THE
INSTITUTION OF LOCOMOTIVE
ENGINEERS, LONDON.

President :
HENRY FOWLER, A.M.Inst.C.E.

Presidential Address.
THE MAINTENANCE AND REPAIR
OF LOCOMOTIVES.

FOURTEENTH PAPER
(OF TRANSACTIONS).

SESSION 1913.

*Read on Thursday, January 23rd, 1913,
at St. Bride Institute, London,*

LONDON :
Published by the Institution
1913.
Price One Shilling net.

The Institution of Locomotive Engineers

PAPER No. 14.

The Maintenance and Repair of Locomotives.

BY

HENRY FOWLER, A.M.Inst.C.E.

THE subject which I have chosen for an address to you to-night is one in which I am particularly interested, although not one which perhaps appeals so readily to the outside public as that of the actual driving of the locomotive itself. A railway man knows, however, that it is a most important subject, and one which perhaps affords the greatest scope for mechanical engineering which exists on a railway. Its importance may be judged by the fact that there are on the six largest railways in England alone about 14,000 locomotives, representing value of perhaps 35 millions sterling. Of these locomotives probably about 20 to 25% are out of service for examination or repairs of various degree, and it will thus be seen that seven or eight millions of capital on these railways alone is idle and non-earning. It is hardly therefore necessary to point out, especially to such an audience as this, the need for every possible care to be taken to minimise to the greatest extent the time spent in examination and repairs during which period the locomotive is out of service.

You will perhaps excuse me if, when dealing with actual practice, I adhere to the methods used on the railway I am connected with, which I believe, however, applies largely to the other roads in this country.

RUNNING MAINTENANCE.

In this, the first sub-division of my subject, I purpose to deal with the maintenance of a locomotive whilst it is in the shed itself, and during the period when it is expected day by day to draw traffic.

First of all we have the question of supervision, commencing with that given by the driver. Just as the driver of a motor car knows instinctively, by the beat of the engine and by its behaviour on hills, how his car is running, so a driver can tell how his locomotive is behaving, but with one very important difference as to the cause of any variation. With a motor car one can look upon the fuel as being absolutely identical as tin after tin of spirit is used, whereas on a steam locomotive the wagons of coal from the same colliery may vary. It is, however, rarely that the indifferent running of a locomotive is the result of want of mechanical maintenance during the time immediately succeeding shop repairs, except trouble due to the valve setting becoming unsatisfactory, owing to the engine settling down on the springs. This is, of course, at once apparent in the loss of regularity of beat and is obvious to the most casual layman. A driver exercises far more supervision of maintenance in noticing any defects as he works and oils the machine; these are chiefly of a minor character, such as leakages of various descriptions, looseness of smaller parts, etc., etc., and occasionally fractures. At the end of a trip the driver reports these defects either in a book or, as is the case with the Midland, on a card. In this latter case the cards are dropped into a locked box and afterwards removed for the foreman fitter to arrange for the work to be carried out in good time for the engine to be ready again for the train it is next booked for.

In this case it is perhaps not out of place to refer to the question of pooling of engines, which is a question of perennial interest. Roughly, it may be stated that in this country practically all the passenger engines are allocated to a particular set of men, whilst the same holds with regard to the most important goods trains. The irregularity of running ordinary goods makes the same arrangement in their case a matter of more difficulty, but on the Midland even these locomotives' movements are now fairly

regular. There seems little doubt that one driver one (and the same) engine is the soundest proposition as far as the maintenance and repair of the locomotive itself is concerned, but whether the economy in this direction is more than balanced by the extra mileage obtainable by pooling is a matter that cannot be readily settled.

In addition to the driver's reports, which, of course, largely consist of remarks on the engine in running, examining fitters are employed to go periodically over the whole of the mechanism to ascertain its actual condition. The periods between the examinations naturally differ with the varying parts, and on the Midland it does not vary much from the sheet given by Mr. C. W. Paget in his paper before the Institution of Mechanical Engineers (1910, p. 825). In this the period is based on either time or mileage. Roughly, the latter is adopted with parts which are in motion, whilst the former is employed with other portions. In all cases the periods are arranged with sufficient margin to allow of the examination of a number of parts to be made to synchronise. From the report of the examiner the work required doing is carried out, and these reports and the drivers' repair cards form a useful record of the state of the engine when the question of "shopping" has to be considered.

As we shall see later the predominating part of a locomotive, I may almost say in every respect, is the boiler and its internal maintenance is specially catered for in a shed. As is well known, the boiler has to be periodically washed out to remove scale which forms to a greater or smaller degree with every water, and also to change the concentrated water itself. It is hardly necessary to say that if cold water is to be used for this process a certain time must elapse between the time the boiler is blown off and the time when cold water may be used for the washing out process itself. If power is scarce there will be tendency to wash out before the boiler is properly cool, with disastrous results from a boiler repairing standpoint. Recently, both in America and this country, and especially in the former, plants have been installed by means of which the washing out is carried out by hot water, the hot water and steam of the boiler itself being used for supplying most of the heat. This has largely decreased the time spent in washing out, etc., as may be imagined. In America I have seen an engine come in the shed, have its water changed (not the boiler washed out) and the engine move out of the shed again with 50 lbs. of steam in its boiler in 36 minutes.

Whether a hot water plant is used or not it is very essential that the washing out should be carried out efficiently. Nothing is worse than to find that boiler trouble, such as wasting away of plates and stay heads, plates cracked, etc., has arisen through scale not being properly removed, and to the plate not being kept cool as it should be by the water in close contact with one side of it. The shed should keep a strict record of the boiler work done to an engine during its service, and of the state in which the various parts of it are found. Periodically, and at fairly frequent intervals where the water is particularly bad, a few tubes should be removed, so that the space between the tubes may be properly cleaned. The tubes removal should be shown on a proper tube diagram, which should be used for reference so that the same tubes are not removed the next time any are withdrawn.

A record should be made of all examinations, and this should be kept on a card or form carried on the engine itself, so that if an engine is transferred temporarily to another district, the examinations may be carried out according to schedule without delay or inconvenience.

It is hardly necessary to a meeting such as this to explain what is meant by a "casualty" in locomotive work, but it is well perhaps to say a few words with regard to their bearing on the subject of this paper. Both the Drawing Office and the Works require to make themselves thoroughly conversant with the causes of failure, and if these latter are carefully scheduled and properly studied, it will be found that one may learn a very great deal by the weak points shown up by these failures, and steps may then be taken to reduce them as far as practicable. The fact that these casualties are properly studied and the blame allocated to the proper person wherever possible, tends largely to proper care being taken all round to prevent failures which may disable an engine and put it out of service.

SHOPPING OF ENGINES.

We must now consider the question of "shopping" engines, and this is a matter of very great importance, as assuming that a "heavy" shopping takes, say, twelve weeks, it is clear that if this occurs every twelve months it will necessitate the engine being out of service for a considerable percentage of its life. Generally, it may be taken that the first thing which requires attention more than can be given between trips is the question of the wear of the tyres.

FIG. 1.

ARRANGEMENT OF CORRUGATED STEEL FIREBOX.

It may be taken roughly that, with passenger engines especially, the tyres require to be seen to in half the time the motion wants attention. By the time the tyres are worn so as to want turning the engine is probably riding a little roughly, owing to there being more play in the axle boxes than is desirable. This being so, it is necessary not only to turn the tyres but to take advantage of them being out to metal up and re-bore the boxes, or carry out a "wheel and box job." Whilst this is being done time will allow of the fire-box interior being examined, and any stay heads which require attention being "knocked up."

If these items receive attention the engine will probably run on for a further equal period, and so by the time the tyres again have to be seen to, the motion, boiler and general details want repair, and the engine is called into the shops for a "heavy" or general repair.

The state of the locomotive itself, considered individually, should finally determinate the length of the period between general shoppings.

If the mileage done by each class of engine is fairly constant it is extremely convenient to fix a time limit, which should not be exceeded.

It should always be borne in mind that with a locomotive, as with all machinery having moving parts, the proverb, "A stitch in time saves nine," holds definitely, for if any part is once allowed to have an excessive amount of play and to knock, it will rapidly increase its liberty to move. In reality not only the mileage, but I think the number of times an engine is fired has a material bearing on the subject.

As I have said before, and shall have to deal with at greater length later on, the boiler is the main factor in everything pertaining to the subject of this paper.

Now in addition to the general wear in service a boiler undoubtedly gets damaged by the strains set up by the changes of temperature, which occur when it is fired and allowed to cool again.

In the proceedings of the International Railway Congress of 1910 the Caledonian Railway quoted a case where an engine ran 78,627 miles between shopping, and Mr. Forsyth, of Chicago, at the joint meeting of the Institution of Mechanical Engineers and the American Society of Mechanical Engineers in 1910 mentioned a railway on which the shop facilities were limited, and on which the passenger locomotives averaged 120,000 miles, and the goods locomotives 95,000 miles between shoppings.

Whilst on this subject it may not be wholly out of place, as closely connected with the subject, to speak of the recent definition of "heavy" and "light" repairs, which has been evolved owing to the requirements of the Railway Accounts Bill. It has been decided that the classification shall depend on the work done, and a list has been drawn up stating what repairs shall constitute a light and what a heavy repair. The list is as follows:—

"HEAVY" REPAIRS.

- (1) Engines re-boilered.
 - (2) Boiler taken out of frame for general repair.
 - (3) New tyres fitted to four or more wheels.
- Any two of the following:—
- (1) Fitting new cylinders.
 - (2) Fitting new axle or axles, engine or tender.
 - (3) Re-tubing.
 - (4) Turning up wheels and re-fitting boxes; or motion and brake-work stripped and overhauled.
 - (5) Boiler repaired in frame with not less than 15 per cent. of stays renewed.

(The two items mentioned in No. 4 would not in themselves constitute a "heavy" repair.)

"LIGHT" REPAIRS.

- (1) Fitting new cylinders.
- (2) Fitting new axle or axles, engine or tender.
- (3) Taking out and re-placing more than 50 per cent. of tubes.
- (4) Turning up four or more wheels and re-fitting boxes.
- (5) Taking down and overhauling connecting rods and valve gear.
- (6) Fitting patch to boiler.
- (7) Renewing 50 or more stays in boiler.
- (8) Removing clothing and re-lagging boiler.
- (9) Fitting four or more new axle boxes, or engine axle box brasses.
- (10) Welding, patching or straightening frame.
- (11) Re-boring cylinders and re-facing ports.
- (12) Taking off and repairing tanks.

This may seem to be a long list and somewhat cumbersome, but it will be found, I think, that the intermediate shopping spoken of previously, and all other repairs which come between the general ones, are included in "light" repairs, whilst the general repairs themselves are in practically all cases "heavy" ones.

HENRY FOWLER, A.M. INST. C.E.,
PRESIDENT, 1913.

When dealing with the question of shopping we cannot omit the question of engines which are shopped out of their regular turn, and on our line go by the name of "casuals"; a name which perhaps does not describe the cases as happily as it might do. However careful one may be and however well calculated a schedule may have been, an accident on the line, a flawed crank axle, a cracked tube plate, or some other such occurrence may call an engine in before it is due in the ordinary way. In working out ahead a programme of work in shops for the year these "casuals" have to be allowed for.

When it is settled that an engine is to be shopped at a certain date, certain special examinations should be carried out so that the shops may be prepared for its reception when it comes in. The information, which should be supplied to the shops a month or two in advance, should in all cases state the condition of the cylinders, also of the frames, wheels, and boiler, and the shop should take steps to see that any large parts requiring renewal are ready, so as to prevent any delay in the progress of the engine through the Works.

Before turning to the shopping of an engine itself, I should like for a few minutes to speak of two of the most important factors in the maintenance of locomotives which are largely bound up in one another, although they may not appear to be so at first sight. These are stores and the question of standardisation.

First then the question of stores. At the shed there will, of course, be the usual running stores, consisting of oil, waste, etc., and in addition the articles such as nuts, bolts, wash out plugs, etc., which may be required at any time. How much farther the stocking of parts in the shed goes must depend not only upon the size of the shed, but also upon the number of engines of any particular class which are stationed there, and the distance from headquarters, and the ease with which articles may be obtained from there. The Lancashire and Yorkshire Railway have a very excellent system by which articles are sent from the central shop to out-stations in travelling stores vans which are run on passenger trains, and Mr. Hughes has stated (Proceedings, Institution of Mechanical Engineers, 1910, page 906) that an article ordered at 5.30 at night would be received at Goole, 84½ miles away, by 8.30 the next morning. If conditions exist which allow of this it naturally follows that the stock which need be kept at an out-station may be very small. If, as sometimes happens, the whole of the one

type of engine is kept at one shed, then naturally this is the place at which all the material peculiar to this class of locomotive should be stocked. In any case, care should be taken to see that the stock is kept on proper stock cards, and that order cards are also used, as it is often impossible for a man to say how frequently he requires an article if he is to depend upon his memory not only for the number, but for the times when they are required.

As I have said the question of standardisation is very largely bound up with that of stores. There are very few sheds where there are not several types of engines, and if the various parts are interchangeable it is obvious that the stock may be much smaller than if all parts are different. This question of standardisation is not as easy as it may seem to be at first sight. On a railway there are two governing factors which bear a resemblance to the laws of the Medes and Persians in a locomotive man's eyes, namely, the rail gauge and the loading gauge, and to these may possibly be added a third, the allowable weight either per axle or per foot run of wheel base. Let us take the case of, say, a big end brass which we will suppose we are anxious to design so that it may be used on all further engines ever likely to be built. In order to get sufficient bearing surface we wish to make it as wide as possible, but are at once met with the controlling figure of the allowable width of the frames apart. We wish to make it larger in diameter, and now we have to reckon with the increase of weight of the crank axle it is to encircle. As another example, take the boiler, we desire a large barrel and big fire-box so that the boiler may not be overworked. Here we have all these controlling features coming in, for the rail gauge determines the frames and therefore in most cases the width of the fire-box; the barrel diameter if increased will give us greater weight, not only in itself, but owing to the larger amount of water it will contain, whilst it will also cause us to pitch the boiler high, which may not give us sufficient room for our cab lights within the loading gauge. In spite of all these troubles, however, a good deal may be done in the way of standardising parts and even boilers (the Midland have over 1,400 boilers of one class, although with various styles of fittings). One has, however, often to reflect as to whether it is better to introduce some improvement in a part and so depart from standard, or to sacrifice the improvement for the sake of standardisation.

Each case must be judged on its merit, and without prejudice and with forethought as far as we are able. If

we can tell accurately the life of the part, and the length of time before one standard will be completely replaced by another, we shall be greatly helped in our judgment, and it is here that a correct system of stock keeping, as set out previously, will be of the greatest assistance.

Now to turn from the Shed to the Shop; if the object of the former is to have all available power running, the object of the latter is assuredly to have the engine out of service as short a time as possible. Although we, at Derby, have spent considerable time and thought of late years on the question of scheduling work in our Shops, I do not propose to deal with this subject to-night, but rather to speak of the actual repairs carried out, and the methods required for doing them.

For certain costing purposes we have divided a locomotive and the work on it into twelve parts, namely :—

- Boiler.
- Frames.
- Motion.
- Cylinders.
- Wheels and Axles.
- Smoke-box and Ashpan.
- Boiler Mountings.
- Cab, Splashers and Clothing.
- Pipes and Rods.
- Tank and Coal Bunkers.
- Brake Work.
- Erection and Painting.

And I purpose shortly to touch on each of these.

For reasons previously stated I have placed the BOILER first, and it must have pride of place here. The repairs needed are due to three causes, namely, the action of the water on its interior; the action of the fuel and heat on the fire-box and tubes; and the defects arising from the expansion and contraction caused by the rise and fall in temperature. These may act separately, or in some cases together.

The action of the water is naturally dependent upon its quality, for if too hard, scale is formed, whilst many soft waters, otherwise admirable, cause pitting of the barrel and of the tubes if the latter are of iron or steel. Pitting usually takes place along a comparatively narrow strip along the bottom of the barrel, and can therefore be corrected if it is too pronounced, by long patches. Whilst on this question of pitting one may point out that this defect may not only be due to water, but to the presence of other

agents in the boiler. Often tallow is used for tapping stay holes, wash-out plugs, etc., and if any trace of this is left in the boiler it will form a fatty acid, and may be the cause of an incipient pitting. It is, of course, necessary to use some lubricant for this tapping, but a mineral oil, with some neutral substance, if necessary, should be employed.

The barrel is the chief part to suffer from the effect of the water, but pitting or corrosion is also found sometimes on the wrapper plates and the steel tube plate; certain parts are liable to grooving which I believe is the joint effect of scale and breathing, due to expansion and contraction. This trouble is chiefly found at the joint of the foundation ring with the steel plate, the bottom of the steel tube plate, and on the flanged double corners of the throat plate. Occasionally we find it down the flanged corners of the door plate, and also along the second or third vertical row of stays in the door and throat plates, although this rarely occurs except in cases where waters giving hard scale are used.

The trouble from the action of the heat in the fire-box is chiefly with stay heads getting "burnt" off and with the plate wasting away between the stays themselves. As a remedy for this, thin slabs of firebrick have been used to protect the parts chiefly affected, but although they do not seem to reduce the steaming qualities of the boiler, they have not proved wholly satisfactory. The chief trouble with the stay heads burning away, and with boilers with higher pressures, is that the new stays which have to be put in must be of a larger size, and so finally a boiler may have to be scrapped, chiefly because of the size of the stay holes. The fire also causes a burning away of the edges of the copper plates in the fire-box, and of the end of the tubes at the fire-box end.

The expansion and contraction of the boiler is, I think, wholly the cause of cracks as opposed to grooves. These chiefly occur between the holes in the tube plate and in the inner corner of the copper fire-box, although they occasionally happen in other parts. By increasing the bridge between the tubes, which can be done by arranging for the tubes to be specially reduced for a short distance at the fire-box end, a good deal of the trouble from cracked tube plates may be avoided.

This arrangement will also allow of tube holes, which tend to get oval, being rounded up without making the bridge too narrow, but to do this one must introduce two or three sizes of tube ends. My remarks on the boiler have

been somewhat drawn out, but its repair is in most cases the determining factor of the length of time the locomotive is in the Shops, whilst the advantage of having a good supply of stock for change will be obvious.

The FRAMES do not usually require much attention in the Shops, the chief thing to be done being to see that they are lined up properly and not cracked through the corners of the horns, the only remedy for the latter, up to recent times, being patching, the patch usually being of no greater strength than the original plates. The use of the oxy-acetylene flame for welding the frame is now practically universal, but it must always be remembered that the weld is never as strong as the original plate, and as the same forces which caused the crack in the first instance will be at work on the frame afterwards, a cover plate should be employed, although it need not be as thick as it would require to be if no welding had been done.

MOTION is a somewhat comprehensive term, and the chief work required on it is to rectify the wear in various parts, and to replace small parts when necessary. Most of the wearing parts are pins and the holes in which they work, and either the hole must be trued up and a fresh pin fitted, or as in the case generally with side rods, big ends, little ends, etc., the bush or brass metalled up or renewed.

Every attention must be paid to detect flaws, and as these usually occur in well known positions they need to be specially examined. Some parts which get comparatively highly stressed should, whenever possible, be annealed or normalised, but care must be taken particularly with special steels to see that they receive the proper heat treatment.

CYLINDERS should have a special ledger account to themselves and their increasing size shown, they should be specially reported upon before the engine comes into the Shop, and their thickness at the top noted whilst a reference to the cylinder book will reveal the state of the valve faces and the diameter. Scoring of the barrel and faces are the chief troubles, and these must be rectified by special machines.

WHEELS AND AXLES are a large item in the Shop repairs, and the crank axle, so universal in this country, is one of the parts which requires close attention owing to its liability to become flawed after it has run a certain life. Fortunately these flaws are fairly easy of detection and generally occur in certain points which can be watched. The life of a crank depends largely on the class of engine in which it is placed and the work it has to do. The flaws

are probably the result of the exceptional stresses set up in running, and on the whole it is probable that the more rapidly the changes in these occur the shorter the life of the crank. It is rarely necessary in this country to scrap a crank axle because of the wear of the bearings, but a machine designed so that these may be turned up without taking off the wheels is an advantage, as it can be used either for these or for straight axles. The most frequent case of repairs of this type being required is when the bearing has been hot and is scored. In this connection it must not be forgotten that a very hot bearing is likely to loosen the wheel centre on the axle, and in all cases where this is probable the wheel should be removed so that it may be seen if it will reach the standard pressure on being put on again. Wheel centres require little attention during their life, which should be long, but an occasionally cracked spoke may sometimes be welded up by the "Thermit" process.

With tyres there has of recent years been a great increase in the tenacity (78 tons tensile with 13% elongation are obtainable) with a corresponding increase in the life and consequent difficulty in turning after wear. Here, fortunately, the improvement in the quality of tool steel has kept pace with the other metallurgical advance. It is somewhat trying at times to find that one has to remove valuable metal from the tread of a tyre in order to obtain the proper profile on the flange.

There is one thing common and important in the repairs of both SMOKE-BOX and ASHPAN, and that is that the smoke-box and damper doors should be made a really good fit, or in both cases combustion may take place where not desired.

BOILER MOUNTINGS include a large variety of articles chiefly of brass, and practically all are subjected to wear during the time between Shoppings. All cocks have to be ground in again, and oftentimes screw-down valves renewed and the seatings refaced. The latter is an apparently simple matter, but every care must be exercised to prevent too much being taken off, as a little extra pressure on a cutter may lead to a valuable piece of brass work, such as an injector, being scrapped.

A point to be watched here is to see that the various fittings have a good seating on the boiler and to use as thin packing as possible, and whenever possible to dispense with asbestos packing, as this will in time, if allowed to get wet, corrode the steel plate.

The repairs required to CABS, SPLASHERS and CLOTHING largely depend on the care with which the work has been originally carried out, and how they have been treated in service. Generally there is little to be done except to dismantle and put together again. Wherever possible with both cabs and splashers, rivets with a good head on should be used for riveting the plates together. Should these, however, become loose and the holes wear oval, it is oftentimes advantageous to weld these holes up with oxy-acetylene flame, and then drill the holes afresh.

The various PIPES and RODS have to be overhauled, and all defective parts put right, and care taken to see that copper pipes are properly annealed, and that no cracks occur under the edge of union cones.

The wear of TANKS and of COAL BUNKERS is due to two different causes; with tanks, however well protected, there will finally be great difficulty in preventing some rust with its resulting corrosion. Wear has to be watched with coal bunkers, and wherever possible these parts should be designed so as to be easily replaceable.

BRAKE WORK varies considerably with different railways, as not only do we have the vacuum and pressure systems in this country, but some companies, including the Midland, use the steam brake on the engines. No special remarks need be made on this section, but its importance is such that it should always be arranged to try the brake actuating portions on a test plant before passing them over to the Erecting Shop.

There may seem little to say in an address like this on ERECTION and PAINTING, but the former essentially depends on the arrangements made for the regular supply of material of various kinds in the order in which it is required, but as I have said before, this is far too great a subject for me to start to-night. Painting may seem a supplementary subject, but nevertheless, if cleanliness counts for anything at all, the painting must be carried out so as to make it as easy as possible.