2.

HIGH PRESSURE STEAM FOR NAVAL PURPOSES.

The period since the war has seen a slow but marked progress towards the adoption of higher steam temperatures and pressures in the boilers and engines of both shore and marine power plants. This development has arisen from the urgent need for improved economy, and, as is usually the case, has been initiated in that field where the highest efficiencies are realised with this type of prime mover, namely, in shore power stations.

The most efficient type of steam engine is the turbine, and, as this is inherently better suited to take advantage of high temperatures rather than of high pressures, progress first proceeded in the direction of superheating the steam up to the safe limits imposed by the strength of the materials available for construction.

Investigation of this latter question indicates that at the temperatures employed in advanced current practice, the decrease in strength is very great for small increases in temperature. This fact exercises a retarding effect upon this, the most favourable line of advance, and it is thus natural that progress should be sought in the direction of increasing the pressure of the steam, while maintaining the temperature at the upper limit above which it is not considered safe to go.

Economy, while of great importance, is not, however, the principal requirement for the machinery adopted in marine installations, where reliability of performance must essentially take the first place. The adoption of any new feature into the Mercantile Marine or for Naval purposes is in general, therefore, refrained from till reliable and satisfactory operation has been obtained elsewhere, and even then, owing to the divergence between the conditions of working at sea and on shore, it is not prudent to take immediate advantage of the full progress made under the latter conditions. This is particularly the case as regards the Naval service, where the varied conditions, the frequent changes of speed, and the prolonged periods of operation at reduced powers, may introduce special difficulties which must receive due consideration.

The competition of the Diesel engine has, however, forced the builders of Marine turbines to consider seriously the improved economy promised by the adoption of higher steam pressures, and the success of the installation in the " King George V." appears likely to result in an extension of this principle in the merchant service.

The considerations affecting any increase in steam pressure for Naval vessels are, however, very different from those obtaining in any other service, and it is proposed in this article to discuss the opposing factors in this connection.

The essential requirements for a prime mover suitable for a modern Naval vessel may be briefly enumerated as follows :—

Reliability and durability under all conditions of working.

Low weight per S.H.P.

Maximum possible economy, consistent with lightness : economy at low powers is a desirable feature.

Reliability as affected by steam pressure.

The stresses induced by the static steam pressure can, in general, be adjusted to any desired value by choosing suitable thicknesses for the parts affected, and this principle can be adopted throughout the steam installation except in parts of the boiler.

The boiler tubes and other parts of the heat transmission circuit are subjected not only to the direct stress due to the pressure of the steam but also to one arising from the difference in temperature between the inner and outer walls of the tube when transmitting heat : this heat stress will increase as the tubes are made thicker, and notwithstanding the lower direct stress attending the thicker tubes, there may be a nett increase in the total stress to which the material is subjected. Due consideration of this point is required when contemplating the adoption of higher steam pressures.

In a modern cruiser boiler (steam at 250 lbs. and 401° F. saturation temperature) the estimated "heat" stress at Full Power in the Fire Row tubes is of the order of 4·0 to 5·0 tons per square inch; to this must be added a direct stress of about ½ ton per square inch due to the internal steam pressure, while the total is further increased by an unknown amount owing to the bending of the tubes due to expansion; this latter factor depends upon the shapes of the tubes and the temperature variations in the nest, thus being very indeterminate. The wall temperature of the Fire Row tubes in such a boiler at Full Power is probably about 500°F., under which condition the elastic limit of boiler steel is about 8 to 9 tons per square inch, giving a factor of safety of about 2·0.

If the boiler pressure is increased to (say) 500 lbs., temperature of saturation 470°F., the direct stress will be doubled, while the heat stress will probably remain sensibly unaltered. On the other hand, the temperature of the tube wall will be increased by at least 70°F. (probably more) with an attendant fall in the elastic limit. The nett effect will be thus in the direction of reducing the factor of safety, which even under present conditions is none too great, as is shown by the failures which occur when circumstances combine to raise the temperature of the tube walls by even slight amounts.

An approximate analysis of the stresses in boiler tubes (of given thickness) with advancing pressure has been given by

Mellanby and Kerr*, but the premises upon which their conclusions are based are somewhat debatable, and their figures should be taken as giving a mere indication of the general trend of circumstances attending a rise in pressure.

Reports of the operation of a 1,300 lbs. plant in U.S.A. indicate that the tube material has been affected by the conditions of working, as both the U.T.S. and the Elastic Limit have been appreciably reduced in the course of 5,000 hours' use.

This news is on the face of it disquieting, and confirms the view that boiler parts should not be designed on the strength of the material at normal temperatures. It is, however, too early to express any definite opinion upon this subject, as reports from other high pressure stations have been so far satisfactory.

The maximum steam temperatures that can be employed are limited by the strength of the materials used, and from this point of view the adoption of higher steam pressures introduces no new problem, as the safe limit of temperature with the present materials is above the saturation temperature at any probable steam pressure.

The reliability of the plant will, however, be adversely affected by the high pressure conditions if the feed supply is not exceptionally pure. In a low pressure plant the margin of safety of the tubes from the point of view of temperature stresses is considerable, and thus any additional "temperature head" due to scaling of the surfaces can be accommodated. The position may be far otherwise in a high pressure plant, where a very thin scale may cause failure, and trouble has been experienced from this cause in the 1,300 lbs. installation referred to above, the circumstances forming an illuminating exposition of the effect of scale upon the heating surfaces.

The station is provided with boilers working at 300 lbs., in addition to the 1,300 lbs. plant, the latter boilers being fed with condensate derived from the former which take their feed supply from a lake. The low pressure boilers have never given trouble either from scale or corrosion, despite the fact that they operate on an open-feed system without deærators.

The tubes of the H.P. plant, however, began to fail after about 800 hours' running, when it was found that the tubes were coated uniformly with a scale, about 1/32″ thick except at positions where failure occurred. The damage in all cases took the form of bulges, about ½″ deep by 1½″ diameter, these being completely filled with scale except for a fine hole at the tip of the bulge.

It appears evident that the formation of the scale promoted local overheating of the tubes, followed by softening of the material and bulging of the wall: the bulge rapidly filled with scale, thus increasing the action which soon led to puncture of the material.

It is interesting to note that in all these failures, totalling about 50, the damage was confined to these small punctures

* Paper before Institution of Mechanical Engineers, 21.1.27.

which, however, did not extend: in some cases three or four bulges co-existed in the same tube without causing it to split. The boiler was steamed for two weeks with active defects of this nature, operation proving to be quite safe: the leakage from each puncture was estimated as about 1/10 per cent. of the total output of the boiler, and appears to have caused a sufficient circulation to prevent further local overheating.

The scale was eventually traced to unsuspected condenser leakage, which was, however, insufficient to cause any similar trouble in the low pressure boilers. The defects due to scaling ceased after the condensers had been made tight and the boiler thoroughly cleansed, but were followed by failure due to rapid corrosive pitting of the tubes, an action which ensued immediately the protection afforded by the scale had been removed. This second defect was finally cured by cutting down the oxygen in the feed water to less than 1/10 cc. per litre and by ensuring alkalinity of the feed.

These defects indicate that in high pressure boilers the thickness of scale that can be safely permitted is much less than in normal plants, while corrosion appears to be somewhat accelerated by the higher temperatures. The experience obtained with this particular plant shows, however, that, despite the more exacting requirements imposed upon the boiler materials, operation at high pressures is a practicable proposition, and this is borne out in other installations of a similar nature. It should, however, be noted that higher pressures necessarily lead to a lesser margin of safety unless materials of better quality are used.

It is also of interest to note that in the plant referred to, priming was conspicuous by its absence, while only a small variation in water level occurred when the fuel supply was suddenly cut off at full power ; it is suggested that the cause of this may be ascribed to the small size of the steam bubbles at such high pressures; this feature is very desirable in Naval boilers, and may prove to be an unsuspected advantage of operation at high pressure.

The turbines will in general be but little affected by an increase in the initial steam pressure, since the effect of this is confined to the initial stages, and designers will be concerned principally with the necessity for developing external glands capable of withstanding the conditions. It is probable that such glands will be of the labyrinth type, as carbon packing does not appear to withstand satisfactorily the high temperatures obtaining at the inlet ends of modern turbines.

The impulse type would appear to be well-suited for the H.P. ends of such turbines, especially in view of the small specific volume of the steam at high pressures and the low blade heights thereby necessitated in turbines operating with full admission. In reaction turbines, excessive leakage losses are to be anticipated unless very fine clearances are employed: these may lead to practical difficulties in marine turbines which may be subjected

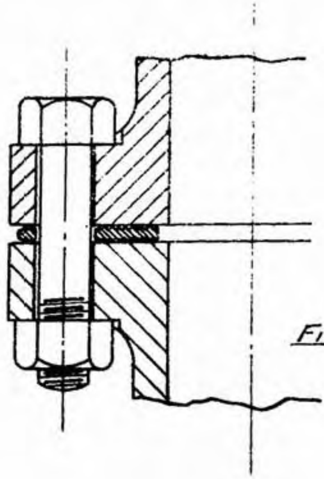

FIGURE 1.

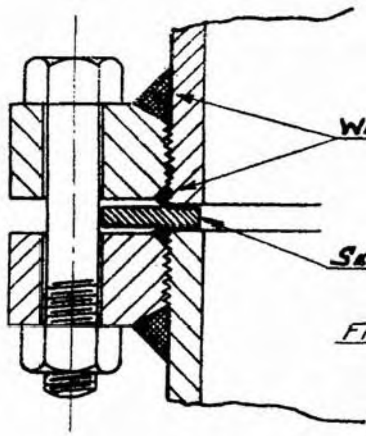

FIGURE 2.

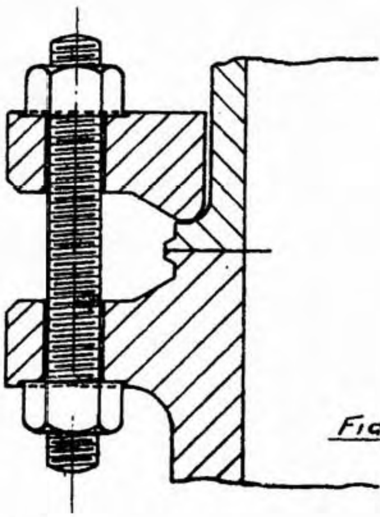

FIGURE 3.

P1758.[A]

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to rapid fluctuations in output, with corresponding variations in the temperature of the different parts of the turbine.

It appears probable for these reasons that, for Naval purposes at least, turbines operating at ultra-high pressures will comprise an H.P. turbine of the impulse type, followed by reaction blading in the remaining unit or units.

One other effect of high pressure may possibly influence the reliability of the main turbines, namely, the increased wetness of the steam at exhaust, consequent upon commencing the expansion from a high pressure, but at the same initial temperature; this may cause marked erosion of the blades at the exit end of the turbine. This effect can only be avoided by increasing the initial temperature concurrently with the pressure, but this is not practicable in cases where the safe limit of temperature has been reached at the lower pressure: the increase in wetness is, however, not marked except where very considerable advances in steam pressure have been made, and, as far as is known, no considerable defects have yet arisen in practice from this cause.

These remarks apply equally to all the turbines, whether main or auxiliary, and it may be said with some confidence that no reduction in the reliability of these units is to be anticipated on account of a moderate increase of the initial steam pressure.

Joints and Glands.—Improvements are undoubtedly required regarding the design of steam pipe joints and glands, some of the modern arrangements suitable for extra high pressures being illustrated in Figs. 1, 2 and 3. Developments are taking place in power station practice in the direction of obtaining satisfactory joints by means of welding, but there appears little prospect of such heroic measures being adopted in marine work in the near future, especially in view of the vibration and the unknown racking strains thrown upon the joints in the latter type of installation.

The modern tendency as regards making provision for the expansion of the steam pipes is to provide these with suitable bends, either plain or corrugated, thus avoiding the troubles which have arisen with long expansion glands in lightly-built vessels. Expansion glands can be made satisfactory with high steam pressures and temperatures, provided that the alignment of the parts can be preserved under all conditions of working, but this requirement is very difficult of realisation in a ship and more particularly so in modern Naval vessels where weight restrictions have resulted in a form of construction of extreme lightness.

Condensers.—The experience, already cited, with a 1,300 lbs. plant serves to stress the extreme importance of tightness of the condensers when pressures of this order are employed.

It is evident, therefore, that possible increases in the steam pressure will still further stimulate the search for the production of either new materials for the condenser tubes or of reliable means for protecting the existing materials against corrosion.

General.—Any reciprocating steam auxiliaries that are required to work with the full boiler pressure will no doubt need special attention as regards the design of the slide valves.

The jointing of boiler gauge glasses is another minor but important point that requires consideration, while the operation of safety valves has presented some difficulties which it is believed have been successfully overcome.

The reliability of the remaining parts of the machinery installation is not, however, likely to be affected by increases in the working steam pressure, provided, of course, that the margins of safety adopted in current practice are not deliberately or inadvertently reduced.

Effect on Economy.

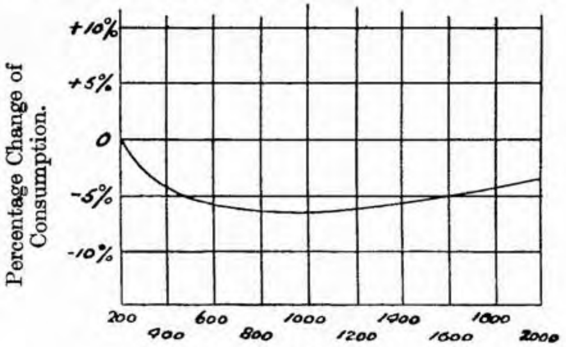
Boiler.—The efficiency of the boiler will be somewhat reduced both on account of the smaller difference in temperature between the water and the gases, and also because the latter will leave the boiler at a somewhat higher temperature. The loss due to the second of these factors may be recovered by the provision of additional economiser and air pre-heater surfaces, but, owing to weight restrictions, this is not usually possible in Naval installations, for which the development of a light type of pre-heater is an evident need if such decreases in boiler efficiency are to be avoided.

Turbines.—The theoretical improvement in turbine efficiency to be anticipated in consequence of an enhanced initial pressure has been indicated in a previous article in these Papers (No. VII, p. 96), and from this it will be seen that the gain is a decreasing one, becoming inappreciable at pressures of the order of 1,200 lbs. It has already been pointed out that the general effect of high pressure on turbine design is to reduce the blade heights at the initial end of the H.P. unit: this may be avoided if the number of stages are increased and their mean diameters reduced, but this cannot be adopted to any great extent in Naval practice, as it involves additional weight and length for the main engines.

Practical experience shows that very short blades and nozzles are less efficient than longer ones, while in reaction turbines the percentage leakage loss increases as the blades are made shorter.

On account of the foregoing, and also because of leakage losses through the external glands, the theoretical improvement will not be realised in practice as the initial pressure is increased. Fig. 4 indicates the probable variation in steam consumption which may be expected with increase of pressure, and from this it will be evident that little practical gain is to be anticipated from initial pressures exceeding about 500 lbs. per square inch.

Auxiliaries.—The reduction in the steam consumption of the turbines should be attended by some decrease in that of all the auxiliary machinery, provided that it is found practicable to use the high pressures to full advantage in these units; a proviso which is, however, likely to prove one of the principal difficulties in connection with the economical use of very high pressure steam in Naval vessels, and will be discussed shortly.



Press. in Lbs./0- 9″.

FIG 4.

The gain from this source may be discounted, however, by the additional power required for the feed pumps in order to overcome the high boiler pressure, and thus, on balance, the total steam requirement for the auxiliaries does not appear likely to be sensibly affected by the change in steam pressure.

Leakage and Radiation Losses.—The leakage losses in the steam pipes and glands will in the nature of things tend to increase owing to the low specific volume of the steam and to the greater difficulty of obtaining steam tightness of the system. The loss of heat due to radiation from the heated surfaces of the boiler must be expected to be somewhat larger than with saturated steam installations as the temperatures of the water and of the funnel gases will be higher; the radiation loss from the steam pipes will, however, be but little charged, as the maximum steam temperature will be the same in both high and in low pressure installations; this factor may even be somewhat reduced in H.P. installations owing to the lesser surface exposed by the smaller steam pipes.

Weight and Space.

The weight and space required for the machinery installations in a Naval vessel is, of course, of great importance, especially in those types where the maximum tonnage is limited by the Articles of the Washington Treaty. The clauses of this covenant include a definition of those factors which are to be taken into account when assessing the displacement of a given ship, and it is to be noted that these do not include the weight of fuel. This agreement tends therefore to penalise economy, since improvements in this respect are in general attended by some increase in machinery weight, which under these terms cannot be compensated for by a reduction in the amount of fuel carried. It becomes a matter of some difficulty to decide in these circumstances how much extra machinery weight can be accepted in the cause of economy, and the decision must be made in the light of the probable services of the vessel under consideration. In the cases of ships designed for ocean warfare and for operation at long distances from their bases, it is evident that economy in fuel becomes of some considerable importance, whereas, on the other hand, in circumstances where endurance is of lesser importance, lighter machinery can be obtained by some sacrifice of economy.

The weight of the machinery is influenced also by the requirements as regards the reliability and the length of life of the various parts, since these affect the factors of safety ultimately adopted : the class of vessel and its relative military value also has a bearing upon this matter, as it is obviously logical to accept a reduced life and lesser reliability in the case of the least valuable ships.

The weight of an installation depends principally, other things being equal, upon the total consumption of steam at the designed full power, and any reductions in the steam requirements that can be made without the addition of extra machinery will in general be attended by some improvement in the weight per horse power.

The present situation in regard to this important question of weight is that the factors of safety have been decreased to the limit which experience has shown to be acceptable with the present materials of construction, and thus, while improvements in metallurgy and the gradual increase of knowledge will no doubt enable a slow but perceptible advance to be made, it is evidently necessary to consider whether any other avenues exist through which progress may be rendered possible. One such avenue is offered by the adoption of higher steam pressures, since that development promises a reduction in the steam consumption of the main engines without any corresponding additions to the number of units in the machinery installation; it remains therefore to consider to what extent this hope may be realised in practice.

Boilers.—The thicknesses of the pressure parts of the boilers will, of necessity, require to be increased if the steam pressure is raised, although for reasons already touched upon it is neither necessary nor desirable to add to the thickness of the boiler tubes, which aggregate some 30 per cent. of the weight of the unit. The thicknesses of the steam drum tube plates and of all the wrapper plates must, of course, be increased in proportion to the rise of steam pressure, but, as it is necessary in all boilers of the Yarrow type to provide very thick tube plates in the water drum in order to obtain sufficient rolling surface for the tubes, from the point of view of stress the scantlings of these parts need not be increased for pressures up to 450 lbs. : these fortunate circumstances have an appreciable effect in reducing the increase in weight which is unavoidably associated with a rise of boiler pressure. The reduced steam consumption of the main turbines, on the other hand, enables a smaller heating surface to be provided for the boilers, and it is estimated that these opposing factors will approximately cancel each other, with the result that the weights of the boilers for a given horse power will be substantially the same for all steam pressures up to the limit referred to in the preceding sentence: at pressures in excess of, say, 500 lbs., it becomes necessary to increase the thickness of the water pocket tube plate, with corresponding additions to the weight of the boiler.

There is an increasing tendency in modern high pressure boilers to abandon the use of riveted joints, constructing the drums without joints. Modern resources have made a practical success of this difficult method of construction and it has been found possible to build drums without any joint whatever, even the end plates being formed in one with the main body of the drum: the method of construction is expensive, but the cost may be reduced somewhat if one of the boiler ends is attached by riveting. Riveted joints under high pressures become somewhat doubtful for very thick plates, and at least one well-known firm advises the use of "solid" drums in all cases where the steam pressure exceeds 500 lbs. Drums constructed in this fashion can be made lighter than the normal type, since not only are the butt straps avoided but also some reduction can be made in the thickness of the wrapper plates, a dimension which is considerably influenced by the efficiency of the joint. Solid drums thus not only avoid difficulties with the joints but also result in a saving in weight, and it is evident that, for these reasons, this type of construction is likely to find a place in Naval boilers working at high pressures.

Turbines.—The anticipated improvement in the steam consumption of the turbines can only be realised if these units are suitably designed to make use of the additional heat provided in each pound of steam, and this necessitates in general an increase in the number of stages. The maximum diameter of the turbine rotor can, however, be somewhat reduced on account of the smaller volume of the steam at exhaust as compared with the case of a turbine expanding the steam from a lower initial pressure to the same exhaust pressure. The combined effect of these two factors will be in the direction of increased weight, but the increment may not be large. Considerations of efficiency tend towards the adoption of small H.P. turbines geared to I.P. and L.P. units which are themselves geared to the propeller shafts: such an arrangement not only improves the efficiency of the H.P. turbine by enabling longer blades to be used, but also has the desirable effect of confining the high pressure and high temperature steam within a casing of very small diameter. This sub-division into three units does not add appreciably to the weight of the turbines, while the adoption of the separately geared H.P. turbine should in general result in a saving in the overall length of the set, as compared with one in which this unit is directly driven from the I.P. or L.P. shaft.

Some reduction in weight is to be anticipated if the H.P. turbine is geared directly to the main gear wheel instead of to the I.P. or L.P. rotor shafts as suggested above; this, however, means some reduction in the revolutions of the H.P., which thus becomes a comparatively large unit; the arrangement also entails an increase in the weight, length and, more important still, in the number of joints of the steam connections to the turbines.

It will be evident that in arrangements of small high speed turbines the reduction gearing forms an appreciable proportion of the total weight of the main power units. The length of the gear face depends upon the horse power of the largest turbine connected with it, and thus, if the total power can be distributed among more than two pinions, the length and weight of the gearing can be cut down at the cost of some additional weight in respect of the turbines themselves due to the sub-division of the power among a larger number of units. On balance, however, such an arrangement should lead to economy in weight provided that the requirements for the gearing under astern conditions do not determine an unduly high limit to the length of the gearing. There is, however, one disadvantage in increasing the number of turbines in each set, namely, that the number of external glands, and therefore the leakage loss, is increased thereby: this drawback may, however, be overcome by making arrangements to collect and condense the steam leaking from the glands.

Condensers and Auxiliaries.—The dimensions and weight of the main condensers can, of course, be reduced proportionately to the saving in steam consumption, while similar economies may be effected as regards the circulating and water extraction pumps.

The scantlings of the water end of the feed pump must, on the other hand, be increased, as must also be the dimensions of the driving end of this unit, the nett effect being an addition of weight.

The weight of the auxiliary engines and of the associated steam and exhaust piping depends largely upon the steam pressure at which they are designed to work and the type of prime mover decided upon. In the latest vessels turbo driven auxiliaries are used to the fullest possible extent, not only on account of the economy in weight and space thereby attained and of their freedom from vibration, but also with a view to simplifying the arrangements of steam pipes, as reciprocating machinery cannot be worked with highly superheated steam and therefore necessitates the provision of additional leads of piping.

The turbines driving the auxiliary engines are but small units, and are unavoidably somewhat extravagant as regards their steam requirements if their weights are to be kept within reasonable limits. These units will be required to make use of a greater adiabatic heat drop if the initial pressure is raised (without a corresponding elevation of the exhaust pressure) and in order to effect this without decreased turbine efficiency it becomes necessary either to fit more stages or to raise the peripheral speed of the rotor. The former of these alternatives will of course result in additional weight, but some latitude exists as regards the latter although this may entail running the rotors through their first critical speeds, a mode of operation which is to be avoided. Suitable designs can possibly be developed to avoid this effect by employing rotor shafts of large diameter, but this is objectionable as it is likely to lead to troubles with the glands. It must be appreciated of course that the actual steam consumption of these small H.P. auxiliaries may not be greater than that of their low pressure counterparts, for, although their efficiency will in general be lower, the additional heat available in each pound of steam may be sufficient to override this factor. It is to be anticipated, however, that for a given weight of unit per horse-power, the high pressure auxiliary will require somewhat more steam.

The possible alternatives are to group the auxiliaries together, driving each group by a turbine of moderately large output, to arrange for all to be electrically driven or, finally, to provide a low pressure steam range for auxiliary purposes.

The disadvantages of the first of these alternatives lie in the difficulties of providing separate control of the individual units, and the necessity for changing over a whole group when defects arise in one component. The provision of electrically driven auxiliaries, while leading to but little additional weight, is desirable only from the point of view of economy, and is quite unacceptable for direct or gear-driven Naval vessels, as it introduces another vital link in the chain of transmission, thus being unsound in principle. In vessels where electrical " gearing " forms part of the main line between turbines and propellers, the foregoing principle is already violated and the objection against electrically driven auxiliaries can no longer be sustained. Modern electric motors should be entirely reliable under all conditions, and can be made water-tight, while the early difficulties as regards speed control have been largely surmounted; thus electrically driven auxiliaries have been adopted in the latest Naval vessels for all services except those of feeding the boilers and driving the forced draught fans, but this provision is additional to the full complement of steam driven units required to serve the main engines under action conditions.

It is evident, of course, that electrical auxiliaries only become an economic proposition after full provision has been made for feed heating by exhaust steam or by steam bled from the turbines. For this reason it may pay to run sufficient steam driven auxiliaries to heat the feed to a temperature nearly approaching that of the auxiliary exhaust, and to drive the remainder by electric motors.

The final alternative referred to above, namely, the provision of a low pressure auxiliary range, is not only open to the objection of additional weight but will also entail the development of a satisfactory reducing valve, in default of which the pressure in the auxiliary steam system would require to be adjusted by hand or possibly by some arrangement of spring controlled relief valves.

It appears probable, on consideration of the various factors just mentioned, that the auxiliary engines in high pressure installations will be driven by turbines supplied with boiler steam, and that a compromise will be necessary to strike a balance between weight and efficiency, taking the following points into consideration. The quantity of exhaust steam from these units may be somewhat in excess of that usual in current Naval practice, and furthermore this steam may also be in a superheated condition, introducing some possible difficulties as regards the material of the feed heaters if the exhaust is disposed of through that avenue: if, on the other hand, part of the exhaust steam is passed to a suitable stage in the main turbines, there is likely to be a reduction in economy as compared with the present low pressure systems where the whole of the auxiliary exhaust can usually be utilised for feed heating.

The designer is thus faced with the alternative problems of either increasing the efficiency of the auxiliary turbines to such an extent that their steam consumption remains unaltered despite the increase in pressure, or of providing sufficient surface in the feed heaters to condense the extra exhaust steam consequent upon the use of comparatively inefficient units: the extent to which this latter course can be adopted depends upon the temperature of the exhaust steam. Either of these alternatives involves additional weight, which may in practice appreciably affect the case to be made for the employment of these high pressures.

Piping.—The weight of the steam piping depends upon the thickness and diameter: of these the former will vary directly as the steam pressure, while the latter will depend upon the quantity and the specific volume of the steam. An increase in steam pressure will thus necessitate thicker steam pipes, which may, however, be of appreciably reduced diameter, while the scantlings of the flanges will also necessarily be increased: the net effect of these modifications as regards pressures of the order of 400–500 lbs. is likely to be largely self-compensatory and no great change in the weight of the main steam pipes is to be anticipated. It may be remarked in passing that for a given loss of energy in the steam pipes, due to the resistances to flow, there will be a greater absolute drop in pressure in the case of high pressure installations than is experienced in current practice: this follows from the properties of steam, and the mere fact that a pressure drop of, say, 70 lbs., is noted in a system working at 500 lbs. does not imply that the steam pipes are unduly small.

The situation as regards the weight of the exhaust pipes, is, however, less easily predicted, since it depends upon the exhaust pressure finally adopted and this in turn is influenced by the efficiency of the auxiliary turbines and by the size of the feed heaters provided: some increase in weight is, however, to be anticipated in this regard.

CONCLUSION.

Preliminary investigations on the lines indicated in this paper show that some improvement in fuel economy is obtainable with a moderate increase in steam pressure, the weight of the machinery per S.H.P. being approximately the same as in current practice, and it remains to be proved by experience whether the extra cost of the installation and any practical disadvantages, which may arise on account of the higher pressures, are adequately compensated for by the increased radius of action.

The problems involved in the design of the joints and glands of the steam system, in obtaining reasonable life and reliability for the boilers and turbines and in deciding upon the most profitable means of disposing of the auxiliary exhaust steam, can of course only be determined by practical experiments extending over a considerable period. It is not possible, therefore, to make any more definite statement regarding the future prospects of high pressure steam than that included in the above, but it is at least evident that any further advances of the purely steam driven plant are likely to come through increases in the initial temperature and pressure of the working fluid to the fullest extent allowed by the strength of the existing material of construction.