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"RECENT DEVELOPMENTS IN CYLINDER LUBRICATION"

BY

Mr. W. H. Pearce, (Member).

At the outset it will be necessary to dwell on the conditions existing in the cylinders when the engine is in motion. It is a fairly straight forward matter to arrange for adequate lubrication of engine working parts which are not exposed to steam, but the lubrication of sliding valves inside the steam chest, and pistons in the cylinder, is considerably more difficult. The presence of steam and the impossibility of watching the application of the lubricant prevents direct evidence of adequate lubrication. The high pressures and consequent high temperatures in which the oil is expected to function as a lubricant introduce problems which have to be solved by the chemist, who specifies the composition of the oil, since obviously no method of application will give good results with an oil which loses its properties when in contact with high temperature steam. The use of superheaters has made the chemist's task more difficult. (It may be noted that lubrication difficulties with superheated steam, forced the Navy to maintain the practice of using saturated steam only for reciprocating engines). It is not, however, the high temperature and pressure which make it difficult to apply the lubricant, but the fast changing conditions in the cylinders. These can best be shewn by reference to cylinder indicator diagrams. In the diagram (Fig. 1) steam is admitted up to 75% of the stroke, then after 18% expansion it is exhausted at a high pressure, starting at 120lbs. per sq. in. On the return stroke the pressure is nearly atmospheric.

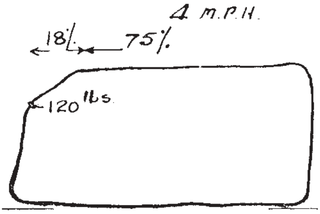


FIG. 1

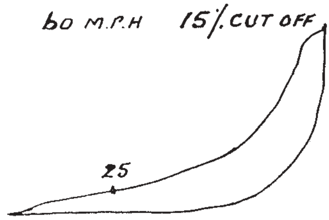


FIG. 2

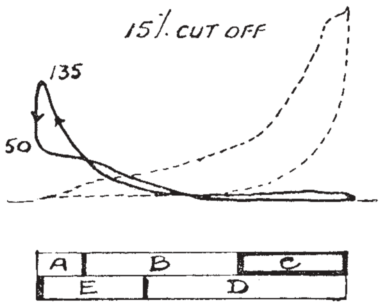


FIG. 3

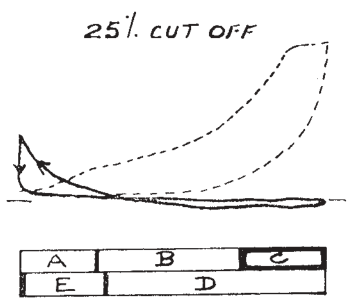


FIG. 4

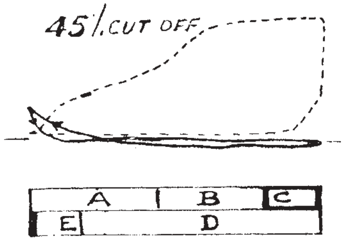


FIG. 5

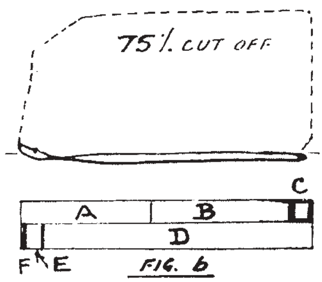


FIG. 6

FULL LINES SHOW CONDITIONS IN CYLINDER AT HIGH SPEED WITH REGULATOR SHUT.

A PORT OPEN TO STEAM CHEST, PISTON CREATING SUCTION IN CYLINDER.

B PORT CLOSED, PISTON CREATING SUCTION, THEN VACUUM IN CYLINDER.

C PORT OPEN TO EXHAUST, PISTON CREATING SUCTION FROM SMOKEBOX.

D " " " " , " EXPELLING PORTION OF GASES TO SMOKEBOX.

E " CLOSED, PISTON COMPRESSING GASES LEFT IN CYLINDER.

F " OPEN TO LEAD, GASES FORCED INTO STEAM CHEST, AND THEN PARTIALLY RE-ADMITTED DURING PERIOD A

In another diagram (Fig. 2) the cut off is 15%, then after expansion for 50%, steam is exhausted at a low pressure, 29lbs. per sq. in., but again it is only slightly above atmospheric on the return stroke. In cylinders with cranks at 90°, the pistons at nearly all crank angles, are in different positions, consequently, the pressures in two- and four-cylinder engines are nearly always different. When the regulator is shut at speed another entirely different set of conditions has to be met. The valve now governs the suction, compression and delivery, not of steam, but of smoke, flue gases and air. These gases, etc., are pumped into the steam chest, in which a pressure is built up, dependent on the position of the reversing lever controlling the cut-off. This pressure is greatest at early cut-offs, falling to atmospheric at about 45% cut-off, and decreasing to a vacuum of 5lbs. at 75% cut-off. The diagrams in 15% (Fig. 3) shew the result with steam on and with steam off, at 60 m.p.h. The admission pressure with steam on records 235lbs. per sq. in., release pressure at exhaust opening 25lbs. per sq. in. and back pressure of 5lbs. per sq. in. With steam off, the back pressure steam is compressed up to 135lbs. per sq. in., then at pre-admission position, or when valve opens to give lead, this 135lbs. per sq. in. is admitted into the steam chest and drops to 50lbs. per sq. in., which later expands in the cylinder after cut-off to atmospheric pressure, then increasing to 5lbs. per sq. in. on the return stroke and is again compressed to 135lbs. per sq. in. With steam off (Fig. 3, full lines), the piston extracts pressure from the steam chest up to cut-off (A), and tends to create a vacuum in the cylinder up to exhaust opening position (B), then this partial vacuum in the cylinder induces the flue gases to enter the cylinder for 35% of the stroke (C). These gases are retained in the cylinder up to point of compression (D), then compressed to 135lbs. per sq. in. (E), and at pre-admission are forced into the steam chest for the next cycle of similar events. These events occur in a varying degree at all cut-offs. At 25%, 60 m.p.h. (Fig. 4), the suction from the blast pipe lasts for 27% of the stroke, and the gases are compressed up to 75lbs. per sq. in, which raises steam chest pressure to 10lbs. per sq. in.

The average back pressure in the cylinder is about 3lbs. per sq. in. At 45%, 60 m.p.h. (Fig. 5), the suction from the blast pipe lasts for 18%, and the gases are compressed up to 40lbs. per sq. in., which does not raise steam chest pressure above atmospheric. The average back pressure at 45% is also atmospheric. Then at 75% cut-off (Fig. 6), the suction lasts for 7% and the gases are compressed to 15lbs. per sq. in. The piston extracts gases from the steam chest up to cut-off and reduces the small pressure to less than atmospheric.

It will be seen from Fig. 7 that the 45% position when drifting gives the best conditions, and the minimum tendency to force smokebox gases through the valves and cylinders into the steam chest. It is for this reason that drivers are instructed to work piston valve engines in 45% when running with steam off, this position being termed "drifting position."

With piston valves this is the best arrangement unless a complicated system of valves and pipes is introduced with the object of providing direct communication between the two ends of a cylinder when steam is shut off. With independent steam and exhaust valves it is possible to have direct communication, merely by keeping open the two exhaust valves while drifting.

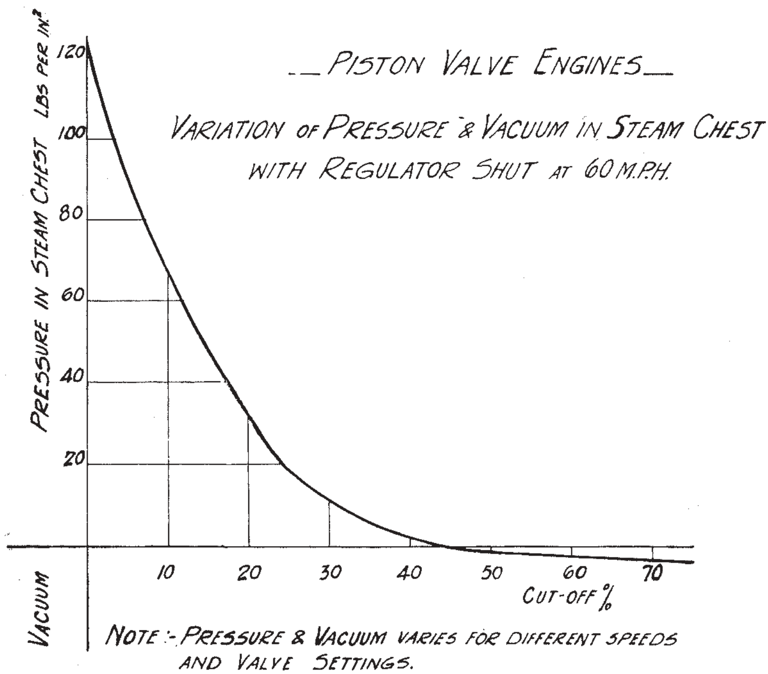


FIG. 7.

This is achieved with the experimental poppet gear now being tried, by an extra cam. The gear has to be moved to put this cam into operation when running with steam shut off.

On modern G.W. engines the best running cut-off for high speed and maximum period of expansion is at 18%, but with steam off, this is the worst position for pumping gases into the steam chest and superheater units. What chiefly counteracts the action of many lubricants is this effect when running without admission to live steam. It is throughout these variations of pressure and consequently of temperature, that the piston and valve have to be reciprocated with the minimum of friction, which means that lubrication must be made possible under all these adverse conditions. It may be noted that engines working on non-stop runs are frequently in a cleaner condition in the steam passages than engines that work on suburban traffic. Some examples of additional variations in cylinder conditions will help to shew other aspects of lubrication. After a locomotive has been stationary for some time, and then restarted, all pistons at the moment of starting, and the valves that govern them, are traversed over cool and unlubricated surfaces, especially on the exhaust side, and in many instances on the steam side. This refers to engines with no initial lubrication to the valve, cylinder, or piston faces exposed to exhaust opening, and to engines that have direct feed of oil in liquid form to the steam chest or cylinder only.

The use of superheated steam subjects the live steam surfaces to a temperature of 140° F. above the temperature of boiler pressure steam. To obtain superheat, the steam admitted through the regulator has to traverse five times as far as in engines using saturated steam only. It also passes through sub-divided areas, each 1/50 of the main inlet. The steam thus tends to collect foreign matter from these surfaces, and a scouring action results on initial steam admission. Prior to starting, the surfaces are exposed to the atmosphere by means of air valves and cylinder drain cocks. The latter provides not only a, necessary exit for water, but also an easy exit for any concentrated oil drops admitted direct to the cylinder walls.

The velocity of steam admission is limited by the piston speed, but exhaust steam velocity is practically constant, or nearer maximum at slow piston speeds. When the piston speed is slow it allows the exhaust pressure at any cut-off to be changed more quickly into velocity, whereas if the piston speed is great the steam expands further in the cylinder after the valve has opened to exhaust, thus decreasing the exhaust velocity. This accounts for oil loss at starting when oil is admitted in liquid form direct to cylinders or valves by mechanical means.

In older type locomotives the lubrication problem was not so acute, and it is interesting to consider how improvements in design from other points of view have increased the lubrication difficulties. The outstanding differences are the use of higher pressures, superheated steam, and higher valve and piston velocities. The increase in temperature is from 370° F. for the 160lbs. per sq. in. boiler, to 540° F. for the 250lbs. per sq. in. boiler with superheater.

Another factor affecting the lubrication is the change in valve setting for modem engines. In recent years the crank angle for lead has been gradually reduced, and the valve opening to steam increased, two distinctly desirable changes made possible by increased valve travel and steam lap. The relative velocity of the valve at exhaust is proportionately increased, from 2·66ft. per sec. to 4·34ft. per sec., with 1″ and 1⅝″ steam laps respectively, thus giving a less restricted exhaust, which demands a momentarily freer outlet from the blast pipe. This outlet is provided in the standard " jumper top." Such a free exhaust decreases the time during which the steam deposits oil particles on the cylinder walls, and its free exit also tends to induce a scouring action.

It is hoped that the foregoing remarks have served to shew in some measure the conditions that have to be met when evolving any method for the application of oil.

It is suggested that some of the requirements for good lubrication are :—

> To maintain a consistent supply of lubricant against all variations of speed and pressure.
>
> To distribute the lubricant over all sliding surfaces in valve chest and cylinders.
>
> To permit of easy and instant control of the rate of feed by the driver.
>
> To provide visible indication in the cab of the amount of oil being fed to each point of application.

The earlier types of lubricators in use on the G.W.R. did not fulfil these essentials, and later types meet the requirements in a varying degree.

A simple method of maintaining oil under pressure is to admit boiler steam into one end of a coiled pipe fixed about 4 or 5 feet above the lubricator. The steam condenses in this pipe which is connected to the bottom of the lubricator, thus a pressure of ·43lbs. per ft. head of water is added to the inlet steam pressure to force the oil from the lubricator as required.

This only provides a uniform rate of feed against a constant resistance or pressure. As has been pointed out, such conditions do not exist in locomotive cylinders. To permit of its use, it is obvious that the maximum rate of feed has to be set to work against small pressures. If set for average working pressure, an excessive amount of oil would be fed at lower pressures, and the flow would vary with any difference in pressure. The rate of flow is easily visible through the sight feed glass, which means that the glass is essential for the driver to know when flooding occurs. Should this occur, a special byepass is fitted, so that the oil supply can be controlled from the lubricator, but without any indication of the amount. It is obvious that such attention as this type needs could not be tolerated on modern high pressure engines. Besides, this lubricator feeds cylinder oil through a long length of pipe direct to the steam supply from the regulator. Should this oil pipe be empty on starting, or become empty due to cylinder suction, it would require some hours of working to refill by ordinary sight feed drops. A pint of cylinder oil contains over 2,000 drops as formed in the sight feed glass. A more satisfactory use for this simple lubricator is to feed the oil above the main regulator valve, thus ensuring a constant slow feed, as the pressure difference in the lubricator and over the regulator valve is very small and nearly constant. It might be thought that this fairly constant pressure would make the regulator an ideal place at which to introduce the oil feed for the cylinders. A consideration of the very high temperatures to which this oil would be subjected in passing through the superheater units will shew the impracticability of this method.

With the introduction of engines that were designed for high steam pressures, it was necessary to modify all existing methods of cylinder lubrication. In the earliest experiments, using oil only or oil combined with a steam jet in the lubricator it was found that the feed could not be easily controlled against the variable pressures and temperatures. It was essential to aim at an automatic constant feed under all working conditions, thus relieving the driver of continuous attention to the lubricator. The initial experiments proved that the oil must be combined with steam before being admitted to steam spaces requiring lubrication. With low pressure boilers and flat slide valve engines, the steam admitted to cylinders does not develop the extreme range of pressures between a vacuum and boiler pressure, being prevented by the lifting of the slide valve, due to compression. This permits of the earliest form of steam and oil combining valve being retained for these engines. The method is to maintain the oil at about 1lb. above boiler pressure by hydrostatic pressure, as previously mentioned. This will feed oil against a pressure slightly below boiler pressure. The combining valve, when shut, permits only a slight flow of oil against boiler pressure, thus the flow of oil is practically nil, as the difference is very small. When the valve is opened the mixture above the valve is admitted to a distributing box in the smokebox, which divides the flow to the various main steam pipes. This flow through the combining valve reduces the pressure against the oil, thus inducing the oil to flow more freely and to mix with the steam. The distributing box is arranged to limit the rate of flow by restricting the area of outlet holes to $\frac{1}{8}''$ dia. each, much less than the area of $\frac{1}{2}''$ dia. inlet, thus the pressure variation at the valve is reduced. This prevents the oil from flowing too freely to main steam pipes when the regulator valve is only partially opened.

When higher pressures than 200lbs. per sq. in. were introduced and piston valves superseded flat valves, it was soon found that further modifications to the lubrication system were necessary.

The defects included :—

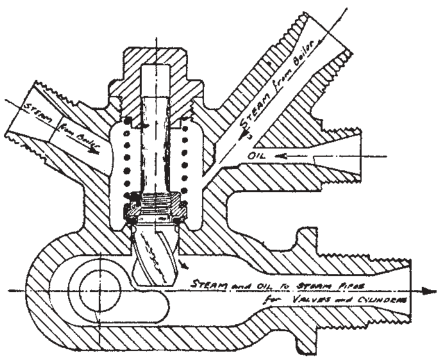
Irregularity of oil drops through sight feed glasses.

Too frequent flooding and breaking of the glass.

Too much of the driver's attention required.

Unequal lubrication of right and left cylinders.

Irregularity of feed was corrected by an improved combining valve (Fig. 8). This included an additional steam pipe connected to the steam fountain. The previous pipe conveyed the carrier



LUBRICATOR COMBINING VALVE_

AUTOMATICALLY CONTROLLED BY REGULATOR HANDLE_

FIG. 8.

steam without restriction through a $\frac{1}{2}''$ pipe to the combining valve ; the additional pipe conveys the balancing steam to a restricted aperture of $\frac{1}{8}''$ dia. in the valve. This limits the flow of steam, thus maintaining on the inlet side a constant pressure drop in relation to the boiler pressure. This development effected a great improvement and assured the maintenance of any required rate of oil flow through the sight feed glasses. The oil drops pass from the feed nipple through a column of water, and if this is displaced or insufficient, the incoming oil will not displace an oil drop at the top, and thus flooding takes place. Increasing the water space had the effect of ensuring regular oil drops. These improvements have practically reduced the driver's attention to nothing after he has made the initial adjustment to suit the engine working and load. The oil distributor was fitted with a short inlet, and did not correct the effect of a bend in the inlet pipe, thus causing an unequal supply. By lengthening the straight inlet this was corrected. The usual practice is to connect the distributor outlets to a perforated nozzle fitted in the steam pipe, thus ensuring that a continuous saturated steam and oil spray will mix with the superheated steam before it is admitted to the steam chest. In this way all live steam is mingled with a proportion of oil which will adhere to all surfaces with which it comes in contact.

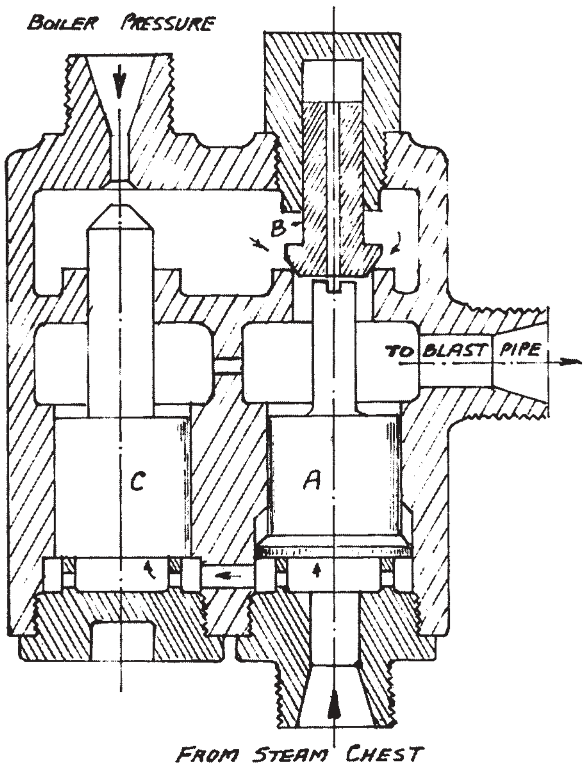


Fig. 9.

Many experiments have recently been made, and it will be interesting to enumerate the principle of each arrangement and shew how useful the information gained has been to achieve more satisfactory working of important lubricator details. Mention has been made of the suction from the blast pipe when running with steam off. In order to reduce this suction an experimental decarbonising valve (Fig. 9) was fitted which admitted a jet of steam at boiler pressure into the exhaust pipe when the engine was drifting. The valve is automatically operated by the pressure in the steam chest and boiler pressure, for the purpose of keeping valves and pistons in a cleaner condition. In early cut-offs, at high speed, with regulator shut, the air pressure pumped into the steam chest lifts piston A and opens valve B. With regulator open, the extra steam pressure in steam chest also lifts piston C and shuts off steam to blast pipe.

The majority of the various classes of G.W. engines carrying standard boilers are fitted with the standard method of lubrication. All these engines are not doing similar work and therefore varied results are obtained from the use of the same type of lubricator. For instance on the non-stop run from Paddington to Plymouth, a mileage of 225 miles in 4 hours, the regulator opening would be fairly constant, and up to $1\frac{1}{2}$ pints of cylinder oil would be required each hour for maximum load. Compare this with an engine working the suburban traffic from Birmingham. For the latter, the engine would be stopped and restarted about every 10 minutes, and $1\frac{1}{2}$ pints of cylinder oil would be required every 3 hours. The driver's duties are equally exacting in each case, and constant outlook is demanded, hence mechanical details on the footplate must not divert focussed attention from the road and signals. Steady regulation of oil feed to suit each case is obviously necessary.

As an experiment an extra lubricator was provided to feed oil to each steam port through an automatic shuttle valve, fixed in mid position over the cylinder. A small plunger moved to and fro about $\frac{1}{4}''$, thus delivering the oil to the port during admission of steam only. In service it was shewn that this oil did not combine sufficiently with the steam to spread over the cylinder walls. A modification of this test was to discard the plunger and admit a steam and oil jet from a combining valve, thus the spray would penetrate to the surfaces, and be retained for a longer period, thus giving efficient oiling when drifting. Also, before starting, if the regulator handle is put into drifting position, this spray can be admitted to sliding surfaces on the exhaust side, in addition to the steam side from the usual combining valve arrangement.

When an engine is fitted with poppet valves, the valve faces have no sliding surfaces, therefore only the pistons and cylinders require lubrication : a steam and oil jet is admitted to the top of the cylinder, this method of lubrication being found satisfactory.

The next experiment included the fitting of oil spray inlets to a circular recess outside the valve bush, with four inlet holes to each valve head, thus lubricating the exhaust and steam rings. On steam admission, the oil would be induced into the cylinder by the steam flow. The arrangement gave improved results over the previous test, though the tendency was to exhaust too freely the oil admitted so near the steam ports. In a later experiment, some spray studs were inserted in the main outside pipes above the cylinders. This simplified matters and gave better results. To ensure some lubrication in the cylinders on starting, a separate inlet was made direct to the top of the cylinder wall, which permitted the driver to insert any desired amount of oil by the feeder. Further supplies of oil when running were fed from a separate lubricator. The variable feed to such intermittent pressures in the cylinder was not satisfactory, and oil thus admitted is lost too quickly by the direct exhaust which occurs just after half stroke position.

It has been shewn that if the oil is injected into the steam in the cylinders, there is not sufficient time for the oil to spread throughout the steam. In order to investigate this side of the problem under other conditions better adapted for this purpose, tests were made on the stationary engines at Brentford Dock. The point at which the oil was introduced into the steam pipe was moved away from the steam chest, and it was found that improved lubrication was obtained in the cylinders. This result suggested that the point of oil inlet should be placed as far from the cylinders as practicable when oil is used unmixed with steam.

A similar experiment was carried out on the large compound condensing engines at Penarth Dock. In this case, the effect of substituting an oil and steam spray for the existing oil drops was investigated. All four engines of 750 h.p. each were fitted with sight feed lubricators that delivered oil into a standard type of combining valve as used on locomotives. This valve was automatically controlled by a small piston operated from the steam chest, thus opening the combining valve and maintaining an oil spray to the main steam pipe when the engine was in motion, but stopping the oil spray when the engine was stalled, by throttling from the accumulator control. Considerably improved results have been obtained over a long period, the effects being apparent from a reduced strain on the valve spindles and gear, and considerable reduction of grease deposit in the oil separators.

The combining valves previously referred to were all of the standard single valve type, but in view of the advantages from the oil spray method, a double combining valve was designed to increase the oil supply and to provide independent feeds. This was fitted with two steam inlets, two oil inlets, and two outlets for the combined oil and steam. The delivery could thus be fed direct to the right and left spray nozzles in the steam pipes without a distributor box. This considerably reduced the length of oil pipes in contact with the smokebox temperature of 600° F, and decreased the possibility of adversely affecting the oil. The advantage of extra oil inlets meant the introduction of extra sight feed glasses. In order to provide ample feed without danger of flooding the glasses, the feed to each side of the engine was given two glasses, and the existing lubricator bodies were re-fitted with units for carrying five glasses ; one for the regulator valve and four to the cylinders (Fig. 10). Each cylinder glass needs a separate

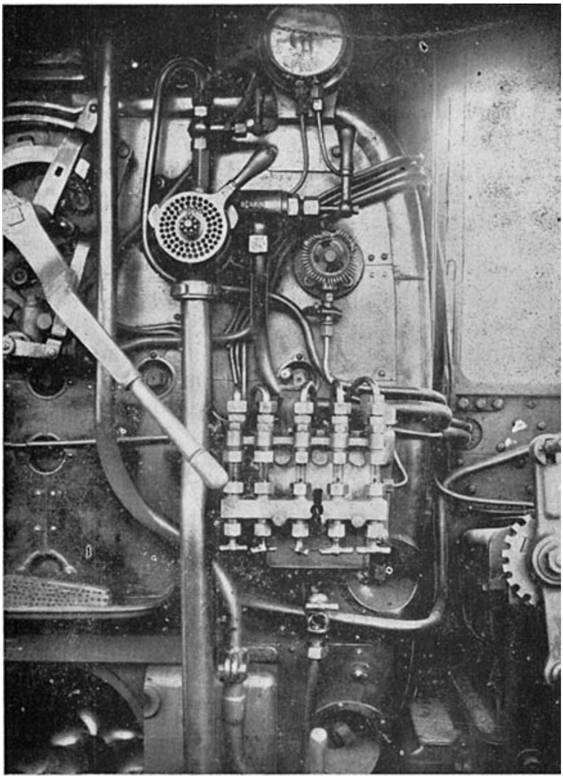


Fig. 10.

control in order to equalize the feeds, but for adjusting the four cylinder feeds together a separate control valve is fitted.

It must be understood that the operating of the combining valve must be arranged to suit the working conditions for which most classes of engines are designed. At present, the usual system is to rely on the driver moving the regulator handle to a standard drifting position while the engine is running and steam is not being admitted to the steam chest. On non-stop trains this extra movement of the handle is only required at long intervals, whereas on ordinary stopping trains, or especially on suburban trains, it is very frequent and yet more important that it should be done. To ensure that the desired position is attained prior to each engine stop, an automatic arrangement has been applied to be quite independent of the driver's method of using the regulator. Most G.W. engines are fitted with a vacuum pump, which is capable of producing a partial vacuum at very slow speeds. As an experiment, a special lever was fitted to the combining valve and connected to a small piston, operated in

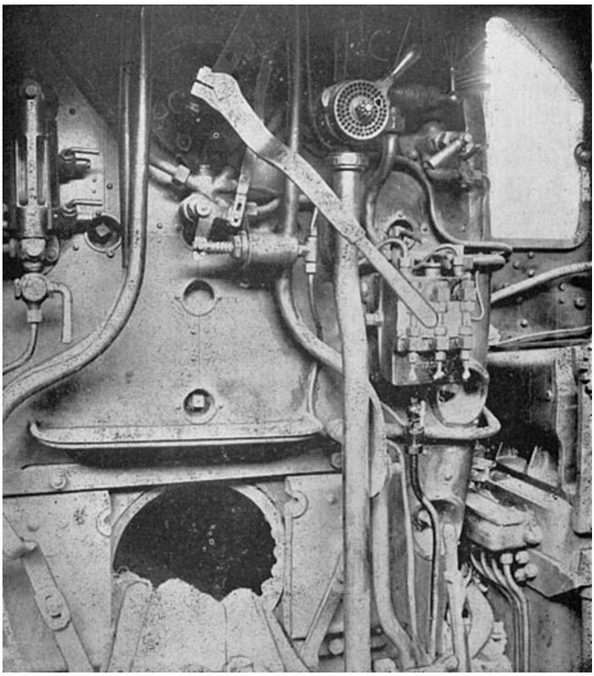


Fig. 11.

one direction by vacuum, and returned by steam, assisted by a spring (Fig. 11). Thus, during engine running, the valve is kept open by vacuum, whether the regulator is open or shut. When the engine stops, the pump stops creating a vacuum, then the valve is immediately closed. The train pipe vacuum is isolated by a special non-return valve. The usual lever connected to the regulator handle is fitted with an elongated slot, which permits the independent closing by vacuum of the combining valve, but ensures a definite opening with the regulator. In this way the driver has only to shut the regulator at short intervals, without the extra opening movement to the drifting position, when working on suburban trains. The outstanding advantage is a continuance of lubrication and of drifting steam whilst the engine is in motion. It will be seen that this is the arrangement tried at Penarth Dock, modified to suit locomotive conditions.

The condensing arrangements have also been made the subject of experiment. Hitherto the coils covered a large area and were secured to the cab by special channelled clips and numerous bolts. They were fixed above the portion of firebox that projected into the cab. This is by no means the coolest part of the cab roof, consequently the effect of moving the coils back to the coolest portion was tried. Subsequently a coned spiral coil of two pipes was made and fitted (Fig. 12). This coil requires only three bolts for fixing, covers a small area, is made of larger bore pipes to retain more water, and has proved very efficient.

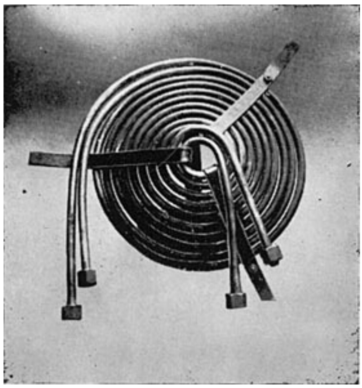


Fig. 12.

An attempt to summarise the foregoing remarks will be made in describing an improved oiling system. A less detailed explanation of the new lubricator and its working will be given, as the reason for its application should be realised from the remarks on earlier types and experiments. With previous methods, the condensing pipe pressure is equal to boiler pressure from the lighting up of the engine to cooling down and the oil in the lubricator is at boiler pressure from the time the engine leaves shed until its return. Actually this pressure is only required for condensing when the regulator is open, or in drifting position. When it was found necessary to have four independent feeds, and to avoid the provision of four control valves in the combining valve, it was arranged that the closing of the combining valve, should destroy the pressure in the lubricator and condensing pipes, thus stopping the oil flow. These latest lubricators (Fig. 13) are fitted with two oil tanks, one of 8 pints for the cylinders, and one of $1\frac{1}{2}$ pints capacity for the regulator valve. It is arranged for independent lubrication of each engine cylinder, therefore requiring four glasses in regular use. A spare glass for each pair to right and left side of engine is provided. There is an additional glass for the regulator valve only. The top and bottom units for the

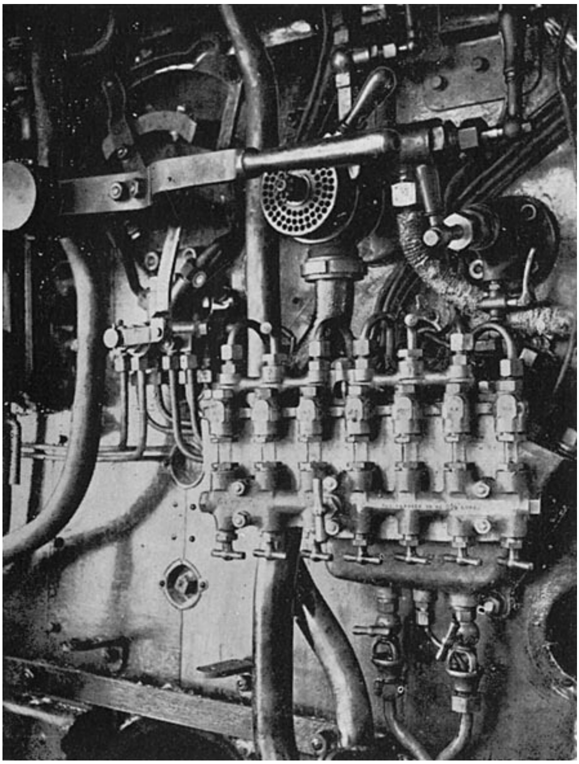


Fig. 13.

glasses are separate castings, which are easily machined. The bottom unit is fitted with a separate control valve for each glass with a master valve to control all cylinder feeds. A warming pipe is cast into the dual tank for the circulation of steam as required. The special combining valves referred to have four feeds and are fitted with two inlets for boiler steam, and two outlet control valves, one of which admits steam to a pressure balancing chamber. This supplies the controlled condensing boiler steam, plus 1lb. extra by hydrostatic pressure to lubricator, and also supplies steam to a limited annulus round the four oil restrictor inlets. The increased velocity of steam due to the restrictors induces an even flow of oil to the atomisers. The other control valve admits the carrier steam for the oil mixture to the spray nozzles in each main steam pipe. These control valves are opened and closed with the regulator handle, being re-opened if the handle is moved to the drifting position, that is, $\frac{3}{4}''$ from the shut position. As it is essential that lubrication should be admitted to all cylinder working surfaces before moving the engine, and that lubrication should be maintained while running with regulator shut, a special hand-operated byepass valve has been fitted in the combining valve. This permits steam admission through a 5/32″ dia. hole direct from one steam inlet into the balancing chamber, thus maintaining constant lubrication while the engine is in train service, quite independent of the driver's movement of the regulator handle. The byepass steam is safely ejected through the air valves when engine is standing, after covering the cylinder working surfaces with emulsified oil. The byepass is opened before leaving the running shed, and closed on arrival at shed, or when engine is required to stand for any considerable time. The drifting position when running down banks has the advantage of admitting extra carrier steam from the four holes of $\frac{1}{4}''$ dia. each in order to inject a supply of flushing steam when drifting at speed. This lubricating arrangement has no moving parts, and there is no pressure in the condensing pipes or cylinder lubricator when the byepass and regulator are closed. The oil pipes are very short in the smokebox, and there is no distributor box. Oil can be fed up to 20 drops per minute through each glass for cylinders. The filling inlet contains filters to prevent blocking of the 3/64″ dia. oil feed nipples. The feed remains constant at all working pressures, irrespective of the regulator position, the percentage cut-off used, or speed. All important steam and oil connections are visible from the footplate. All pressures can be shut off from the oil or steam pipes by suitable plug cocks on the steam fountain and at the smokebox end of oil delivery pipes.

For locomotives using superheated steam, the results still leave a margin for further improvements and reduction in wear, but in the application of lubrication to cylinders it has been demonstrated that the present G.W. methods are very consistent under all working conditions, and lend themselves to easy application to all reciprocating engines with high or low pressure boilers : their operation in service does not entail undue attention from the drivers or fitters, especially with the later types of combining valves and lubricators. Other methods have been tested and much time could be spent in explaining how they were applied and why they were not adopted, but on the Great Western Railway it is considered the best policy to specialise in lubricators without revolving or reciprocating parts, and only these types have been described in this paper.

With regard to the question of wear, this depends on many factors, such as the class of work on which the engine is employed, the water used in the boiler, and type of oil selected. The effect of each of these and other factors has to be considered separately, and makes the subject of wear too large for inclusion in this paper.

DISCUSSION.

In opening the discussion, Mr. W. A. Stanier (President of the Society) remarked that it could readily be seen from the experiments that had been carried out that considerable efforts had been made to make the lubrication of high pressure steam locomotives successful, but it was necessary to go still further to ensure valves and pistons being properly lubricated.

He hoped the members present would come forward to take part in the discussion. He would like to see the younger members take more part, if only from the point of view of improving their knowledge.

The Author had been very rapidly through the various phases of lubrication as applied to G.W.R. locomotives, and there were several points which lent themselves to discussion.

Mr. K. J. Cook said that the consumption of oil on the railway was very high in the aggregate, and oil was one of those commodities isolated in the Annual Accounts because of the yearly expenditure involved. Lubrication, and its application, consisted mainly of two things—quality and distribution—the theory being that it was necessary to provide and maintain an oil film between two moving parts, and that if this film were always maintained, wear would be reduced to a minimum.

In considering the question of quantity one felt that possibly the tendency had been for the amount of oil allowed to be restricted to below what was required. It had been mentioned that the general figure per engine was something like $6\frac{1}{2}$ pints per 100 miles, and that of this quantity $1\frac{1}{2}$ pints related to cylinder oil. One additional pint of cylinder oil per 100 miles would be an increase of 66% in the quantity for this purpose and this could be provided for 100,000 miles before the cost reached the equivalent of a new pair of pistons. Therefore it was very necessary to hold a balance between the restriction of lubrication and rectifying the effect of wear.

He thought that the function of the condensing coil should have been stressed. The basis of the operation of the lubricator was that a column of water was provided to make a working pressure above that of the boiler pressure and above the pressure that might be met in the cylinder.

The AUTHOR, in reply, stated that $6\frac{1}{2}$ pints per 100 miles was considered excessive, but with the maximum load it might be required. There were other factors which upset lubrication theories. If during the fitting of pistons into the cylinder the initial clearances were not made correct, no method of lubrication would stop the tendency to seize either the piston rings or the piston itself.

With regard to the valves, it was certainly wished that the oil film could be obtained, but there were ways to reduce friction besides varying the lubrication, as, for example, by altering the angle of the rings.

MR. H. G. JOHNSON said there had been more money and time spent, and experiments carried out, on lubrication than on any other portion of locomotive equipment during the last ten years. The point which caused some surprise was the absence of oil when examining pistons as they came into the shops. It was very surprising to find the surfaces quite dry as though no oil had been used. It was known that the oil was reaching the cylinders because it disappeared from the oil containers, but there was little evidence of oil adhering to the cylinders themselves. Internal combustion engines were very efficiently lubricated and he enquired if any experiments had been made in using castor oil which was so successful on high powered aero engines.

There appeared to be two systems which engineers supported to put oil into the cylinders, either the hydrostatic system or the forced lubrication system. A great point was made of the spray system, but he wondered whether it did achieve the best results. Considering a two-cylinder locomotive with $6' \ 8\frac{1}{2}''$ wheels running at 60 m.p.h. on 20% cut-off, one cylinder was admitting steam when the other was just cutting off, then steam was moving for two-fifths of the stroke at 180ft. per second. The question was whether that velocity of steam was sufficient to pulverise the oil effectively. The pump system was not used very much in this country, but on the Continent it was used because compound engines were in use in which the varying steam pressures might cause the hydrostatic system to break down. He would like to know if there were any information on the influence of the steam pressure itself on the oils.

The AUTHOR replied that all methods of pump lubrication had been tried on the same engines as the sight feed lubricators.

There was no evidence that the pump lubrication gave better results than the spray lubrication. The spray method lent itself to ample lubrication throughout the run. The latest lubricators were giving improved results because they had independent feeds. Each cylinder had its own amount of oil from the combining valve so it was quite independent of the other cylinders. The French engines came to this country fitted with pump lubricators, but when applied to G.W. practice the lubrication was not satisfactory. The pump lubrication was retained but the spray system was added. The spray system alone was finally fitted to the engines and they ran for years with less renewal of the slide valves than before the alteration.

Different oils had been tested at various times, but there was no oil outstandingly better than that provided in the combination used by the G.W.R. It appeared to be the method of applying the oil rather than the quality of the oil that was important. The quality of an oil could vary fairly considerably but the oil still gave consistent results.

On internal combustion engines the pressure was only on one side of the piston, and on the lower side of the piston there was a very small pressure, rather less than atmospheric. The rings could be kept soaked with oil, and the oil would be carried almost up to the combustion chamber, then the rings would return and pick up sufficient before returning to the top. It was not a parallel case between a locomotive and an internal combustion engine.

On low pressure cylinders the saturated steam itself became a lubricant and an oil injector was not necessary.

Mr. H. W. Knott believed that the oil certainly reached the cylinder, otherwise no carbonisation would be found.

In any lubricating system there was bound to be a deposit of smokebox ash in the cylinders and steam chest. He thought that some system for preventing the ashes entering the steam chest or cylinder could be employed and thus improve the oiling system. He suggested that two flaps fastened to the blast pipe should be used when the regulator was closed. If the regulator were open, then the flaps would be automatically closed.

The Author agreed that the prevention of ashes from entering the steam chest was a point to be watched. If Mr. Knott were to turn up Patent Specification No. 116,169, 1917, he would find that there was a patent blast pipe damper made to open and shut automatically, but such appliances needed to be kept in good condition, which, in smokeboxes, was difficult to do, and one must be careful not to increase the number of "gadgets."

Mr. S. A. Millard enquired the cause of the cylinder wear being greater on the inside cylinders of a 4-cylinder class engine than on the outside cylinders.

The Author replied that it was known that there was often a difference in cylinder wear on the same engine and this fact led to the development of independent oil feeds to each cylinder. One cylinder would tend to draw more than another and lead to uneven lubrication. In the case of the inside cylinders the steam chest diameter was larger than that of the outside, and this might tend to cause it. The temperature of the steam chest, which was in contact with the cylinder wall, tended to distort the latter, and this might cause an increase in the wear. In some designs the steam chest wall was independent of the cylinder wall, and less wear was experienced in the cylinder.

Mr. E. H. Gooderson agreed that the application of the oil was more important than the quality of it and he supposed that the amount of wear, which was most important to the workshops, played a very big part in deciding what lubricant should be used, and how much. He would be glad if the Author would give some idea of the reasonable amount of wear that should be expected on cylinders, rings and piston heads with a perfect system of lubrication.

He gathered the impression that the driver knew the exact amount of oil to put through the lubricator, and yet did not know when to put the gear into 45% cut-off.

The Author said that the question of wear was certainly very interesting, but he had not come prepared with any figures ; the wear varied with so many factors, and what would happen in the West of England district would not happen elsewhere ; it was sometimes impossible to get the same results even with the same method of lubrication.

With regard to the amount of oil being left to the driver to determine, there was rather less energy required in setting the lubricator than in using the handle to regulate the cut-off. If one saw the driver on a suburban train, and saw him shutting the regulator, etc., every seven minutes, he did not think one would expect the driver with lever or screw reversing gear to put the gear into 45% cut-off every seven minutes.

Mr. A. Davies said he had taken a great interest in the paper because it was a subject in which drivers were always interested. The driver wanted to get the most out of his engine with the least possible lubrication. The old driver was taught to save oil, and certainly some of the men did it very well. Drivers would like to run an engine in an oil bath because they found that the more oil they could get the less coal they used. He understood that for one pound of extra coal per engine mile the cost was £40,000 per year, and the driver wanted to reduce that consumption so that the fireman's work would be easier. On one of the new systems the oil was fed direct into the cylinders. That appeared to be a better method as each cylinder would receive its supply of oil instead of there being the possibility of all the oil passing down one pipe. It appeared that this method was more likely to give greater efficiency and greater economy in coal consumption. He believed it would be better to use a little more cylinder oil rather than less as better results would be obtained from the engines. The driver had to make his supply of oil last for a long time ; he was given an 8-hours supply and had to make it last 8 hours, and it meant that a driver who took an engine on some heavy work would do some harm to it because he had starved it of oil. A good deal of attention was paid to the high speed engines, but he thought that more attention should be paid to the lower speed engines with a view to increasing the efficiency, because the lower speed engines were using a large amount of coal, and he thought it would be cheaper to pay for oil than for coal.

Mr. W. J. Wheel enquired how the drivers knew how to work a new type of lubricator so as to obtain the best results.

With regard to the lower speed engines, the Author said that at present they were treated almost the same as the high speed engines, but the recently introduced system that had proved more satisfactory on the other engines could not be applied in such a short time.

If any departure were made from the existing practice a special instruction card was put in the cab explaining how the new lubricator should be worked. In all special experiments the drivers were asked to report immediately in case of difficulty in operation ; the drivers were also allowed one extra pint of cylinder oil per 200 miles.

Mr. W. F. G. Aldridge enquired if a decarbonising valve was to be fitted on the "Saint" class engines.

With regard to the extra amount of oil on the 40XX class engines, the steam pipes were found to be heavily coated with carbon deposit at the point where the spray entered, which seemed to indicate that the oil was burned up there.

The AUTHOR replied that a decarbonising valve did not appear to be required on that class quite so much as on the other classes. There was also practically no carbon deposit on the " King " class cylinders as the proportions of the cylinders were so arranged and the valve setting so fixed that a better distribution was obtained ; the lubrication, although sufficient, produced less carbon on the valves and cylinders without introducing decarbonising valves. Carbon was certainly rather excessive in some spray methods, but in the new method the amount formed would be less. It must be remembered that the smokebox temperature was about 600°F. and this would naturally tend to increase lubrication difficulties.

MR. C. K. DUMAS said that many speakers had already raised the question as to whether sufficient oil was being used. He was not an expert on lubrication, and he would like to enquire, if too much oil were used excessive carbonisation would be the result.

As to the advisability of fitting an automatic valve to prevent ashes getting into the steam chest, there were methods of preventing the ashes, to some extent, from getting into the steam chest, and he imagined that the G.W.R. were the only company to apply those methods.

Mention had been made of the multiplication of " gadgets, " etc., and he quite agreed that it was desirable to keep them down. If one looked back 40 years the only lubrication on an engine was a small lubricator, holding about ½ pint, over the top of the regulator. The old " District " engines had cocks in the front of the cylinders, and that was the sole method of lubrication then, but modern conditions had necessitated further elaboration.

He thought it was a great advantage, in that latest form of lubricator, that it was impossible to flood the glass, and he considered that this was a point that should be stressed.

The AUTHOR regretted he was unable to say whether any other railway had introduced a gear for preventing ashes from passing into the steam chest from the smoke box. Some companies had introduced piston valves with automatic arrangements to put the ends of the cylinders into communication when the engine was drifting. When at various London termini the Author had heard more groaning and grinding of pistons and valves on other Companies' engines than occurred on G.W.R. engines. Whether that was an indication of faulty lubrication he was not prepared to say.

MR. E. H. GOODERSON enquired if an engine had been allowed to drift and then a cylinder had been opened to see if the ashes were in the cylinder, and Mr. W. C. Dew asked if it were possible to damp down the ashes in the smokebox with a steam nozzle.

The Author replied that some years ago efforts were made to trace the ashes. The cylinder cover was taken off after a short mileage but the percentage deposit per stroke was too small to collect. Actual ashes were not found but a fine deposit which was formed into ash on the lubricating surfaces. In the days when the spark plates were fitted too near the blast pipes, the ashes fell into the blast pipes, but in the modern type no ashes could find their way down.

With regard to the damping of ashes, he thought that it was not a practical proposition. Difficulty was experienced when the drain pipe from the ejector was placed inside the smokebox : the ashes were damped but rust was caused. He would like to see a practical method of damping ashes ; at present it could only be carried out in the sheds, but no method had been applied when the engine was in motion.

Mr. H. G. Hall said that the Author had mentioned that there was difficulty in placing condensing coils in the right place, and he suggested that they could be placed outside the cab instead of inside.

The Author replied that one engine had already been fitted up with the coils outside the cab, but it was purely experimental. It was not suggested that this was the best position because in cold weather the pipes would become frozen due to the velocity of the air over the cab.

Mr. A. V. T. Chubb enquired if there were much falling off of temperature in the condensing coil, to which the Author replied that the temperature at the inlet to the coils was always the same as the temperature of the boiler steam. The temperature of the water at the outlet from the coils was practically that of the air in the cab.

The Chairman, in closing the discussion, said that the limit of wear on valves and pistons should be such that an engine could be run from general repair to general repair.

Another speaker had referred to the question of the evidence that ashes found their way into the cylinders. As the Author had said, it was not so much ashes, as fine particles of ash in the smoke deposit which formed on the slides of the pistons, piston valve spindles, etc. Analysis had proved that a very large proportion of it was the carbon obtained with ashes, a certain amount of lime and very little oil.

He thought that the paper had been particularly designed to shew that it was realised that the engines were not getting enough oil in the valves and pistons to lubricate them, and one of the causes was that the distribution arrangements did not give reliable arrangements for ensuring that each piston and valve obtained its share of the oil—that was really the reason for the double and quadruple combining valves, in order to get an independent supply.

Some of the experiments were very instructive as to the problems which had to be met, and he hoped that the efforts the Author was making would ensure adequate lubrication. The present arrangement was not entirely satisfactory with superheated steam and the evidence was in some blue piston rings and dry surfaces that were seen.