8.

WATER-HAMMER IN STEAM PIPES.

Engineering progress proceeds in general through the more or less intelligent application of the lessons learned from the operation of existing machinery, the designer striving to arrange matters so that the possibility of accidents is avoided as far as lies within his powers of observation. There are, however, many eventualities for which the designer cannot entirely provide, and these are essentially matters in which the operating engineer is principally concerned.

A typical example of this latter class is the danger to material and to personnel arising from the occurrence of water-hammer in the steam pipes, a type of accident which figures all too frequently in the records of the Board of Trade. An examination of these reports shows that these accidents are almost invariably due to a lack of appreciation on the part of the designers or of the operating personnel of the few general principles which make the difference between safety and danger.

Such accidents have in the past been rare in H.M. Navy as the personnel have fully realised the proper precautions, and have ensured that these have been carried out, while the provisions for drainage are usually more generous than in Merchant vessels. This comparative immunity from damage has, however, the disadvantage that in the course of time the existence of such destructive forces may be forgotten and their potentialities ignored. It may therefore be of interest to give a brief account of some typical accidents of this nature, together with a summary of the lessons to be learned therefrom.

Causes of Water-Hammer.—The fundamental causes of the phenomenon known as water-hammer are not definitely known, but it probably occurs in two distinct forms, the more simple being due to the entrainment of large quantities of water in the steam, thus giving rise to damage in valve boxes and fittings in similar positions where the momentum of the water is suddenly destroyed by shock. The second type, and probably the most severe in its effects, is surmised to be caused by an action very similar to "cavitation," its sudden and violent effect being due to the almost instantaneous collapse of vacuous cavities formed in a body of steam. The enormous forces that can be developed by effects of this nature were first demonstrated some years ago by Sir Charles Parsons in his Paper on "Erosion of Propeller Blades" before the Society of Naval Architects in which he applied the appropriate name of "implosion" to this action.

This latter form of water-hammer may be accounted for as follows :—When an accumulation of water occurs in the presence of steam it is probable that only the surface layer is at the saturation temperature, the interior of the mass being somewhat cooler. Thus, if the surface of the water is disturbed, by the sudden manipulation of drains or otherwise, so that the comparatively cold portions come into contact with the steam, sudden local condensation will occur, followed by the formation of a void into which both steam and water will flow instantaneously. This sudden collapse not only results in further agitation of the water, followed by a repetition of the action with renewed violence, but also the water is impelled into the cavity with such velocity that the momentum generated may be sufficient to cause damage to the surrounding walls of the steam pipe.

The heavy water-hammer that can be set up when steam is discharged below the surface of water collected in a drain tank, must have been experienced by many Engineer Officers. The action in this case is exactly similar to that described, but in general, owing to the comparatively small supply of steam and relatively large bulk of water, it is not so likely to cause damage.

I.—Water-hammer due to opening up steam without draining pipe line.—The pipe line indicated in Fig. 1. was fitted to a

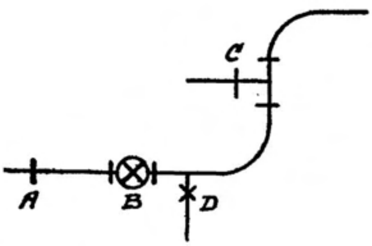

FIG. 1.

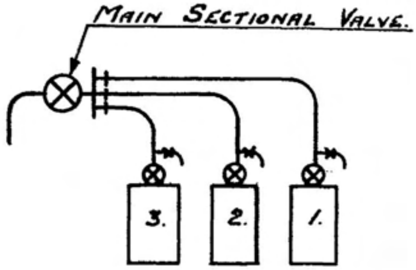

FIG. 2.

steam press, a branch (*C*) being provided on the boiler side of the master valve (*B*) in order to feed certain drying ovens.

It became necessary to remake the joint (*A*), and for this purpose valve (*B*) was shut off, but the steam supply to the drying ovens was continued. The drain (*D*) unfortunately was kept shut throughout the whole period that the repair was in progress and thus water collected at the back of the master valve.

After the repair was completed (*B*) was eased about three-quarters of a turn, corresponding to a lift of one-eighth of an inch. This action was followed by slight water-hammer, succeeded by a loud report and a violent escape of water and steam.

The drain should have been opened a suitable amount when (*B*) was first shut, and kept eased during the whole of the isolation period. It may be remarked that had the drain been opened on completion of the repair, an equally violent water-hammer would have been brought about.

II.—Faulty operation of drainage system.—Steam was being raised in No. 1 boiler (Fig. 2), which was connected to the main steam range for "warming through" purposes. Nos. 2 and 3 boilers being at WW with their stop valves shut. The drains on the stop valves of these two latter boilers were shut, while that on No. 1 was open while steam was being raised.

The connections from the main sectional valve to the stop valves had, as is not unusual, a considerable vertical fall between these points, and thus under the conditions just described an appreciable accumulation of condensed steam must have occurred in the "dead ends" associated with the two non-steaming boilers.

It appears that leakage was observed from the cover of No. 2 stop valve and that two men ascended to the upper grating level to deal with this defect.

The first action taken seems to have been to open the drain cock on this valve, and this was sufficient to initiate water-hammer, which fractured the studs securing the cover, causing it to be blown off.

Evidence was not wanting in this case to show that the stop valves on these two boilers had been jambed off with wheel spanners, as they were thought to have been leaking: this would undoubtedly have put an additional strain upon the studs, so rendering them less able to withstand the shock of the water-hammer which was considered to be the direct cause of the accident.

The drains on the stop valves of No. 2 and 3 boilers should have been slightly open in order to prevent any accumulation of water, and this occurrence stresses the serious dangers attendant upon any attempt to drain water from a steam pipe in full communication with a boiler.

III.—Accumulation of water disturbed by causes other than opening drains or valves.—(*a*) The arrangement of the boilers and main steam connections in a certain vessel were similar to those indicated in Fig. 2.

While steam was being raised a defective tube was discovered in the port boiler, which was thereupon shut off and repairs effected.

The vessel meanwhile proceeded to sea on the remaining two boilers, while the port one was emptied and the defects were made good. The latter boiler was subsequently filled and lit up, but about one hour after fires had been started there was a sharp report followed by the noise of escaping steam. Investigation showed that the port main stop valve had cracked.

The fractured valve had been shut for only about 2½ hours prior to the accident, and during that time the stop valve drain remained closed, thus permitting water to accumulate above the valve.

Water-hammer is invariably preceded by a disturbance of the surface of water lying in a steam pipe, and ordinarily this effect is initiated by some such act as the opening of a drain or steam valve. In a steamship, however, a slight movement of the vessel may bring about the necessary disturbance and cause a most unexpected shock of water-hammer.

(*b*) The machinery of a frozen meat ship comprised four boilers, each boiler being fitted with an independent valve chest supplying steam to the refrigerating engine steam range, which is entirely distinct from all the other pipe systems. On the occasion to be described (B), (C) and (D) boilers were in use, the refrigerating plant being supplied from boiler (C).

The arrangement of the refrigerating steam range is indicated on Fig. 3, from which it will be seen that, while the connections

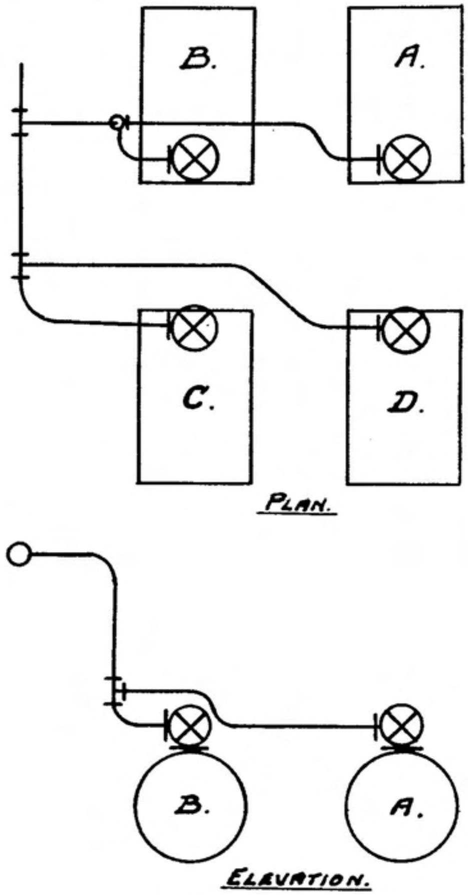

FIG. 3.

from (B), (C) and (D) boilers rise vertically to the range, there is a length of horizontal pipe in that from boiler (A). Under the condition of working in this instance it is evident that water would be likely to collect in this horizontal length; drain cocks were provided on the system, but not only were these placed too high to be effective but also they were not made use of.

At the end of a voyage of 24 days the vessel had a list of about 7° to starboard, and steps were taken to correct this by pumping water out of ballast tanks. The vessel slowly righted and when upright the ballast pump was stopped. Two or three minutes later she fell off to port by about 7° and as the vessel listed an explosion occurred at the refrigerating master valve on (A) boiler.

It is evident that the amount of water of condensation must have reached a critical condition coincident with the change of list, thus setting up water-hammer and causing fracture of the valve chest.

IV.—Connecting up ranges of steam piping that are seldom used. —The arrangement of the steam leads from the boilers to the dynamos in a certain ship are as indicated in Fig. 4, the auxiliary

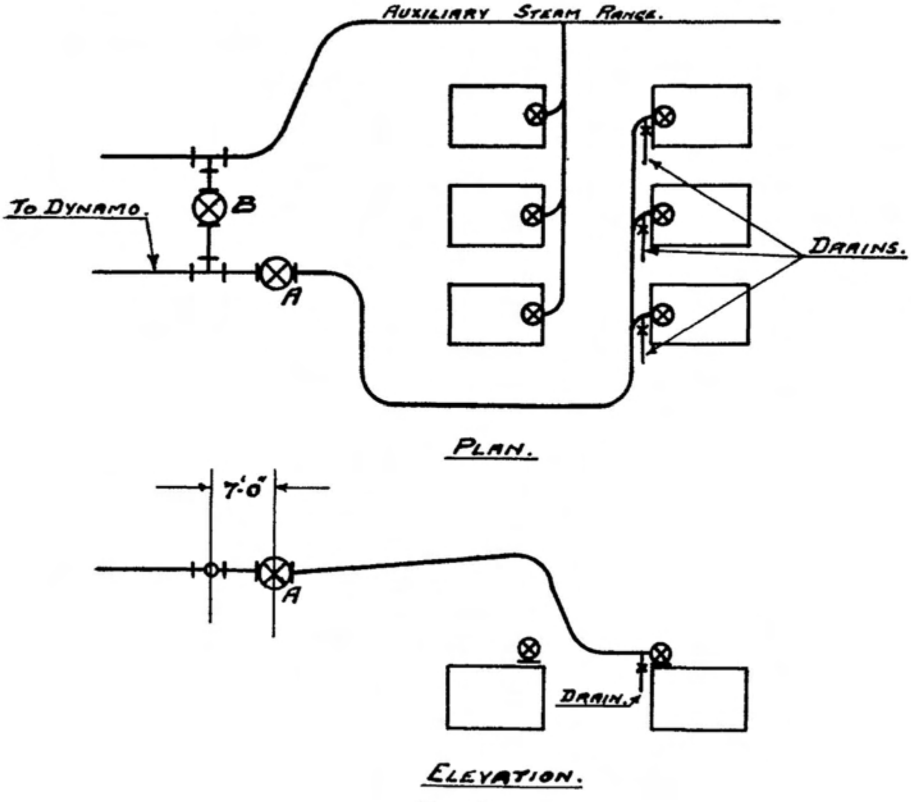

FIG. 4.

and direct dynamo steam ranges being interconnected through a pipe and the stop valve (*B*).

The necessity arose to remake a joint on the auxiliary steam range, which had therefore to be shut off for this purpose. In order to avoid stoppage of the dynamos during repairs it was decided to use the direct dynamo line, which, however, had not been in use for the previous two years.

Instructions were given that the auxiliary range should be shut off and drained: the valve (*B*) was then to be closed and steam put on the direct dynamo line, by opening valve (A), thus enabling the dynamos to be run if (B) proved to be steam tight.

The drains on the stop valves to the dynamo line were first opened on each of the three forward boilers.

After a suitable interval to permit the pipe to drain, the stop valve in connection with this range was opened about three-quarter turn on the centre forward boiler, the drain cocks on all the stop valves then being closed as steam was issuing from them. The subsequent action of easing the valve (A) was followed by violent water-hammer, whereby the neck of the valve chest was fractured and the cover blown off: it is worthy of mention that no preliminary knocking was heard nor was there any loud report when the chest fractured.

An examination of the figure showing the layout of the piping will make evident that there is a rapid inclination of the direct dynamo line immediately forward of (A), the slope being in fact too great to permit water to be cleared from behind the valve by motion of the ship at sea: it should also be noted that the only drains on this particular steam line were those fitted at the boiler stop valves.

At the time of the accident the vessel was trimmed 4 feet by the stern and thus all the lengths of piping shown as horizontal were in fact inclined aft. It may be accepted beyond doubt that water had collected in the relatively low lying portions of the range, and especially immediately before the valve (A): further, owing to the length of time that the line had been out of use, accumulations of water were extremely likely as any leak, however slight, would gradually form appreciable quantities of condensate.

When the stop valve on the boiler was eased it is evident that the full boiler pressure would rapidly be attained in the range up to (A), thus banking up the accumulated water against the valve.

The after side of valve (A) was, of course, also subject to steam pressure as the original plan of closing off (B) before opening up (A) was not adhered to: this pressure would, however, clearly be less than that in the boilers owing to the pressure drop, between the latter and the valve, necessary to maintain the flow of steam to the dynamos.

Immediately abaft (A) there is a 7 foot length of "horizontal" pipe before the branch containing (B) is reached, and thus, on opening the former valve, the accumulation of water was able to gain an appreciable momentum before it met the main stream of auxiliary steam.

This disturbance of water in pipes under steam pressure and its introduction into other similarly situated pipes, provided all the elements of water-hammer. It was deduced from the nature of the fracture, which was confined to the upper part of the valve box (*i.e.*, that part in connection with the after part of the range) that the hammer action occurred in the 7 foot length referred to, and it is probable that the water completely filled the piping forward of (A), only becoming agitated as it passed the seating. This body of comparatively cold water on meeting the steam in the auxiliary line would cause instant condensation of part of the latter. The momentum generated by the collapse of the cavities so formed would be sufficient to drive the water forward again, the force of its impact shattering the valve cover.

It is clear that, if the original plan had been adopted and steam not admitted to the direct line till the valve (B) had been shut and (A) opened, then there would have been a better chance of avoiding damage from water-hammer. Owing, however, to the lack of drainage arrangements and to the peculiar slope of the direct dynamo range it is obvious that under any conditions it would be necessary to exercise extreme caution in carrying out this operation.

CONCLUSION.

These typical accidents here described occurred in merchant ships in most cases, and resulted in considerable damage being done: it should be pointed out, however, that the valves and fittings in that service are frequently constructed of cast iron and thus are more likely to fail under shock stresses than similar fittings in H.M. Navy where cast steel or gun-metal are employed. It is by no means improbable therefore that equally serious water-hammer has been occasioned in Naval installations without any obvious damage having ensued, and thus the possible dangers of such action tend to be obscured. In this connection it should be observed that water-hammer may readily cause damage other than actual fracture, and that stretched bolts (accompanied by leaky joints) or weakened parts are frequently occasioned by these often quite unsuspected means.

The proper management of the steam system in order to avoid water-hammer is well illustrated by the examples already given, and it is sufficient to sum up briefly as follows :—

(1) Water of condensation should never be permitted to accumulate in pipes under steam pressure, as any factors tending to disturb the surface of such water may be sufficient to cause violent, and frequently most unexpected, water-hammer. The drainage arrangements on "dead ends," &c. should be kept in constant use, to prevent water from collecting.

(2) When water has been allowed to accumulate in a pipe under steam pressure, or if the presence of water is to be anticipated owing to the existence of undrained "pockets," it is a most unsafe proceeding to open drains or isolating valves unless the steam pressure is entirely shut off the portion where the water is lying. The process of drainage may be rendered less unsafe by greatly restricting the quantity of steam, which can find access to the water-logged section of piping, but, as the limit to which such

restriction must be carried in order to ensure safety is not readily determinable, it is unquestionably preferable to isolate entirely the accumulation of water from all sources of pressure before attempting to effect drainage.

(3) Cold lengths of steam pipe should preferably be put in connection with a cold boiler, in which steam should then be slowly raised, all drains on the system being kept wide open throughout the process until it is judged that the pipes are sufficiently heated to prevent condensation from occurring.

When this is not practicable, any connecting valves between hot and cold ranges should be manipulated with caution and great care taken to thoroughly drain the pipes, especially in the immediate vicinity of the cross-connection valves.

(4) Drains on ranges under boiler pressure should not be opened suddenly to their full extent except in emergency, and even then the action should be as gradual as the circumstances permit.

(5) If water-hammer is initiated it is not generally possible to stop it, but the best chance of doing so or of minimising any consequent damage lies in immediately isolating the affected part of the system from the source of steam pressure. Opening drains may serve to aggravate the trouble.

(6) The choking of drain cocks and pipes or the wrong marking of the plugs of these cocks may readily lead to accidents of this type. These points should therefore be kept under special observation.