FAILURES OF DETAILS OF MACHINERY AND BOILERS SUBJECTED TO STEAM PRESSURE.

An examination of a large number of recent reports of official investigations made by the Board of Trade into the causes of failure of boilers, steam pipes and details subject to steam pressure, shows several features of interest, and are of practical value in revealing the necessity for care in operation and in the design, construction and fitting of these details. Some of the investigations naturally reveal the cause of failure as being due to ignorance or carelessness, in which the best of precautions in other directions have been nullified. In this category are cases where boilers have been worked for periods amounting to several years without thorough examination and cleaning, instances in which steam has been raised with a boiler short of water and cases in which the safety valves, having been leaky or considered objectionable by their operation, have been gagged or screwed down, and the boiler or container has been subjected to pressure exceeding that for which it was designed.

There have been other cases where a relapse from normal care of operation has brought about disaster whilst in other instances, where reasonable care has been exercised, reflections have been made on the materials used or on the design, manufacture and fitting of certain details. It is, therefore, proposed to refer either generally or particularly to a number of cases coming under these headings, observing that one important failure, viz., the explosion of the steam drum of a water-tube boiler was dealt with in detail in the No. 3 of these Papers.

It will not be necessary in all cases to make remarks on Admiralty procedure with similar fittings, but they will at least serve to emphasise the various regulations in force to prevent similar accidents in naval practice, which regulations are generally based on the extended and comprehensive experiences of the past.

A frequent cause of failure brought out by the investigations is that due to " water-hammer " set up by the admission of steam into a pipe that has been insufficiently drained. If water is lying in a pocket in the system then the admission of steam is accompanied by a rapid local condensation near the entrapped water. The further result is that other water of condensation which may be carried along with the steam is thrown with considerable force into the place occupied by the condensed steam and produces a heavy shock of " water-hammer " on its motion being arrested.

In a number of cases this " water-hammer " action is brought into play while draining water from pipes or valves which are connected to the boiler at the time. If such water has been allowed to accumulate this operation appears at times to lead to the " water-hammer " action being set up in consequence of the disturbance of the water-level in contact with the steam. The drains should always be arranged that all parts of a pipe line can be cleared of water and when resuming the use of steam pipes which have become cool, it is essential for safety that they should be closed to the boilers during the process of draining. The first admission of steam should be made gradually until the pipes are heated and it is discerned by the issue of steam from the drains that all water has been effectually expelled from the range. All risks of "water-hammer" being thereby removed, the valves connecting the boilers with the steam pipes can be opened up with safety.

It is nearly always risky to drain a steam pipe line of any considerable size whilst the boiler stop valves on the pipe line are open and the violence of the shock appears to depend largely on the speed with which the water is drained away.

Remarks of the above nature have been made on a number of cases of failures of stop valve chests and steam pipes. The fact that such failures in the majority of instances have occurred with cast-iron valve chests or fittings, and with plain lap-welded steam pipes does not detract from the care necessary in all installations. It serves, however, to illustrate that with such fittings particular care is necessary, especially when cast-iron details are used, as this metal owing to its lack of elasticity is particularly susceptible to failure by shock.

As regards lap-welded steel steam pipes there is in many cases an element of doubt respecting the soundness of the weld which a hydraulic test does not reveal. The Admiralty specification allows for this and states that where such pipes are fitted an external strap not less than 1/16 inch thicker than the material of the pipe is to be fitted over the weld, the rivet holes for securing this strap being kept well clear of the weld.

It must be borne in mind that steam pipes and details especially in marine installations are, at times, apart from "water-hammer" effects, subjected to stresses considerably exceeding the static stresses set up by the pressure of the steam. These additional stresses may be brought about by relative movements of the bulkheads and points of support and attachment, and also by expansion effects. These stresses are felt particularly at the fixed positions such as the stop valves on the boilers, &c. Then, again, there may be a certain amount of strain due to the vibratory movement of the engines and other incidental causes.

A case presenting some of these features was seen in the failure of a cast-iron stop valve chest on the boiler of a trawler. In summing up, the surveyor stated :—"The chest was of sufficient strength for the boiler pressure alone, but in view of the absence of webs between the flange secured to the boiler and the body of the casting and the limited thickness of the body at that part, it would seem that in designing the chest no consideration was given to the possible effects of the various racking and bending stresses which would inevitably be set up by the movement of the steam pipe and the vibration of the ship and machinery. It also appears to have been possible for the boiler itself to move to a greater extent than is desirable and this would necessarily, by throwing greater stresses on the chest, hasten the formation of the fractures by which it was gradually weakened until it failed."

In the case of the failure of a copper steam pipe in a mail steamer it was reported that the brazing of the flange to the pipe was defective. This pipe had, however, stood up for several years and, shortly previous to failure, had been annealed and tested. It was brought out, however, that for some time previously considerable trouble had been experienced through leakage at the joint between this flange and the T piece to which it was attached, which indicated that notwithstanding the long period it had been in use, the pipe was heavily stressed in service. Owing to the trouble with this joint the T piece had a short time previously been fitted with clips to the deck, which appeared a mistake in this case, as it lessened the flexibility of the steam pipe installation generally. With regard to the defective brazing, the flange was found to be a driving fit on the pipe and no space had been provided for the flow of brazing metal between the pipe and the flange. The similar flange at the other end of the pipe was examined and the flange was forced off the pipe. Great difficulty was experienced, however, in doing so, and it was then found that the brazing material extended for practically the full depth of the flange. This was interesting as the arrangement of the installation was such that this joint under normal working conditions was subjected to similar if not greater stresses than the one that failed. The failure was accentuated by the employment of jointing material 1/16 inch thick which was placed in the form of a ring inside the bolt holes, and the repeated tightening up owing to the leakage troubles produced additional stresses in the material at the back of the flange.

Another case that presented several features of interest was that of the failure of a cast-iron boiler stop valve in a large passenger liner. The investigation showed that from time to time considerable trouble had been experienced with the main steam pipe ranges of this vessel and the particular stop valve under discussion was one that two years previously had replaced one that fractured on service. In addition, two cast-iron T pieces and a cast-iron bulkhead valve chest had developed cracks and had been replaced by gunmetal or cast steel fittings. The cause of these failures was traced to the particular expansion glands fitted in the ranges, these glands being of a sleeve type without packing. This particular type had at one time been considered for naval use, but had been found unsuitable owing to its tendency to seize if correct alignment were not preserved. This is almost impossible in such installations, owing to the effects of lateral expansion and the relative movements of points of support. The consequence of such seizing is the imposition of heavy stresses particularly on the fixed points of the range.

The Surveyor remarked as follows in his report:—" The failure of the stop valve chest illustrates the necessity for free expansion in steam-pipe ranges, as well as the desirability of using cast steel for important boiler mountings. Cast iron is of very variable quality and possesses little or no ductility and it rarely gives any visible indication of approaching breakdown under stress. The expansion joints fitted in the range of pipes appear to have been sluggish and irregular in their movements and consequently considerable stresses were thrown on the neck of the stop valve chest, resulting in ultimate fracture. The various parts of the range had been under careful observation for some time past owing to the trouble previously experienced, but no indication of failure appears to have been observed until a matter of minutes before the chest completely failed." (Four men were killed by this explosion.)

The expansion joints have since been replaced by others of the common type with soft packing, and the cast-iron stop valve chests on some of the boilers by cast steel.

A general résumé of the foregoing cases indicates that the desiderata of a reliable steam pipe installation are :—efficient drainage arrangements, freedom for expansion, correct design and the use of reliable materials particularly for the stop valves and fixed details which are subjected to the greatest stresses, good workmanship at the joints, and careful alignment which obviates excessive stresses being brought on the necks of the flanges when jointing up.

In one instance the Surveyor expressed an opinion that the necessity for periodic hydraulic tests of the steam pipes was indicated, a procedure which in naval practice is laid down for the installations in torpedo craft where the racking and vibratory strains are appreciably greater than in larger vessels.

Two cases of failures of boilers will now be instanced to bring out some special features.

The first case was the collapse of the side of a fire-box of a small boiler. The subsequent examination revealed that several of the supporting stays of the firebox had failed some time previously. The increased stresses on the remaining stays ultimately caused their failure under normal working conditions. These stays are exposed to racking stresses owing to the expansion of the fire-box and as their condition in small boilers cannot be seen, it is necessary that hydraulic tests should be carried out in such boilers. The fire-box stays fracture most frequently at the inside surfaces of the plates and when they are inaccessible it is good practice to drill a small hole along the axis of the stay to a greater depth than the thickness of the plate so that fracture is at once indicated by a leakage of water through the stay. Single stays can then be renewed before so many become broken as to render the boiler quite unsafe.

The second case was that of a donkey boiler in a steamship, the boiler being of the ordinary cylindrical type 9 ft. diameter, the boiler shell consisting of half-inch steel plates jointed longitudinally with treble-riveted lap joints. The boiler was about

20 years old at the time of the explosion. The cause of the failure was the wasting of the shell plates, in particular at the lap joints, in consequence of which the boiler was unable to withstand the pressure of steam to which it was subjected. The explosion was very violent and attended with a fatality and much material damage.

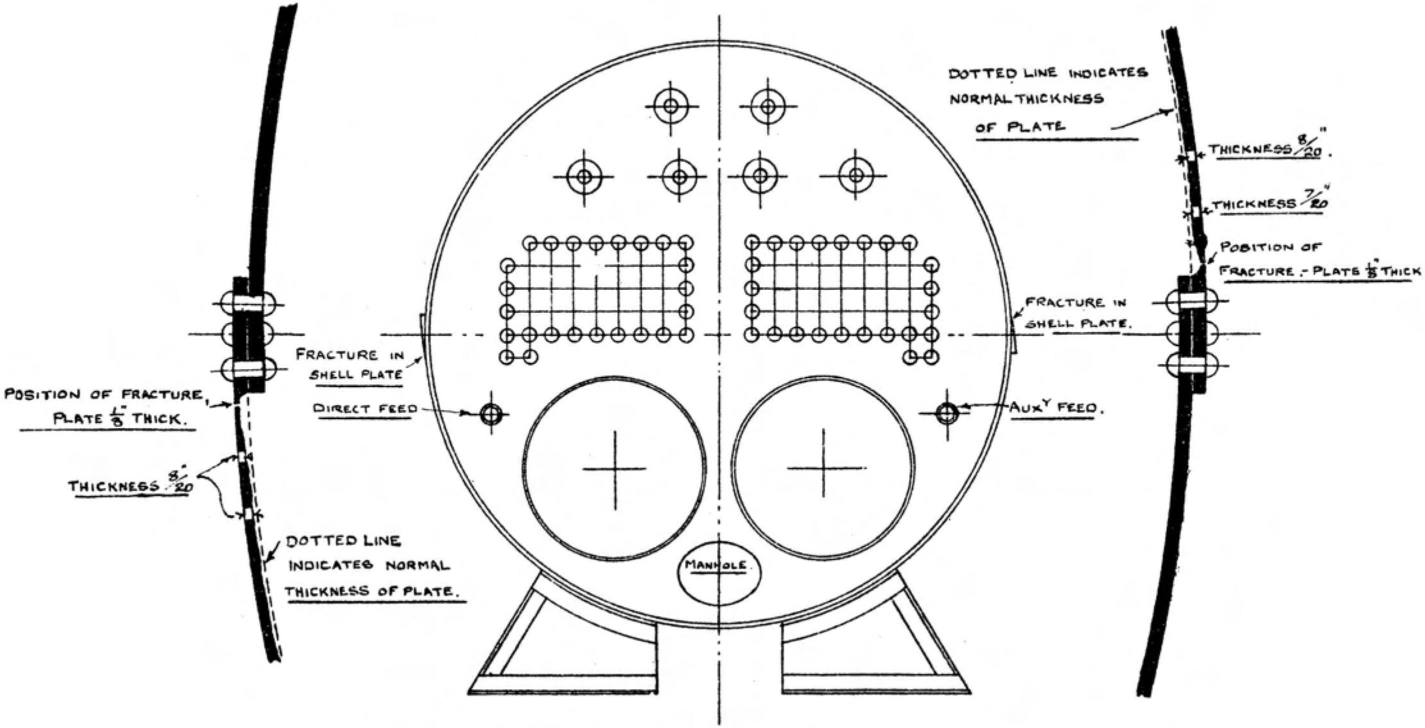
The boiler had been tested hydraulically to $1\frac{1}{2}$ times the working pressure after retubing, less than 2 years previously, and had been certified about 12 months before the failure as approved for its stipulated working pressure of 80 lbs. per sq. inch as the result of a thorough internal examination. The general structure of the boiler and enlarged views at the lap joints are shown in Figure 1, and the non-observance of the serious corrosion seen requires a little explanation.

Unfortunately there was no evidence of any defects having been observed during the re-tubing when the facilities for a very thorough examination existed, and when it is considered that some wasting should have been revealed in the neighbourhood of the lap joints. When examined later with the tubes in position it will be noted that the wasting at the port side in any case would not be observable, whilst that on the starboard side, although somewhat more accessible, was likely to pass unobserved if the wasted plate presented, as it did, a comparatively smooth surface down to the lap. Conclusive evidence could, however, have been obtained if a drill test had been carried out and positions in the neighbourhood of the lap joint had been selected. The Surveyor was probably also misled by the fact that he observed no pitting on the lap, stays, etc., and, therefore, suspected no wastage.

A Surveyor who was employed to investigate the cause of failure had had considerable experience in these lap-jointed boilers, and the result of his experience is that the lap-joint inasmuch as it takes the boiler out of the circular form to the extent of the thickness of the lap, sets up a breathing action, the axis of which is at the joints and that this produces a wasting of metal, reducing it not only in thickness, but also in strength owing to the fatigue of the metal caused by the constant movement. Action of a similar nature has been found from experience to take place in fittings in the naval service, viz., the D-shaped water pockets of boilers.

As a matter of fact it can be demonstrated that in the absence of fatigue in the metal, the boiler in spite of the reduced local thickness of the plating could have withstood the pressure at which it burst. The opinion was expressed that the corrosion arising from the breathing action would after it had reached an advanced stage, become very rapid and that considerable extension had probably occurred in the time following the hydraulic test two years previously.

The conclusion arrived at was that boilers of this size and thickness of metal with lap joints must be considered as having a shorter life than those with butt-strap joints in which the



BOILER EXPLOSION DUE TO WASTING OF SHELL PLATES.

FIGURE 1.

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circular form is preserved, and that the life can only be permitted to be prolonged if the condition of the shell plates about the lap joints is closely watched. Absolute reliance cannot be placed on a hydraulic test and, moreover, if local wasting has taken place, the boiler may be strained by subjecting it to excessive pressure. The hydraulic test to be applied should depend on a knowledge of the thickness of the parts being tested, and it can then be used to verify the proper working pressure as previously estimated by calculation, depending always upon the margin of safety desired or demanded.

Some of the cases investigated refer to simple machinery used for heating, drying, cooking and laundry work, and it is not unusual to find that efficient safety or drain arrangements were absent. Not infrequently such apparatus is put into the hands of inexperienced operators, and may be at times connected to sources of steam supply considerably exceeding the stipulated working pressure without an intermediate reducing valve being provided. These cases serve to emphasise the necessity of all such details being manufactured, fitted up, and worked under efficient engineering supervision. To take one example, the working pressure was 10 lbs., the safety valve had been tampered with and was set at 93 lbs., whilst the steam supply was 60 lbs. So long as the drain was efficient it appeared the pressure did not rise in this particular receptacle, but on being worked with the drain closed or choked the failure that took place was inevitable.

With the adoption of machinery of this type into the naval service it has been at times difficult to carry conviction that a strict supervision of such every day fittings at all stages is essential, but when the possibilities, as seen in an actual case as that referred to above, are presented, the need for such supervision is made very apparent.

Safety valves if correctly set are generally looked upon as the most reliable of fittings and cases of failure of these valves to operate are extremely few. At times they may show sluggishness, but not such as to allow the working pressure to be considerably exceeded. The failure of the boiler of a locomotive recently, therefore, which was attributed purely to over pressure under otherwise normal conditions, caused a searching inquiry to be made. In this instance the excess pressure was revealed on the pressure gauge, but inasmuch as the safety valves had generally functioned at their correct pressure the pressure gauge was assumed defective, such cases being not uncommon, whereas the non-operation of a safety valve near the pressure at which it was set was assumed to be unlikely. The failure was extremely violent resulting in complete wrecking of the engine. The safety valves themselves sustained such damage by the explosion that it was difficult to prove conclusively why they were inoperative, but it was possible to arrive at some general conclusions which would appear to throw some light on the cause of failure.

The safety valve was of the ordinary duplex type, Fig. 2, the casing being of cast iron and the valves and valve seatings of brass. The valves were provided with three webs and fitted with conical recesses at the tops to ensure that the pressure of the spring was applied centrally. The examination of the valves after the explosion revealed the following relevant details. The width of the bearing surface of the valves seat was $\frac{1}{8}$-inch and the angle between the webs and the valve face was 150° in each case. (Such a steep angle is not desirable in valves and particularly in safety valves. To obtain the maximum area of valve opening for a definite lift, and to minimise the wedging effect of a conical seat, it is desirable in safety valves to have an angle of 90° as is always the case in the naval service.) The webs of the front and back valves projected $\frac{5}{16}$-inch and $\frac{3}{16}$-inch through their respective bushes, the ends of the webs were not bevelled and the marks of the webs were visible in each bush. The valve seats were not truly circular and the webs of the valves were not uniform in diameter, the minimum clearance between valve webs and the respective bushes being ·0095 inch for the front valve and ·012 inch for the back valve when the valves were cold. This clearance is small and would be less under working conditions.

Taking all these observations into consideration and the history of these valves since a refit three months previously, the following general conclusions were arrived at :—

The main contributory cause of the non-functioning of the safety valves was the small clearance between the valve webs and the seats when cold; the difference in the expansion of the cast-iron chest and the brass valves and seats and probable distortion of the latter would reduce this clearance under steam to a dangerously small amount, accentuated if, as was the case, the air temperature was low at the time. It was noted that the pressure gauge had at times been previously reported defective by the drivers, always during cold weather, but no complaints had been made during warm weather when the valves would appear to have operated satisfactorily. If the valves were not free to lift owing to the binding of the webs at normal lifting pressure, any increase of pressure and corresponding temperature of the steam would tend to bind the valves more firmly. It was obvious that the dividing line between freedom and jamming of these valves was very fine, and that a combination of several factors, of which the cold weather was one, was required to produce a dangerous condition. Another contributory cause appears to have been due to the valve faces being machined to a steep angle resulting in the valves being lowered in their bushes. This would not in itself necessarily lead to any danger, but such steep angle may have facilitated slight tilting of the valve and the possibility of increased resistance to lifting being set up owing to the prolongations of the webs bearing against the lower corners of the valve bushes (Fig. 3).

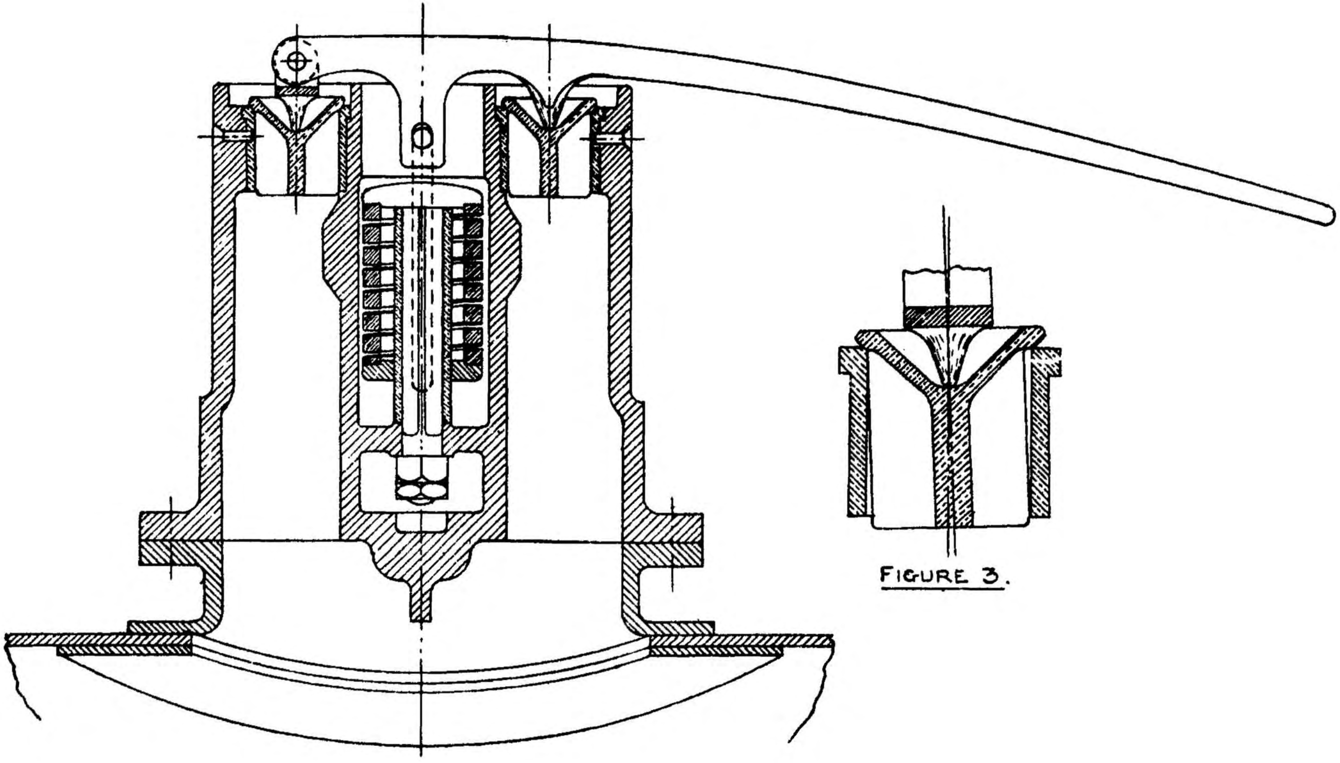

FIGURE 3.

FIGURE 2.

LOCOMOTIVE SAFETY VALVE.

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Apart from the number of the small defects in the valves the disaster would in all probability have been prevented if two pressure gauges had been fitted to the boiler, a desirable arrangement in important units, as it is not conceivable that two such gauges recording similar pressures would be looked upon as less reliable than a safety valve. In any case unless a pressure gauge is known to be defective, the non-lifting of the safety valves at the stipulated pressure evidently requires immediate investigation. It is, perhaps, difficult to conceive a failure of this nature in ordinary installations as the presence of pressure gauges on the ranges would generally indicate if excess pressure were being generated in the boiler, but in the case of a locomotive or similar arrangement there is no direct indication of this nature.

A case of failure by over-pressure was seen when the explosion of an evaporator was investigated. The cause of the explosion was due to the failure of an evaporator coil, which allowed high pressure steam to escape into the body of the evaporator. This in the ordinary way should not have led to failure as a relief valve was fitted on the evaporator body, but this valve had apparently become salted and was inoperative up to the pressure at which the shell failed. The conclusions arrived at in this investigation were to show the necessity of providing adequate and efficient safeguards against over-pressure in an apparatus used for generating steam. The fact that the relief valve was inoperative at the time of the explosion would point to a grave oversight on the part of those in charge who no doubt were lulled into a false sense of security by the low pressure at which the evaporator was normally worked, and the possibility of a sudden increase in that pressure by the failure of the heating coils was overlooked. The failure of the coil in this particular evaporator was attributed to severe stress having been set up in the end connections. The coils were mounted on swivel pieces which enabled them to be swung clear for cleaning, but unless the plugs at the ends of the swivel pieces were eased and the swivels kept clean, the possibility existed of severely straining these coils at their connections.

As a final example and a particularly glaring illustration of the necessity for keeping the design and inspection of steam devices in the hands of those experienced in their application may be cited the failure of a low-pressure vessel through over pressure consequent upon a safety valve becoming inoperative. In this case the so called safety valve was actually fitted with a solid guide which was nearly a fit in the bore of the connection below the valve and so prevented the escape of steam in the required quantity when the valve lifted.