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Locomotive Boiler Examination,
Defects and Repairs.

BY
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Member of Council.

With an abstract of the discussion upon the Paper.

SEVENTEENTH PAPER
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PAPER No. 17.

Locomotive Boiler Examination, Defects and Repairs.

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The development of the modern locomotive during the last twenty-five years, including, as it has, increased steam pressure, has also necessitated larger boilers being supplied for the heavy work that has to be done in so short a space of time owing to increased speed, and this has brought with it greater problems to be considered both by the boiler designer and maker than was the case when boiler pressures were as low as 120 and 130 lbs. per square inch. Tubeplates, also sides of fireboxes, cracking and bulging, stays breaking, and the many other defects which are frequently found in locomotive boilers have brought into being an altogether different class of men to the old-time boiler examiners, men who are practically specialists and who specialise in all the defects as they occur, and whose peculiar capability it is to discover broken stays by sounding, also deterioration of thicknesses of metal and cracked plates by the same means. These men seem to the uninitiated to be gifted with some subtle and mysterious power quite uncanny, and they are oftentimes of a studious nature and give much time to thinking of the peculiarities they discover in boilers from day to day; and they develop into authorities on the diseases of locomotive boilers and fireboxes and are able in many instances to suggest many useful remedies for the cure of these peculiar and vastly different causes of trouble. There is no doubt that they pride themselves on these unique qualities of which they have become possessed and it is only natural that they should do so. At the same time it is essential that they should not neglect

or overlook during their examination any portion of either firebox or casing which is not wearing so well as other parts, and, of course, should endeavour to find the reasons for this inequality of wear. They should also be always very wide awake to any unusual developments and realise that their particular duties are also to prevent as far as possible the necessity for boiler repairs. It is not enough simply to be able to report that they have discovered this or that to be cracked, bulged or broken, wasted or dirty, as the case may be, and say it is due to over heating, unequal expansions and contractions, or to the unsuitable condition of the feed water. They will, of course, realise that a steam boiler is not a plaything by any means, and that any examination or repairs that may be required to be made cannot be done by any "jack of all trades," but require both deep thought and careful consideration on the part of a competent boilermaker, it being well known that many a good boiler has been practically spoilt through bad work and also through the inexperience of the person who has been concerned in the matter. Compulsory boiler inspection is most necessary, the responsibility of the locomotive engineer being quite as great as that of the manufacturer of the locomotive boiler himself, as each of these, as well as the boiler inspector, knows that if anything should go wrong the lives of the railway company's employees, and the travelling public as well, would be endangered. It is well known that as soon as a boiler is placed in service it gradually becomes weaker, due to the destroying forces continually acting upon it. These forces are of both a chemical and mechanical nature. Corrosion and oxidation are continually acting upon the material which has been used in the manufacture of the boiler and take place both internally and externally and thus give rise to the most serious and subtle causes of weakening to which a boiler can be subjected. Fig. 1 shows the grooving around the barrel line in water space on a steel tubeplate; Fig. 2 a copper tubeplate showing cracks caused by weakness of bridges and excessive expanding of tubes, also elongation of tubeholes caused by the working of the box whilst in service. Generally speaking, the railway company is held responsible for the general design and construction of the boilers under its control, the safe working pressures of which are fixed by the locomotive engineer or one of the mechanical engineers under his direct control and are determined from the minimum thickness of the plates used, the lowest tensile strength of the plates and the efficiency of

the longitudinal joints, the inside diameter of the barrel and the lowest factor of safety allowed after full consideration has been given to the general design, workmanship, age and condition of the particular boiler under consideration. The leading boilermaker in charge of each depot on a railway where boiler work is done should be held responsible for seeing to the proper inspection of and repairs to all locomotive boilers and their appurtenances under his control, and should personally see that all defects found at any inspection are thoroughly repaired in an efficient manner before the locomotive is again returned into traffic. The interior should be thoroughly inspected at any time when sufficient tubes have been removed to allow of examination. All tubes of boilers in service should be removed every three or four years—or earlier if considered necessary—and a thorough examination of the interior of the boiler made at each removal. After the tubes have been taken out the barrel and every place possible should be thoroughly cleaned and the entire interior of the boiler should then be carefully examined for cracks, pittings, grooving, or indications of over-heating, and for any possible damage that may have been done by the accumulation of sediment or scale. Fig. 3 illustrates rivets taken out of a boiler firebox, showing the corrosive action of the feed water on the heads, and Fig. 4 direct roof stays from a Belpaire boiler showing the results of corrosion in water space at top of firebox. The edges of plates, laps and seams, and any points where cracks are likely to develop should receive the most minute survey, and any boiler which has developed cracks in the barrel, or, in fact, in any part, should at once be taken out of traffic, thoroughly repaired, and certified as being in a satisfactory condition before again being put into service. Lap-jointed seams should also have special examination for grooving and cracks at the edges of the laps. Every boiler should be taken out of its frame at least once in five years for proper examination of the shell of the boiler and foundation ring and rivets. All stays should be tested by hammer-testing at least once every four or five weeks, and the broken stays found by the sound emitted. If such tests are made with the water still in the boiler, there should not be less than forty pounds pressure, but much more efficient tests can be made when the boiler is empty as it is then so much easier to detect the broken stays by the sound produced by tapping on the heads with a light hammer. No boiler should be allowed to work if stays adjacent to one another are found to be broken or if they

are found to be broken in any great number in the boiler. Eight or ten stays, if spread over the box in different places, should be the maximum allowed, and even these should be removed at the earliest possible moment. Fusible plugs—or what are more familiarly known as lead plugs—should be taken out of the boiler and examined every month or five weeks and any scale formation which may have adhered to them cleaned off; and if the lead should be found faulty the plug should be replaced by a sound one. If any doubt should exist in the inspector's mind as regards the thickness of the firebox plates, he should drill several test-holes about $\frac{1}{2}$ in. diameter through the parts of the plate about the thickness of which he has doubt, through which holes he can pass a slide gauge and determine the thickness; or he can remove a stay and pass in a reciprocating caliper, and so get to know by either method exactly the thickness of plate; but this is only done when plates are getting thin and more precautions are required than trusting to hammer-testing. If the plate should then be found satisfactory as regards thickness, the hole or holes can be tapped and plugged up with a piece of screwed copper. A proper record should be kept of the thickness of plate found by the putting in of the test-hole. Every boiler should be fitted with at least one pressure gauge, to correctly indicate the working pressure, and this should be placed, as far as possible, in a position where it will keep reasonably cool and also at the same time where it can be read conveniently by both driver and fireman. The pipe connection of this should enter the boiler direct. Before being fitted to a boiler, this pressure gauge should be carefully tested, and, if any inaccuracy of registering is found, should be repaired and put absolutely correct. It should be periodically taken off and tested so as to ensure true reading at all times. Every boiler should also be equipped with a double safety valve, one valve being screwed down or set to blow off at the working pressure of the boiler, and the other at 4 lbs. heavier, so that, if by any chance the working pressure valve should stick or not work properly, the other one would release the steam as soon as the extra 4 lbs. pressure had been made in the boiler, and would also be a check on both the steam indicator gauge and the first blow-off valve if both should fail to work properly. When any irregularity is reported in the working of the steam gauge or safety valves, these should be at once subjected to an exhaustive test, and, even when working properly, should be overhauled periodically. Every boiler which has been given an overhaul and thoroughly

repaired should have a hydraulic test of not more than 25 per cent. above working pressure. Twenty-five per cent. is mentioned because the author is of opinion that damage is often done to work by over-testing. The fact of putting so much stress or pressure on a job does not go to prove that the job is better than one which has not been so heavily tested, but there is certainly the possibility of fracturing a good job by using unnecessary pressure, and this may, in fact, be proved to have done more harm than good and may be, practically speaking, "the last straw that broke the camel's back." If the hydraulic test should prove to be satisfactory, the boiler should then be steamed at working pressure for four hours—or more if desired. Both tests should be witnessed by the leading boilermaker and the general foreman, and proper records carefully kept of the same for future reference; also, any peculiarities noticed should be put down and carefully studied.

Having now considered the examination of locomotive boilers, it will be well to refer to some defects before proceeding with boiler repairs, and with this in view the author would like to mention steel and best iron boiler rivets. Some twenty years ago, the steel rivet was practically unknown, and the boilermaker of that day would have been struck dumb with surprise if he had been asked to use steel rivets in the place of the best iron rivets then so much in vogue, the word steel at that time being generally used to convey the impression of a hard, brittle and unyielding material. But with the advent of the basic open-hearth steel, a material was placed on the market which was a surprise to the most sceptical. Fig. 5 shows some rivet tests. In fact, this method cannot be surpassed for rivets which require both the greatest strength and toughness, and, what is more, it is most moderate in cost, and, if it were not for the improvements made in the manufacture of all classes of steel, it is safe to say that it would have been impossible to have accomplished what is being done to-day in all parts of the world. Rivets are practically tested to destruction and are expected to stand up to their work quite as well as the plates into which they are hammered; yet often cases occur of rivets being hammered till they are almost cold, which should not be allowed. The steel rivet should also be heated intelligently so as to suit the class of work on hand at the moment. Hand rivets should be heated to almost white heat, care being taken in all instances that the head and shank is hottest, the knocking down point

being somewhat cooler to allow of the rivet being properly upset into the hole to ensure good work, but should not be heated to such a pitch that the rivet begins to sparkle or run. Hydraulic rivets should be heated to a dull cherry red, whilst pneumatic rivets should be a bright red, always bearing in mind, as regards the hydraulic and pneumatic rivets, the amount of pressure the different machines are capable of putting on the rivets at the knocking down point and regulating the heating of the rivets accordingly; the greater the pressure, the lower the heat within reason; such rivets properly finished should not require to be caulked. Also, never allow the rivet to soak in the fire and never have a rivet knocked down which, when it comes out of the fire, shows a tendency to run, for that particular rivet will surely cause trouble, as it is liable to remain loose in the hole or crystallisation will take place and the head fall off. Best iron rivets, however, are preferable to steel for riveting up copper fireboxes. The firebox material being soft, it is advisable to use the softer rivet for this class of work to save the plate from being distorted. Again, when repairs are being done and rivets are being changed in the seams of fireboxes, if rivets can be got in they are what are termed wedge bar rivets. These rivets, in some instances, where water spaces are close, have to be bent before they can be inserted in the holes and straightened out by the riveter as they come through the holes, and, oftentimes, before he can start to knock these down they are nearly cold; therefore, if these rivets had been made of steel, the amount of hammering they have to receive after they have begun to cool down would have a tendency to set up crystallisation, and the work would not be so trustworthy as would be the case where best iron rivets are used. Steel rivets are inclined to be granular, whilst good iron rivets are fibrous in structure; therefore, the test for one is not the same as for the other. Steel rivets, if nicked and broken, should show a good clean grey fracture, quite free from crystallisation, and not a coarsely fibrous fracture, the same as an iron one. Thus, rivet heating, if properly looked after, will do wonders in preventing defective and leaky rivets.

Other and much more serious troubles are, however, found in leaky stays and tubes and they appear to be general on all railways; in fact, with the modern high-pressures, the temperature of evaporation is so much increased that the provision for circulation which was sufficient for the lower pressures formerly used is now

probably insufficient ; again, in the Belpaire type of boiler, the width of the box at the tubeplate end has enabled the tubes to be placed very near to the barrel and it is quite possible that the water to feed the space between the tubes near the firebox tubeplate has to be drawn in a considerable quantity from the front portion of the barrel, and this may account for some of the tube trouble. It is also possible that the upward draught or circulation of water through the spaces between the tubes where the hottest portions of the tubes and the copper tubeplate are, is so strong as to prevent the necessary feed of water into the water spaces between the casing and the firebox and so may be the cause of considerable stay trouble. Of course, at the same time, many of the causes of stay trouble may be traced to bad work, such as taps not being in pitch in threads, stays not being in pitch with taps and copper bar of inferior quality being used in the manufacture of the stays, unskilful tapping of holes, holes also not being cleaned out properly after being tapped before the stays are run in, too much oil being used on the stays whilst being put in position, stays being put in slack or being upset in the thread, even after being put skilfully in the boiler, by reason of the riveter giving the stay a hard blow with the riveting hammer before his mate—who should be holding up on it with a heavy hammer—has had time to get it into position on the stay end. Then, again, it is quite probable that the fireman on the engine is not so careful as he might be, and when the engine is standing still will leave his damper open and let his fire get in holes instead of keeping it level over his firebars, with the result that he often starts stays and tubes leaking. Inferior coal may also be put down as one of the causes of such trouble. Again, many engineers assert that the primary cause of leaky tubes and fireboxes, and stays giving trouble, is unequal expansion and contraction brought about by over-heating of the metal owing to its being insulated from the water by a layer of scale formed by the precipitation of lime and magnesia salts in the water. These troubles are increased by sudden cooling of the metal, by cold draughts being allowed to get into the firebox, by working the engine very hard and then suddenly shutting off steam, and also by washing out boilers with cold water. The water in a boiler of 200 lbs. pressure would be something over 350 deg. Fahrenheit and the maximum temperature with clean tubes at the firebox end would be considerably over 400 deg. F. ; but with a heavy coating of scale they might probably be as hot as 1,000 deg. F. Again,

with tubes as with stays, want of efficiency on the part of the workman may cause much tube trouble, many tubes being expanded unnecessarily. Fig. 6 shows the collapsing of brass tubes caused by sediment being allowed to accumulate in the water spaces between tubes. To an inexperienced and not thoroughly practical man, when looking into a firebox where tubes are leaking, there may appear to be an immense amount of leakage, and a large number of so-called tubers, instead of studying their work in a sensible manner, will start in with drift and expander and do more harm than good by beginning at the bottom and working upwards, whereas, oftentimes, a tube may be leaking in the top row and the water and dirt from it may roll down over the lower rows of tubes and make it appear as if several were leaking. Therefore, if the tuber starts expanding on the top row and works downward, carefully noting the effect of his work as he goes, he will sooner come to the leaky place, get his work done quicker, and also save unnecessary expanding, which will soon ruin both tubes and tubeplates. Expanding of tubes should never be done in a haphazard manner; note, as carefully as possible, the position of the leaks and only expand the tubes sufficiently to stop them. The life of tubes, however, is most variable, depending very much on the quality of the water used in the boiler. The length of time a tube will remain good is oftentimes lessened by the excessive amount of expanding and rebeading the tube has to stand. Some tubes last only six months, whilst others will last three years or more. This, however, depends, to a large degree, on the use to which the engine or boiler is put, but more so on the quality of the water. Tubes become perished in many instances, both through the chemical action of the water and—at the ends—through the amount of expanding that has to be done to keep them tight and through the cutting action of the flame at the firebox end. But if the water be good, so that no pitting takes place on the tubes, new ends can be put on several times and will thus help to diminish the cost which would otherwise be heavy if the whole of the tubes had to be renewed. The firebox ends of the tubes suffer most owing to the extreme variations in temperature and the liability of the beaded ends to drop off, due to the intense heat; in fact, “leaky tubes” is about the most common complaint known as regards boilers. Many different classes of tubes are used in locomotive boilers, such as brass, copper, iron, charcoal iron, lap-welded steel, and seamless steel tubes. The seamless or solid-drawn

steel tube was introduced some years ago and soon established a name for strength, ductility and endurance under hard-working conditions. There is no doubt that the steel tube is a good tube for locomotive boilers, but that such tubes are liable to pitting and corrosion, especially if certain substances are in solution in the feed water, such as dissolved oxygen or carbonic acid; but if these harmful properties are removed from the feed water it is very probable that much less will be heard of steel tubes corroding, and, consequently, the water should be treated to make it as harmless as is possible. A remedy for some of the tube troubles must, therefore, be avoidance of over-heating by avoiding scale formation, and this can only be done by, as already mentioned, chemical treatment of the feed water. Much is now done in this direction by the fitting up of proper water softening plants, but it is quite possible that too much is being done in these efforts to avoid scale formation, the water probably being made too soft, with the result that our steel boilers of to-day will certainly suffer more from corrosion than would be the case if a certain percentage of hardness was allowed to remain in the water to form a slight scale deposit to protect the plate. It is well known that many engineers still resort to the use of boiler-cleaning compounds and anti-incrustation powders, but, unfortunately for these compounds, although they will remove the scale, they also attack the boiler plates as well. What is really required is a compound which can be put into a boiler periodically to loosen the scale or keep it in solution in such a manner that it can be easily washed out on shed or washing out days, and, at the same time, to have a protective action on the surface of the interior of the boiler. Hard water is known to possess scale-forming properties, but soft water is corrosive and much more dangerous to a boiler than water with some of its scale-forming properties left in it. Some time ago, the author came across an article in one of the engineering papers, in which it was stated that an engineer had had a unique experience. He was having a 25lb. bag of graphite taken down from over the top of a boiler, the boiler manhole cover being off at the time, and, by accident, the man dropped the contents of the bag into the boiler. The engineer, thinking it would do no harm, did not trouble to have it removed and forgot all about the incident. Some time after, however, in having this boiler, along with others, opened out for examination, he found much to his surprise, when he went into it to examine it, that the boiler was clean, and the sediment from the

water, instead of being in the form of a hard scale attached to the boiler plates, had worked down into the bottom of the boiler and could easily be removed in the form of sand ; whereas, after going into the other boilers, he found it was necessary to send men to scurf the plates, as had been his practice before. This set him thinking, and he then remembered the incident of the bag of graphite. Reading this account also set the author thinking, especially as the engineer emphatically stated that, as a boiler cleaner, graphite was good enough for him, and did not hurt either the boiler or any of the joints or fittings. So permission was obtained to use some in a stationary boiler and 3 lbs. of Dixon's No. 1 Coarse Flake Graphite, which costs approximately 1s. 8d. per lb. tin, were put in, and the result was surprising, the old scale being cleaned off the tubes or laid on the tubes in so soft a state that it could easily be washed off. A considerable quantity of the old scale was removed from the boiler at the first application, some of the pieces of scale being as much as $5/16$ in. thick. After this demonstration, permission was obtained to keep on using it, and, with a view to reducing costs, a considerably reduced amount was put into the boiler, and good results are now being obtained by using a 1lb. tin in each stationary boiler per month. This cost, however, will be much more than covered by the fact that there is no scaling to do, owing to the boilers being cleaner ; they should—and do—steam freer, and should, therefore, make a decided saving in coal consumption ; also, owing to the plates being kept cleaner, over-heating—and, with it, possible fracture—is not so liable to take place, and so a reduction of boiler repairs should be effected ; anyway, graphite as a boiler cleaner has given very satisfactory results.

The brick arch also is another item which might be studied and a considerable variation of opinions be formed with regard to it. In the first place, it is well known that the brick arch possesses some decided advantages, such as saving of coal, tube protection, improvement in steaming, the avoidance of tubes being stopped up with cinders and ashes (especially at the firebox end), also smoke abatement. There is no doubt that the saving due to these advantages must be considerable; at the same time, there are probably also some disadvantages which may go far to reduce the amount saved, such as the cost of the maintenance of the brick arch itself—which must be considerable—also that the arch may be found detrimental to the life of the firebox and stays. From the author's experience, a boiler, when steamed with-

out a brick arch in, invariably shows very little, if any, signs of trouble in the way of leaky stays ; but when the arch is in position many of the stays below the line of the arch give a considerable amount of trouble, especially in the case of new boilers. Again, the sides of the firebox at the end of the brick arch wear thin and, when these have been cut out and the lower half sides renewed, it is found that the laps of the half sides wear away rapidly owing to the cutting action of the flames striking at that point. The bottom portion of the firehole copper also suffers from the same cause, this trouble being aggravated at this point owing to there being no water to keep the copper cool, the firehole ring going to make a solid mass of the material at this spot. However, a considerable amount of protection has been given here by the introduction of what is known as a cast iron firehole protector, which is slipped into the firehole, the longer flange of it dropping over the copper and rivets on the inside of the firebox and so tending to do away with this trouble. Years ago, what were known as welts used to be riveted on at this point, a welt being simply an additional thickness of copper placed over the copper at the firehole ring. This, however, only went to aggravate the evil by increasing the thickness at a point where there was no water, and the welts have now been dispensed with in favour of the casting, which is a much better protection and is both easy to place in position and remove as required. At the same time as the bottom casting was introduced, a top one also came into being. This was fastened into position by putting in three iron studs—over which studs the top protector was passed and then brass nuts were put on the studs to retain the casting in position. The idea, however, was soon discarded, as it was found that the castings buckled through the heat and allowed dirt and ashes to accumulate between them and the copper plate, this dirt, etc., soon setting up a corroding action—worse for the rivets and plate than the cutting action of the flame, which was not anything like so fierce and disastrous to the top lap of the firehole as to the bottom portion.

Locomotive boilers, however, are subjected to the roughest kind of treatment, and are often worked to the full limit of their capacity ; and, in order to burn the coal required by heavy trains, and do it in a necessarily small space, the draught is bound to be very strong. It therefore follows that the cutting action of the flame also must be strong, unfortunately, and, therefore, the fewer projections there are inside the firebox, the better. If, for instance,

you have large stay heads, the flames are parted and pass round the stayheads and the plates suffer in consequence by being reduced in thickness by the flames' action. Also, at the same time, if stayheads are low, then the flames passing over them still further reduce the heads and, in time, it is necessary to change these stays ; but it is cheaper to change stays than to renew firebox sides, because, in renewing firebox sides, it is not only stays, but plates, rivets, and stays, which then have to be removed and renewed, and the job is a much greater charge to the repairs account. The lives of fireboxes, however, vary considerably, according to the different qualities of the coal and water used ; also, at times, there appears to be a great difference in the wearing qualities of the plates used in manufacturing the boxes ; but the average life, roughly speaking, can be taken as five years. That figure is not far out, although some will last as long as from 8 to 10 years ; at the same time, a compilation of the life of the different classes of fireboxes in use would be a difficult thing to get with any degree of accuracy, owing to the plates wearing differently, although the copper plates may have been manufactured in exactly the same manner as one another and according to the same specification. Of course, this peculiarity is hard to account for ; but it appears that the more carefully you study the peculiarities of the locomotive boiler—and there are many of them—the less one appears to know about them, for what is, apparently, absolutely proved by one test, is, in many instances, disproved by the next, with the result that nothing remains to be done but to try again. Then, again, there are many people who are interested in the manufacture and upkeep of locomotive boilers, and each, in many instances, have their own opinions of what is right and what is wrong ; and sometimes they are wrong.

But to continue, as regards copper stays, there exists a considerable difference of opinion as to the manufacture of what are known as "riveter stays" and "steamtight stays." The term "riveter" as applied to stays, means that this is the class of stay which is put in a boiler when the boiler has had its lagging removed and has been lifted out of the engine frame for a thorough overhaul, and when, after the stays have been renewed, they can be riveted down on both firebox and casing side of boiler. But, when stays are required to be changed with the boiler in the frame and the lagging is not taken off, they can only be got at from inside the firebox ; then these renewed stays are what are

termed "steamtight." On some railways "riveter stays" are manufactured parallel in the thread, being exactly the same size on both lead and back end; and, for this kind of stay, as for all others, the size should be determined from the size of the taps in use, some taps being a trifle larger or smaller than the standard gauge, and if all the stays were made to the standard gauge, many stays would have to be rejected through being either too tight or too slack; and this would cause much annoyance and expense and would also be the means of spoiling much manufactured copper; in fact, it is always advisable to study the sizes of the tapped holes produced from each tap in use and have the stays made accordingly. If the parallel stay is manufactured, it should be screwed into the boiler from the casing side. The reason why this method should be adopted is because it would then require only about 1 in. of the thread to be screwed into the copper plate and would not have the same tendency to wear away the thread and make the hole larger, as would happen if the whole length of the stay had to be screwed through the copper plate before entering the steel casing plate. Again, on other railways, the taper stay is in vogue to be used as a "riveter stay," which has a graduated taper from the lead end to the back end, the lead end being screwed to normal fit and the stay being $1/200$ th part of an inch larger at the extreme back end. With this class of stay, the method of putting them in is from the firebox side of the casing, the idea being that some engineers prefer to make sure that their copper stays are quite tight in the plate on the firebox side, even if not so tight on the casing side. Personally, the author considers this idea to be quite right, as very rarely do stays give trouble by leakage on the casing side of a boiler, and as also, by this means, the trouble of having a slightly increased size of hole on the firebox side, owing to the tap not being exactly to truth during the operation of tapping from the casing side of the boiler, which is due in most instances to the difficulty of keeping the pneumatic tapping machines steady and thus causing what is roughly spoken of and known amongst boiler makers as "wobbling," is eradicated, the taper on the stay leading from the front or lead end through to the back end, being sufficient to allow for the slightly increased size of the hole on the firebox side, which has been caused by the "wobbling," and will allow the stay to tighten itself in the copper plate as it is being screwed home. Steamtight stays are, however, quite different, it being advisable to have them made larger

on the lead end than on the back end. To put these stays in properly requires a most skilful workman, he having to do most of his work, not so much by seeing as by feeling. To get a satisfactory steamtight stay it will be necessary to put up with a slight looseness of the stay on the firebox side, because, not being able to see the work or get at it to test it, owing to the lagging or frame plate being in the way, it is impossible to be absolutely certain that the stay is tight in the casing plate if it is tight in the copper plate as well. As one cannot get at the point of the stay to do anything to it, if it should leak, considerable trouble may be caused, the probability being that the driver's outlook glasses in the cab will become clouded by the steam escaping from under the lagging and the stay will become a source of danger, as a good look-out, which must always be kept, would not be possible under these conditions; so that it is more than probable that, after all, one will have to go to the expense of removing the lagging, which need not be done if the manufacture and putting in of the stay has received more intelligent consideration, the ideal steamtight stay being one that, at the lead end, is slightly reduced at a taper for about two threads (to enable it to be entered into the plate), from this point, is $1/200$ th part of an inch larger than an ordinary fit, and then is tapered away to an ordinary fit back to where the stay is shaped out, the back end portion of the threads all being parallel in size with the ordinary fit of the front portion; if this stay is put in a boiler in a proper and workmanlike manner, there will be no trouble from its leaking under the lagging. There also exists much difference of opinion regarding the pitching out of the stays and the size of stays to be used, the more general idea, however, being that boilers carrying pressure of from 170 lbs. to 220 lbs. should be pitched at from $3\frac{1}{2}$ in. to 4 in. and that the normal size of stays for new boilers should be $15/16$ in. diam. Of course, it is well known that the removal of stays from any cause compels the enlargement of the new stays put in, it being impossible to put back the same sized stays as were taken out, owing to the copper plate having been stretched or the hole increased in diameter by the action of riveting down the stay-head in the first place, and also through the extra amount of the spreading of the stay-head with a stay hammer when hammering it up. If the stay should have leaked while in service—thus causing the hole to be required to be tapped to a larger diameter—this increasing of the size of the stays, causes them to become more stubborn and resisting

to any bending or working, and as the plates get thinner by the impinging of the frame on the plate and by general stress and wear, this has a tendency to produce bulging of the copper towards the fire, which is often to be found between the stay pitches, and which, in many instances, is assumed to be caused by heat and pressure, but more often is caused by want of flexibility on the part of the stay itself, and this is more serious than some people believe, especially when the plate has become thin, owing to the liability of the plate to rip, and so cause an explosion. In all cases such as this, the bad plates should be removed from the boiler and new ones put in, and, as far as possible, the casing plates should either be bushed or cropped so as to bring the stay sizes back to their original diameter, this being much cheaper in the long run than taking chances, which may so easily end in disaster.

Again, collar bolts, studs and lacings, for fastening on patches or for holding seams steamtight, all make for many differences of opinion as to the best method of doing this class of work, some railway shops believing in the advantages of collar bolting, whilst others adopt either studding or lacing as their standard practice. The author is of opinion that the best job and the one that can be done at the least possible cost should be adopted. Taking each particular idea in order as they are mentioned: Collar bolts are very wasteful and expensive, owing to the fact that after the rivets are taken out for renewing (the plate having been closed first), the hole is then tapped on both plates, after which a cleaning-out tool has to be used to clean the thread out of the first plate, and the outside of the plate at the hole has then to be faced with a facing tool to form a seating for the bolt. The fact that the hole requires to have a clearance, to allow of the collar bolt drawing the outside plate up closely to the inside one, reduces the lap, and, if, after being in service, and through the expansion and contraction of the plates, these bolts should begin to leak—as often happens—then nothing can be done to them, except take them out and change them, which is most expensive and annoying. The studding comes next, and this may be considered to be the best job, but even in this matter many people differ—the iron or copper counter-sink stud is a good job if properly done, but some believe, however, that, before these are put in, the clearance tool should be used and the thread taken out of the outside plate to allow of the plate being drawn closely up to the under one by the collar bolt itself. The author is not of that

opinion, his contention being that both holes should be tapped and the ratchet countersinking tool only used, so as to be sure of having the countersunk face in the plate in alignment with the threads and also to make certain that the proper standard of 60 deg. countersink is maintained to suit the countersunk face of the stud. Of course, it must be understood that the plates must be made searcher-tight before being tapped or the job will be defective; but what is claimed for this method is that, owing to the threads being in both plates, the joint is not able to work, and so, if the studs are put in properly, there should be no danger of leakage breaking out in the same degree as has been found to be the case where clearing holes have been introduced. The lacing, again, is generally made up of copper and is, roughly speaking, a short copper stay about $1\frac{1}{2}$ in. long for use on double plates and longer for the joints where three plates lap and, for this class of work, the lap of the flange or patch, as the case may be, has to be thoroughly closed before the plate is tapped; the lacing is then run in with a stay or stud box, the stud box taken out and the lacing caulked round with a spoon tool, and the head is then hammered down, the same as an ordinary copper stay would be. This cannot be considered to be altogether satisfactory, although good jobs have been done in this way, owing to the amount of upsetting the thread must get in the hole during the process of forming the head, no holding up on it being possible. Generally speaking, exceptions can be taken to everything, it being, however, advisable to exhaustively test each method before adopting any particular one; and this is mostly done, but, even then, one will swear by one way whilst another adopts quite a different idea, there being no hard and fast rule laid down as to which method is the better.

Another point to be noticed is the necessity of looking out sharply for fractures in the inside corners of the flanges of steel tubeplates and also the necessity for care on the part of the marker off in the use of sharp scribes, a practice to be deplored owing to the tendency of a deep scribe mark developing into a bad fracture.

The author has now given an account of some of the defects to be found in locomotive boilers and also the reasons for some of them, but, owing to the lack of time and the vastness of the subject attempted, he finds it will be necessary to leave the more practical side of boiler repairs to be continued in the form of a second paper, or as an addition to this first part at a future date.

DISCUSSION.

The Chairman (**Mr. Suffield**): Mr. Bennett's extremely practical paper is now open for discussion, and I cordially invite any of our visitors present to take part in the discussion.

There are just one or two points that I would like to ask Mr. Bennett, and one is in reference to Figure 2. I am not quite clear as to how Mr. Bennett accounts for what he terms the elongation of the tube-holes of the box whilst in service.

In Figure 3, Mr. Bennett remarks about rivets taken out of boiler firebox showing the corrosive action of the feed water on the heads. I am not quite sure as to the particular locality of these rivets, and I would rather like that explained.

In regard to testing; in one portion of Mr. Bennett's paper he states that one valve is screwed down or set to blow off at the working pressure of the boiler and the other at 4 lbs. heavier, and later on, he informs us that if any hydraulic test be found to be satisfactory, the boiler should then be steamed at the working pressure for four hours, or more if desired. I take it that he means that the boiler could be steamed at the working pressure, or more than the working pressure, for either four hours or longer. I do not see how he reconciles these two remarks. He apparently does not believe in putting the boiler under test for more than four pounds above the maximum steam pressure, yet a great many boiler inspectors test boilers to 15 pounds or more above the maximum.

Respecting rivets—Mr. Bennett makes a very bold statement; he says that rivets made by the basic open hearth process cannot be surpassed. Well, I am rather inclined to disagree with Mr. Bennett on that point, as I think you will obtain far more reliability from rivets made by Siemen's acid process for instance, or Lowmoor iron. It would highly interest me to hear what Mr. Bennett has to say on this process as against the basic process.

There is another question which would no doubt be of interest to the members—what is Mr. Bennett's experience and opinion as to the difference in durability and efficiency of riveting by the pneumatic, hydraulic and hand processes?

And which of the three methods does he consider the least likely to destroy the threads of the stays?

Mr. Bennett also remarked that leaky tubes were caused by water being drawn from the front portion of the barrel to the water space near the firebox tubeplate. Personally, I do not quite follow this line of argument. Is not the tube leak due more to the continual contraction and expansion of the boiler itself, rather than to the withdrawal of water from the space indicated by the author?

In reference to the fracture caused by scribe mark Mr. Bennett mentioned, I should like to know whether he has had any experience of cracks on the outer radius of the crown plate.

Mr. Hughes, jun. (Great Western Railway): I was very much interested in Mr. Bennett's paper and also in one or two of the questions asked by our Chairman to-night. One question he asked was with regard to the elongation of tube holes. I have found in my experience as a boiler maker and boiler inspector—particularly on locomotives—that the more tubes are expanded when they have leaked the more we find the tube holes elongated and also the meshes, or the bridges, cracked in the top corners of the tubeplate, as shown in one of our diagrams. I may say that we have had considerable trouble on the G.W., and our experience to-day is that that is caused, in some cases, by men not using the expander with discretion, and, in other cases, by the expansion and contraction of the tubeplate.

The other question asked by the Chairman was about reduced rivets. I may say that I myself have had experience of these reduced rivets, and have generally found them in the lower part of the flange seams of the tubeplate and the backplate in the firebox, and have also found them in the throatplate and in the saddleplate—the throatplate and in the backplate of the firebox.

Tubes leaking, which our Chairman mentioned; I may say that we have had a great deal of trouble until within the last two years; and I dare say a good many of the gentlemen here know that the G.W.R. have recently adopted a new system of feeding in the boilers. They put the water now—instead of under the bottom of the boiler or in the side of the backplate or firehole plate—in on the top of the barrel, and in doing that, it runs into a tray, and this tray has some cross angle irons riveted, which circulate the

water right along into the steam. I was talking to a gentleman some few weeks ago about that. He was an old engineer and he thought it was rather a foolish idea to put the cold water into the steam. He said he always thought you wanted the steam as dry as possible to get the most power out of it. I think that has been the idea of a good many engineers, but the experience of the G.W. with that top feed has been—I can say from experience—a considerable success, and has done away, to a great extent, with leaky tubes and also leaky stays in the fire or at the mouth of the brick arch, as mentioned by Mr. Bennett in his paper.

Mr. Garratt: I think possibly it might interest the meeting generally to examine the few tools I have here, for staying and so forth of boilers, and I think I will, for the moment, confine my remarks to stating that they are here for the inspection of anybody who feels interested in looking at them. I think the work they do is pretty satisfactory, and I will leave them to the criticism of those who know more about boiler making than I do.

(The tools referred to were Messrs. Rogerson and Halstead's Patent Stay Snap for riveting with pneumatic hammer and a tube beader.)

Mr. Hughes, sen. (Shutt End Railway): Where Mr. Bennett has failed in any respect in his paper, I think it was qualified in the remark that he made, that results obtained from one locomotive firebox were not the same as those from another.

He said something respecting the riveting by hand, pneumatic and hydraulic. I will tell you of our experience in riveting copper stays with a pneumatic hammer. I must say that it was a complete failure, but whether that was because it was our first or second trial, I cannot say; but the force of the pneumatic hammer on the stays forced the copper plate in, as though the hammer was too strong for riveting it.

Another point mentioned to-night concerns the different kinds of steel and very mild steel for rivets. This latter is obtainable and has been so for some time, but I find the best rivets for fireboxes to-day are Lowmoor iron, although it is rather expensive, we know. For about 17 years we have used Lowmoor iron in our fireboxes for riveting, and we have never had one drop off up to the present time. Previous

to that, when we used to rivet with copper, they were very nearly all failures.

Some years ago, Sir Gilbert Claughton, the Earl of Dudley's principal agent, went to America, and he came back with the idea that he would like a steel box put into a locomotive, and I believe they got the best mild steel that it was possible, at that time, to procure. That would be about ten years ago. It came from South Wales, and you could do anything with it—bend it, weld it—anything. In about three months after it went out, the tubes began to leak, the steel crystallised, and it was a complete failure. Every other night we were being sent for to fasten the tubes up again, or something like that. At last they got so tired that they said they would have it out and put copper in its place, and the copper has been in about nine years and there is very little the matter with it to-day. My opinion is that steel will never come into general use in locomotive fireboxes, neither do I believe in steel rivets, because they very quickly cool, and unless you have very experienced workmen to rivet them and rivet them at the right time, they are failures; and, as I have said, there is nothing, in my opinion, better than best Lowmoor iron.

There is one thing which has been mentioned to-night which will repay me for my 120 miles journey from Dudley to this meeting, and that is, Mr. Bennett mentioned, when speaking about the tubes in the tubeplate, that their experience was that a little reduction in the holes up the two sides gave them strength. That is a grand idea in my opinion.

Mr. Fry: I should like to ask Mr. Bennett if he would give us some further information about the use of graphite, which appealed to me as very interesting. Would he let us know the size and type of the boiler in which it was used.

With regard to the use of steel for locomotive fireboxes, to which the last speaker referred. Doubtless, you are aware that all the locomotives in the United States—something over 60,000 in number—use steel fireboxes, and not copper. A very mild grade of steel is used for the boxes, with iron stay bolts and, apparently, entire satisfaction is obtained. Of course, the life of a firebox there, as here, varies very much with the water. I have known fireboxes which required changing in a year, but I can also parallel Mr. Bennett's experience—I have seen a boiler which has had a steel firebox in service for 30 years.

Mr. Bennett has warned us about the handyman approaching the boiler, and, as he told us that it should be left to specialists, I propose to take his advice and without further words leave the discussion to those more experienced than myself.

Mr. Walters (Midland Railway): The first thing I should like to ask Mr. Bennett is about broken stays. He does not give us the position of those stays in the firebox. My experience is that broken stays are found chiefly in the top portion of the firebox in the sides leading to the tube-plate, and on the firebox backplate. But those stays are not broken exactly in the manner he showed. I find that broken stays are an entire growth, probably due to some defect in construction. If a stay is put in absolutely parallel, the expansion in the top part of the firebox being so much greater than that of the shell puts the top part of the stays under much higher tension, with the result that there is greater risk of fracture. You will find, if you follow broken stays up, that the next one below is just forming itself into an oval and shows fracture both at top and bottom, and in the next one to that there is a still larger oval, until, at last, you come to a stay that is whole right the way down. I have placed our stays of late a $\frac{1}{4}$ in. higher on the outside than on the inside of the firebox. By that means, the box is allowed more breathing, and it is unusual for us to get a broken stay once in three months.

The next thing I should like to ask Mr. Bennett about is riveting. He showed some rivets on the diagram, but he did not state exactly whether those rivets were the class he used for machine riveting, which, I presume, the cup-head was. If it was, I am going to say that it is absolutely wrong for machine riveting, and I say that because no machine rivet should be flat under the head. It ought to have a fillet of at least 1-16 in., and I find that a machine rivet head should be made more of a conical shape and should be 3-16 in. deep with $\frac{1}{8}$ in. less in diameter counter-sink under the head, on account of the scale which forms under the head and which might prevent the rivet being properly clinched.

With regard to the question of steel or iron rivets, I shall take the opportunity to say that I am greatly in favour of steel rivets, for the simple reason that, in all my experience, I have found that, if they are put in at the proper heat and the foreman knows what he is doing and can show his men the proper way to put them in, nothing

is to be gained by using Lowmoor iron rivets. I am speaking now on 27 years' experience; and steel can be got for rivets as low as 26 tons tensile that is quite soft and mild, and that we can rivet as easily as we can rivet iron.

Another thing I would like to hear a little more about is the use of graphite. I should like to hear in what proportion it is used and at what times it is put in, after each washing out, or periodically—weekly or monthly, or how.

The next thing is the firebox with the pitting on it. My experience is that pitting on the copper-plates of the firebox is not so much due to the water as to the treatment. I should say, if it were gone into thoroughly, that that black scale being on the firebox was due to the boiler having had some grease or oil in it. Undoubtedly, grease or oil causes pitting, and rapid pitting, too. Otherwise, I have not found any dangerous pitting with water.

Mr. Garratt: With your permission, I should like to ask Mr. Bennett his opinion of pneumatic riveting, both for heading over stays and for beading over tubes. Could he give us any particulars of the cost of both beading over the ordinary boiler tubes and the superheater tubes; and the cost of heading the copper, bronze or iron firebox stays, either by hand or by the pneumatic process if he uses it at all? I can supply a few figures, which may be of interest, with regard to what these tools will do. These tools are the invention of a couple of old friends of mine in the North, Messrs. Halstead and Rogerson, and they have given me some figures. According to what they say, the saving on the cost of beading over tubes, owing to the introduction of these tools, is a penny a tube, which comes out at about 15s. for the average boiler with 180 tubes, with an economy of about 70% in time. The saving for riveting over a set of copper stays is about £2 16s. per average boiler; for riveting bronze stays, £7 10s.; and iron stays, £12 3s.

The saving in time when riveting over copper stays is about 50%, and much more in the case of iron.

Mr. Mansfield: There is one particular point that appeals to me and that is with regard to Mr. Bennett's ideal steamtight stay. It appeals to me that he should trust to two threads only to keep it steamtight in the outer casing. I do not quite follow the method of introducing the stay, whether the tapped hole in the firebox plate itself will be slightly enlarged so that the end of the steamtight stay has a chance to be a good tight fit in the hole, which, I presume,

is already tapped in the casing; but if the hole through which it was passed in the firebox was slightly enlarged, then it seems to me that a reasonable amount of taper should be given instead of just the two threads tapered off to allow the stay to enter and this being backed off again. If the whole of the end was slightly tapered up to the maximum diameter of the clearance hole through which it was to be passed, then the man could feel better when he had got that right tight home in the casing.

Mr. Barnett: Respecting Mr. Bennett's remark about hydraulic riveting, I might say I have had a little experience with that, but I prefer the steel rivet like Mr. Walters; and the steel rivet should be made well hot, put in well hot from a perfectly clean fire, and the pressure should be maintained on the rivet while you could count up to 20 in your own mind; but it must be followed up and every rivet treated the same, and the snaps should be cooled after about six or eight rivets; that is to make perfectly good sound hydraulic riveting. I find very little trouble with the boilers. Mr. Walters made a remark about the shape of the rivets under the head. Well, I get rivets made specially with a very small cone underneath the head, and these rivets are put in from the outside of the tubeplate—the smokebox side; and when the rivet is put into the hole, it just shows about 1-16 in. above the plate. The rivet head is made well hot and this is forced right into the hole. We used to put in rivets which were perfectly square on the head; these rivets leaked, but one with a small cone is perfectly tight. I have had large tubeplates with almost every rivet leaking when those square under the head were put in, but when using those with a small cone under the head, I have hardly had one rivet leaking in a tubeplate when testing the boiler up to 225 lbs. It is the same with the barrels and the strips for the barrels; I have had barrels tested up to 225 lbs. and have hardly had one rivet leaking—under the cold water test and the steam test, too.

As far as boiler making goes, everything must be perfectly clean and perfectly put together. You never see a tinsmith put his plates together without cleaning them properly, and it is just the same with boiler making. Boiler making to-day is almost a science and it requires a great deal of watching and cleaning.

I noticed a remark that Mr. Bennett made about cracking in the corners of the tubeplates and the tube holes. I have found a good practice is to reduce the number of

tube holes in the corners and to divide them out a little more. I noticed he had three in his corner; we generally have two there. That would compare with one gentleman's remarks about the size of the tubes to give a little more strength in the bridges.

A great deal of the trouble with boilers is due to the shape and construction of them; and there was another of Mr. Bennett's remarks I noticed, about a sideplate, when he talked of the flame licking the plate. I thought when I saw the plate that it was cut rather low down—that was the cause of that mischief.

Brick arches, I find, work better away from the plate, about half an inch to three-quarters as a rule.

From what I have seen to-night, I think a great deal lies in the cleaning of the boiler. If a boiler is well washed out, cleaned and attended to, half this pitting would not take place. It is what is left behind in the boiler that causes the mischief.

Mr. A. R. Bennett: I was on Cardiff platform yesterday (I am telling you this in reference to a remark by one of the speakers, Mr. Hughes) with an engineer, and we noticed a locomotive fitted with the feed through the top of the boiler, on the Great Western Railway's recently-adopted plan. My friend remarked that introducing water into the steam surely could not be a good thing, but when I pointed out that steam for the cylinders was taken from quite a different part of the boiler, he began to see that there might be something in it. I am sure, from the fact that the Great Western are apparently making every effort to fit all their engines in the same way they must find great practical benefit from the new appliance.

The remark by Mr. Lawford Fry about steel fireboxes in the United States interests me, because I have often wondered why they cannot be made successful in this country. Of course, Mr. F. W. Webb tried them in different forms at Crewe years ago, but found few, if any, imitators. I once had a conversation on the subject with an engineer of the Norwegian State Railways, who had had some training in the United States, and found that he was greatly in favour of steel; but he said it must be steel from the States. He knew that because he had unsuccessfully tried steel both from Great Britain and Sweden. When he ordered steel fireboxes ready-made from the Baldwin Works they proved to be as excellent as he had found them to be

on the other side. I said, "It is surely very expensive to get them over." But he replied, "Not at all; they are used as packing cases and come full of dry goods, or what not, so that the freight does not amount to much."

I should like to ask the author whether he has had any experience with the pitting of steel tubes when used with steel fireboxes as distinguished from copper boxes, because every electrician can see that the combination of a steel tube or stay with a copper box in the presence of water containing acid, or even some kinds of alkali, is just the sort of thing to promote voltaic action at the expense of the steel. This voltaic action, which would be extra or additional to any other destructive cause that might be present, would not occur if both tubes and box were of the same quality steel.

Mr. Higgs (Great Western Railway): I should just like to say a few words about the top feed referred to by Mr. Hughes. I had a good deal to do with that and I might say that a good deal of the trouble with locomotive boilers at the present time is due to the way the boiler is fed. I think the water is not put in at the proper place, and I think that the way the water is now put in by the G.W. is similar to a motor car when it uses a carburetter, that is, the water, instead of being put in in volume, is spread; and that is why the tendency is for boilers to last the time they are doing and why we have so very few leaky tubes. In the past, the feeding of boilers, I think, has not been paid enough attention to. When you get a gardener to water flowers, he takes good care to put the rose on the water pot and the consequence is that the plant is not chilled; and it is just the same with the boiler—the more you spray it the better results you get. That is why they go in for water tube boilers, the more you split up the water the nearer you get to the perfect boiler. I believe the day will come when we shall not have to make boilers to boil water to get steam; we shall be able to make steam in the same way as petrol gas is made from petrol by the carburetter. I am not a boiler maker; that is my experience as a fitter. I might say we have about 800 to 900 boilers fitted with that top feed, so the results have evidently proved satisfactory, or else we should have dropped it long ago.

Mr. Whitelegg (member): Mr. Bennett mentions the fact that stays and other parts of the boiler are damaged by the action of the oil used on the stays in running them

in. He states that, in some cases, this damage is due to the large quantity of oil used, but my opinion is that it is not so much the quantity as the kind of lubricant. I know there is a diversity of opinion regarding the lubricant used for this purpose, and some engineers use tallow, while others use mineral and different kinds of machine oil. I have had very good results from ordinary common oil, but this, of course, depends largely on the chemical composition of the feed water.

The second matter I should like to mention is that of the life of fireboxes. I think the author states that a good average is five years. Well, I am rather inclined to think that it is fallacious to make any time limit for a firebox. I think it should be done on the mileage basis, because two boilers may be put into two locomotives at the same time, turned out of the shops, and at the end of another stated period, say five years, the mileage may differ to the extent of 30 to 40% and, consequently, the amount of wear and tear on the firebox is, to all intents and purposes, proportionate to the mileage, not taking other things into consideration, such as the purity of the water, the use of the boiler when in service, and other things which tend to wear out the plates, stayheads, etc., and I think that is the right way to calculate the life of the boiler or firebox.

The author also mentioned the question of testing of boilers, and he states that it is the practice of the company with which he is employed to test boilers by hydraulic pressure at not over 25% above the working pressure. In my opinion that is rather low, as I think that if a boiler or firebox is designed with a fair margin of safety, if it will not stand more than 25% over and above its working pressure, it is hardly fit to turn out of the shops.

Mr. Lawford H. Fry: The question of firebox steel has been raised, and I think it might be of interest to you to hear the American Railway Master Mechanics' Standard Specification for firebox steel, which is as follows:—The desired tensile stress is $25\frac{1}{2}$ tons, with maximum and minimum limits of 28 and 23; the elongation in 8in. shall not be less than 26%; the chemical requirements are:—

Carbon, .15—.25

Phosphorus, not over .04 for acid steel and

„ .03 for basic steel.

Sulphur, „ .04

Manganese, „ .3—.5

Firebox steel, before and after quenching, shall bend cold to 180° flat on itself without fracture on the outside of the bent portion.

The question of the use of steel for fireboxes is one that has interested me very much, and I have made a good many inquiries to ascertain whether there really was much difference in the life of copper and of steel fireboxes, and so far as I can learn, there is very little difference in the life of the box. Of course, the two metals require different treatment, and very often where a steel firebox is put into the hands of boilermakers or of round-house running shed men who are used to copper fireboxes, the result may be unfortunate. Steel fireboxes require to be cooled more slowly and to be heated up more slowly than copper fireboxes, and as the steel is less flexible it requires a little more careful treatment; but, given the treatment it requires, there appears to be very little difference in the life of the fireboxes in similar service.

Mr. Hughes, sen.: As Mr. Fry states he is interested in the life of steel boxes, what is the average life of steel boxes? I have heard that some last 10, some 12, and some 14 months.

Mr. Fry: That is an extremely difficult question to answer, because the life varies so much with the class of water, with the kind of service, and with the type of locomotive. There are so many factors to be weighed that I do not think that any figures I might give would serve as a basis for a fair comparison. I prefer to say that after careful study of the question and after comparisons made in countries where both metals are used, the best conclusion I have been able to come to is that there is not a great deal of difference between the service obtainable from a steel and that obtainable from a copper firebox.

Mr. Barnett: What was the pressure of those boilers in America?

Mr. Fry: The pressure used in the steel fireboxes is anything up to 220lbs per square inch.

Mr. Burtt: There is one question I want to put to Mr. Bennett, and that is about the graphite. He has spoken about this graphite being tried on stationary boilers, but, apparently, it has not been tried on locomotive boilers. Perhaps he will tell us why it was not put into the locomotive boilers.

Mr. Bennett (replying to the discussion): Mr. Suffield, in the first place, spoke about the elongation of the tube holes; he would like to know rather more about it.

(Figure 2 was then thrown on the screen again.)

Mr. Suffield said he is not quite clear as to how I account for what I term elongation of the tube holes in service. We get elongation of the tube holes in quite different ways. It depends in the first place on the way the crown of the firebox is stayed. If you have a direct-stayed boiler and a round crown casing, they will elongate diagonally from the outside rows towards the centre of the tubeplate on each side. But in a solid-bar boiler, the roof is so rigid on the top that, when excessive expanding is done, the holes elongate across the plate. This peculiarity may be accounted for by excessive rigidity in one part and to the material having a tendency to work towards the line of least resistance. Then again, I might tell you as regards the direct stayed round crown casing boiler, you will find if a gauge is made and put over the casing, from the crown centre at top on each side to the centre line of that boiler and tried carefully under the working pressure and water tests, that the boiler comes out materially from the last direct stay on the crown to the first row of copper stays on the side, so that the boiler really flattens on the top and goes out in the unstayed portion. In fact, we had rather an exhaustive test of that on the L.B. and S.C. not so many months ago, owing to the crown bolts giving trouble by breaking. We wanted to know what was taking place, and we made gauges to test. We tested cold, warm, and when we got the steam pressure on, and every shape of that gauge was different when taken off on a chart plate.

Figure 3, Mr. Suffield also remarks about the rivets taken out of a boiler firebox showing excessive corrosive action of the feed water on the heads. He says he does not quite gather the way in which the rivets were located. As a matter of fact, there is no particular way of locating bad rivets, as they are down in the water spaces. It means that you must take something out of the boiler, until you can get ocular demonstration of anything that may be taking place. You can see it if you have somewhere to look through. You take some rivets or stays out, pass a light in and see what is taking place in the water space, and act accordingly.

Mr. Suffield also said that I state that one valve should be screwed down or set to blow off at the working pressure and the other at four pounds heavier, and later on, that if any hydraulic test should prove to be satisfactory, the boiler should then be steamed at the working pressure for four hours or more if desired. He does not quite reconcile these remarks, and he also says that I apparently do not believe in putting a boiler under test for more than four pounds more than the working pressure, yet a great many boiler inspectors test boilers to 15 pounds or more above the maximum. Mr. Suffield has rather misunderstood my remarks. I did not say anything of the kind. In my paper I mentioned the fact that I consider it would be safer for one valve to be weighted to blow off at four pounds heavier than the ordinary working valve, in case that one should stick, as then you would have the other to act as an additional safety valve to the boiler. We have had cases, in fact, we had one a few years ago where we had two valves, twin valves working off the same spindle—they both stuck, and it was considered we had over 300lbs. pressure in the boiler, and, as it happened to be a good boiler, nothing happened, and a very good thing for us, but personally I would prefer such risks to be made impossible.

As regards the hydraulic testing; our rule is to put 40% above working pressure on for our water test; but I believe that we can do too much by over-testing. I think it is possible that we might damage a good job by being too severe. It does not follow that because you put a heavy load on a chain that that chain will stand the same weight the next time, but it does follow that it is very probable that you have spoilt the chain and that it will not be fit to lift that weight the next time.

In reply, *re* rivets—Mr. Suffield says I state that the rivets made by the basic open hearth process cannot be surpassed. Well, if I said it, I ought not to have done so. I should not have said that that steel cannot be surpassed. In fact the British Standard Specification for Locomotive Boilers asks for acid open hearth steel and it is considered to be more elastic than the basic; but I have shown you the tests I have made with rivets of that sort, and rivets that will stand that are good enough for me to put in boilers if I have got to be answerable for them, whether they are by the basic or acid methods. But as it happens, I am not responsible for any specified class of steel rivet. I only want the best rivets to stand the load which may be put upon them.

In regard to the efficiency and durability of pneumatic, hydraulic, and hand riveting, and which of the three methods I consider the least likely to destroy the threads of the stays, I take it that in this case Mr. Suffield means the copper stays. Well, probably you will tell me that I am rather conservative if I tell you that, personally, I would sooner have a hand riveted stay than all the machine riveted stays in creation. A hand riveted stay worked by a sensible man and with a proper hammer—you cannot get anything better than the work done by the hand riveter in the way of stay nobbling.

Then, again, as regards leaky tubes caused by the water being drawn from the front portion of the barrel to the water space near the firebox tubeplate, Mr. Suffield says he does not quite follow my line of argument. Unfortunately, he is not the only one. There are a good many people who cannot follow that line of argument at all. Had I been speaking about a top-feed boiler, the same as Mr. Churchward has introduced on the G.W., I certainly should not have made the statement. I am talking about a boiler where the feed water is introduced into it on the sides of the barrel, or a boiler with bottom clackbox, where you have your cold water to be drawn along and fed up between the spaces at the hottest portion, which is about 16 in. from the copper tubeplate; then I say, in that case, the water cannot get round in sufficient quantities, in my opinion, and the result is that you cause somewhat after the condition of a vacuum in the sides. The water does not circulate through as quickly as it ought to do, or you get it too cold, maybe, and you get leakage of both stays and tubes.

Mr. Suffield also would like to know if I have had any experience in cracks on the outside radius: I take it that Mr. Suffield means the outside shell. No, we do not get any such thing in the round crown boilers—you never find a fractured shell. I have never seen it yet, not where the shell has been in one continuous plate right round. On round crown boilers we do get the direct stays breaking at the point where they work, at the top, and, as I explained just now, the crown goes down and the unstayed portion goes out perceptibly at the side. Of course, it is more noticeable with a gauge; you could not see it with your eye. But if Mr. Suffield meant the water side of the radius corner of the firebox, I say Yes, but very rarely.

Mr. Hughes, jun., spoke about the reduced rivets. Well, I think I have already explained about them; also, I think Mr. Hughes was kind enough to explain it for me.

As regards the elongation of the tube holes causing tubes leaking, he also answered that, for which he has my thanks.

Mr. Garratt spoke about the tools he has been kind enough to show us. The beading is very good done with a rotating hammer. I like the beading done with a pneumatic tool, more so than by hand, my reason for that being that you get a more direct blow on the tube end.

(Mr. Bennett then explained the difference between the tools he used and those exhibited by Mr. Garratt, dealing with their relative merits.)

Mr. Hughes, senr., from Dudley, mentioned about riveting by pneumatic, hydraulic, and hand. Well, I think the riveting is the same as the staying. Riveting down rivets is the same as riveting down iron or copper stays. There is no doubt about it, that if you want to go in for a first-class rivet, a hammered rivet into a countersink hole is hard to beat. That is a very old-fashioned way of riveting, and I may tell you that we have still running on the L.B.S.C. boilers we cannot cut up without resorting to drilling first. When I first went to Brighton, I was not very pleased about it, when one of my men told me he could not cut a boiler up. I told him it was nonsense, I had never seen a boiler that could not be cut up. "I'll show you how to cut it up." I went out, and, after about an hour's thumping on one rivet, I decided to let him have a drill to drill them out, as punching them out was impossible. They were faced holes—countersunk inside and out—the finest work ever in a boiler to my knowledge. But the general consideration of cheapness means that we must have a cheap product, so we have to put in hydraulic; that is next best, at reasonable pressure. I think it is possible to get too much pressure, and so not only spoil your rivet, but crush your plate into the bargain, whereas, by sensible treatment, you may manage to get a first-class job from hydraulic riveting. As regards pneumatic riveting, I may tell you that some years ago we riveted up some twenty or thirty boilers by the pneumatic hammer, and it was more a point of cheapness with us than the point of utility. At that time things were rather troublesome, and we were in a difficulty in regard to getting the quantity of output, and, as two full-paid men went to make a squad of riveters, when I gave them a long-stroke hammer, it meant that there was one man put out of a job, and the result was that that man was employed on something else. But, after things were

altered, and piecework came into vogue, and things were going smooth, we reverted to the hydraulic, and, where we could not get the hydraulic work in, we put them in by hand.

Mr. Fry would like to know a little more about the use of graphite. Well, as I explained in the paper, I came across it more by accident than by design. I thought if one man could get the result and did not try for it, surely, if I tried for it, I should get it too. I started, as already explained, in a stationary boiler. I should say the boiler is about 12ft. long and about 6ft. in diameter, under-fired, and with about 130 tubes 3in. in diameter in it; and this boiler was one of the dirtiest we had in the place. It was a source of trouble to us, and a source of anxiety likewise. Being under-fired, you know what that meant if much dirt accumulated; I should very soon, perhaps, have had an explosion. I put three pounds in, and I let her run seven weeks. Such a thing had never been done before. We always washed the boiler every month before that; but I let her run seven weeks, just to see what would happen to the scale. The boiler fireman had had so many incrustation powders and one thing and another that he fairly got what he called "sick" over it. I took him the graphite, and, at the end of seven weeks, asked him how much stuff they had got out of her. He said they had done pretty well, but that he did not think it was caused by the graphite. I told him to keep on using it, and so we followed on next month by putting a pound in. He rather fancied there was perhaps a bit of something in it, and now they all run after me for graphite. We are following up with it, although we have not tried it yet on the locomotives. We are finding such good results from it on the stationary boilers that, where we used to have to have the expense of sending men in to scurf, we send no men now; and it means this to me, that, instead of having to superintend the boiler scurfing during the holidays, I get my holidays to myself, so graphite has done me a good turn.

Mr. Walters spoke about broken stays. He said I omitted to mention where they were found. Well, I did, for this reason, that, on different classes of boilers, you find them in different positions. On Mr. Walters' boilers, I expect he knows where to find his broken stays, and I know where to expect to find mine. On one class, I go to the top corners of the backplate, and, where they have got solid bars, the end stays that run through from the back into the solid bar. Then, again, on the generality of boilers I find I get broken stays on the top corners against the tube-

plate, and the back top corners against the back-plate. I have found them as far down as seven rows down on the second row in on either end, but that is very rare. I have never found one down in the fire, but, as I say, I do find them up in the top. In the "Atlantic" type or wood-burning boiler, the "Wootton" type firebox also, we find the three top rows all round go worst, and there is our source of trouble, and that is where we have got to watch them closely, on the two sides and on the backplate.

Mr. Walters was kind enough to tell us about riveting, and I may say that I quite agree with his remarks.

As regards the firebox that I described, you said, I think, Mr. Walters, that the pitting was due to grease. Now, the peculiarity of the pitting was that it not only affected the firebox, but it affected the copper pipes, and even the copper pipes that went up into the dome. Now, I should say that, if grease had got in with the feed water, the action of the grease would only be felt up to the water-line. I should not imagine that anything up in the dome, where the dry steam was, would be affected so much as we found it. Personally, I am of opinion that somebody was trying to patent a "graphite" of their own for boiler cleaning.

Mr. Garratt was asking my opinion about the beading of tubes and pneumatic riveting. I think I have already sufficiently spoken about that, Mr. Garratt, but you said something about £12 3s. for riveting iron stays. What do you mean? Complete stays, inside and outside, for £12 3s.?

Mr. Garratt replied that that was the economy obtainable, compared with hand riveting.

Mr. Bennett: You mean to say that that idea is cheaper than by hand riveting, meaning to say that, taking the G.N. for example, they knock down 24 stay ends for 9d.? Can you knock down 24 for 9d. with that tool?

Mr. Garratt: Well, I can only go on the information received. There is supposed to be a saving of $\frac{3}{4}$ d. per stay on copper stays, 2d. on bronze, and $3\frac{1}{4}$ d. on iron stays, each.

Mr. Bennett: If you can get them done for 2/- per dozen, you are not doing so badly.

Mr. Garratt said he was sorry he could give no more information.

Mr. Bennett: Mr. Mansfield spoke about a steam-tight stay, and I do not think he quite follows my idea as to

what I meant when I said that practically I was relying upon two threads. I was not relying upon two threads ; I meant that all my work was done by the first two threads, because you have tapped your hole, and, as you tap that hole probably a trifle smaller with a No. 1 or lead tap, when the stay is passed through the copper and begins to pull home on the steel, the stay hole being taper or smaller on the back side of the hole, as we are working forward with the stay, and the stay end being higher after the second thread, and then working back conical or taper to the minimum, I have pulled home solid when that is right up to the outside edge of the plate. If I go further, I am going down the taper, and so doing away with the good I have already done. It is only done by feel. I want to feel the job. Of course, you would use a length gauge, and so, obtaining stays of proper length, you would not go further than you ought to do. If you do, instead of having all your power on the point of that stay where you require to make it tight, you are going to get slacker. You oftentimes see, when leaking has been taking place, and men have been sent in to put in steam-tight stays who do not know what they are about, they will turn the stay in too far through the casing plate, and it will leak like a sieve.

Mr. Barnett mentioned about hydraulic rivets, and some very good remarks I think he made ; but I do not agree with him about steel rivets being made well hot. There is the possibility that he is making them too well hot. What does that term convey to the ordinary tyro ? If you tell him to make a rivet well hot, he would make the rivet to swelter, and it would be spoilt. If they know what you mean by "well hot," then, by all means, have them well hot. "Well hot" means sensibly hot. You mean to say that your head and shank should be the hottest, so that at knocking down point there should be a tendency to force stuff into the hole, and so have the finished size of the rivet according to the size of the hole you have in the plate.

Mr. A. R. Bennett was speaking about the top feed on the G.W. engines. I quite agree with him that this is the ideal place to put water into the boiler, and I think if everybody adopted it we should hear less from boilermakers about troubles.

Then you say they have some useful steel fireboxes in America. Why not in England ? We tried one on the G.W. some 12 or 13 years ago. In fact, I may tell you, I happened to put the firebox in the casing myself, and it was made of $\frac{3}{8}$ in. steel, with, as far as I can remember, a

5-16in. wrapper plate. The casing and barrel were made of 11-16in. and $\frac{3}{4}$ in. plate, and it went into traffic for nine months. Then it came back to have the firebox taken out—why, I don't know. Since then, I believe other people in England have tried them; in fact, I have five already waiting to go into casings at Brighton to-day. They are made ready to go in, but we bought the steel specially from America to a special specification, something like Mr. Fry gave you just now.

Then you mentioned about steel tubes and copper fire-boxes. Personally, as I have said, I believe that the steel tube is an ideal tube, for this reason, it is hard-working, tough, and will stand the work. The worst point we have got about it is the liability to corrosion. But copper tubes are expensive, and to end them means a big expense again, whereas you take the ordinary steel tube, for which you pay 4/6 to 5/- each, you get three to three and a half years' wear out of them, and then sell them to the Birmingham bedstead makers, and buy a new set.

Mr. Higgs remarked about the top feed and the way the water is spread on the G.W., but I do hope that Mr. Higgs' ideas about the steam boiler being done away with won't come right, or else I should have to find another way to get my living.

Mr. Higgs said that the idea he had was that there would be some kind of generator come forward that would generate the steam in a different manner to what was done at the present time. We are practically in the same position now as in Stephenson's time, but the tendency now in stationary plants was to begin to divide the water up as well. The tendency was that way all the time, and he thought that, in time, it would come to the locomotives.

Mr. Bennett: Mr. Whitelegg questions me about too much oil used on stays. What lubricant? Personally, I think that the finest oil you can get should be used—a good rape oil. I do not believe in tallow, and I do not believe in blacklead, but I believe in a good fine oil, as pure as you can get it, free from any sediment.

Mr. Walters: Do I understand that this is the lubricant for tapping, etc.? I do not believe in oil at all. I have used a composition now for this last four years with great success. I tried first of all crude vaseline and mica powder. I then went in for the crude petroleum jelly and mica powder. That answered very well. Then I went in after a while for

the crude petroleum jelly and graphite, and that has answered much better, I can assure you. That is our experience on the Midland. The proportions are 8lbs. of petroleum jelly to 10z. of graphite.

Mr. Bennett, after thanking Mr. Walters, continued :—

Mr. Whitelegg says he does not agree about the life of the fireboxes. He said he would work on the mileage system. Personally, I should say the mileage system is not much help. You must take into consideration whether the plates are wearing. If you have a cracked tubeplate, and the boiler is getting thin all over, and it shows only a small mileage, you cannot say another one has run so many miles, and, consequently, this one will have to do the same. You must work by what the state of the box is—by wear and tear, not by mileage.

The meeting closed by a vote of thanks (to which Mr. Bennett suitably responded) to Mr. Bennett for his excellent paper, moved by the Chairman, and seconded by Mr. A. R. Bennett.

CORRESPONDENCE.

Mr. A. Rosling Bennett writes as follows:—To my remarks as to the voltaic consequences of combining steel tubes or stays with copper fireboxes, I should like to add that, if the water in the boiler could be kept alkaline by means of caustic soda or caustic potash, there would be no action of the kind described to the detriment of the steel, inasmuch as steel (and iron) in the presence of such a solution are almost as electro-negative as carbon, and more so than copper, so that steel and copper may be combined under such circumstances without risk of material voltaic action between them. Under almost all other conditions steel is strongly electro-positive to copper, and must in time be eaten away if the water is conductive through the presence of acid or alkali other than caustic. If the water be very pure its conductivity will be so low that voltaic action can scarcely take place at all, notwithstanding the presence of the two antagonistic metals. An insulated iron or steel tube, rod, or plate introduced into the water of a boiler with a copper firebox would tell interesting tales if a galvanometer were connected between it and the copper. The purity or otherwise of the water could be deduced from the amount of deflection. Action, but of course to a lesser degree, takes place between brass tubes and copper boxes, since the zinc in the brass renders it electro-positive to copper. To reveal this would require the insertion of a brass plate or rod of the same quality as the tubes.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 5.

Fig. 4.

Fig. 6.