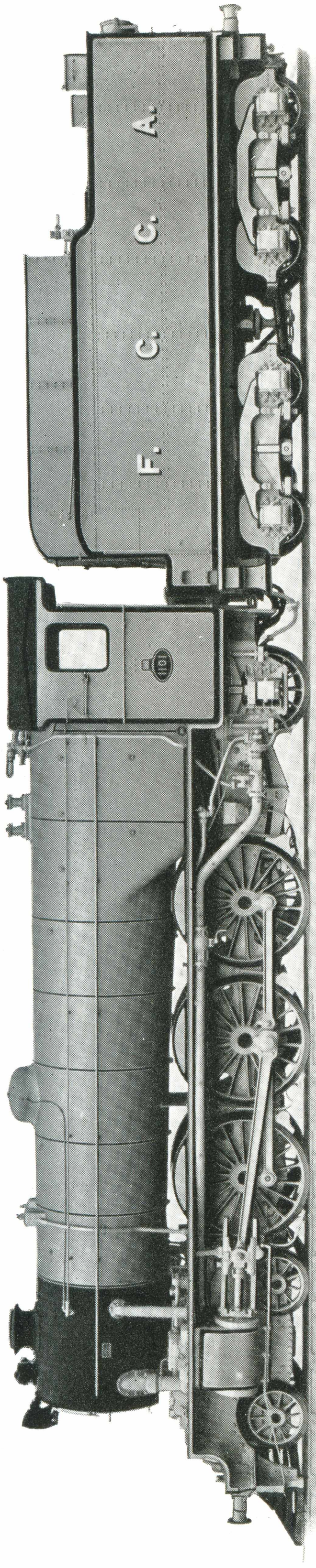
Fitted with **METCALFE'S PATENT EXHAUST STEAM INJECTOR**



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

2-8-2 Locomotive.
Buenos Ayres and Pacific Railway.

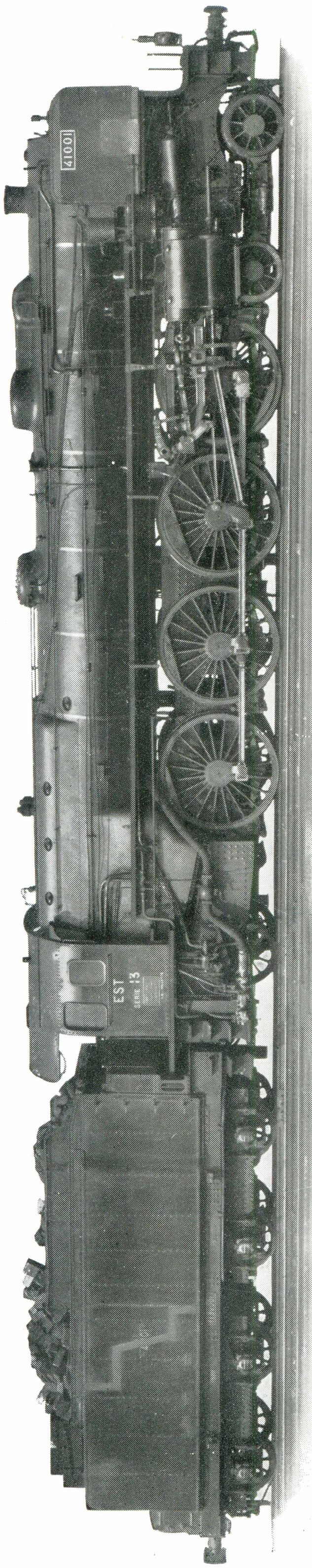
Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.



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.

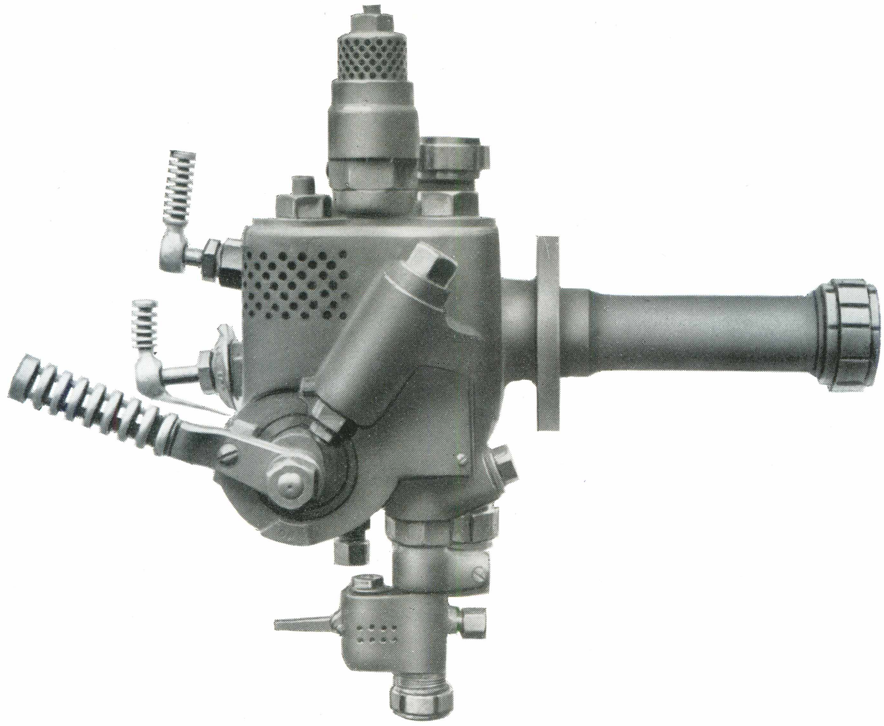


Type 4-8-2 Compound. Est Railway, France

Fitted with METCALFE'S PATENT EXHAUST STEAM INJECTOR.

DAVIES & METCALFE L^TD

The Metcalfe Vacuum Brake Ejector

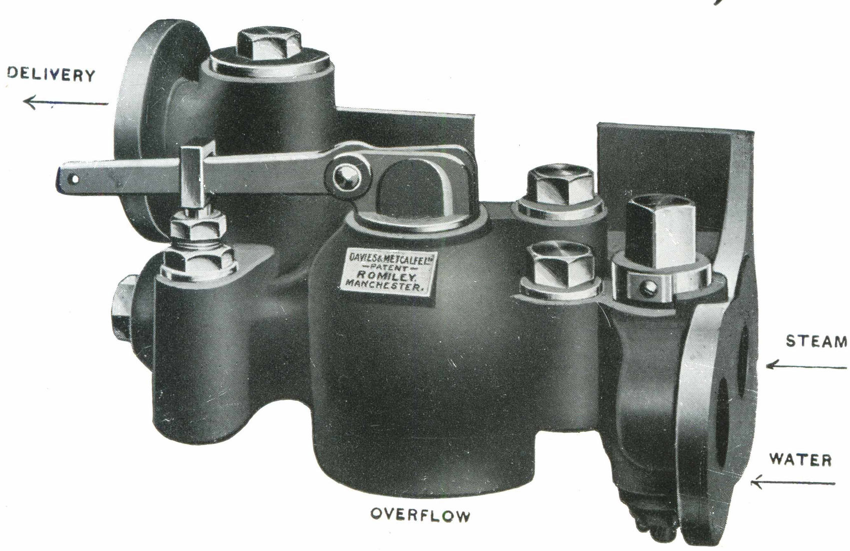


FOR POWER, SIMPLICITY AND RELIABILITY

Low Steam Consumption and Low Maintenance Costs.
Interchangeable with existing standards.

THE METCALFE PATENT

Locomotive Hot-water Injector



Works with Feed Water at 140° F.

INJECTOR WORKS, ROMILEY.

C. Nicholls & Co. Ltd., Philips Park Press, Manchester.