24th March, 1892.

A REVIEW OF MARINE ENGINEERING DURING THE PAST DECADE

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The Institution has previously had two papers dealing with the progress of Marine Engineering—that by Sir Frederick Bramwell, read at the meeting in this city in 1872; and that by Mr. Francis C. Marshall in 1881. The writer purposes now to review briefly the progress from the latter date until the present time.

The results of Mr. Marshall's investigations were that the type of engine then employed was the two-stage expansion compound; and from a series of examples of performances of such engines, he found that in long sea voyages on the average the boiler pressure was 77·4 lbs. per square inch, the piston speed 467 feet per minute, the heating surface per indicated horse-power 3·917 square feet, and the consumption of coal per indicated horse-power 1·828 lbs. per hour. No mention was made by him of the three-stage expansion engine, although at that time at least two had been constructed, and had worked successfully for seven years. These were the engines of the "Propontis," with cylinders 23 inches 41¼ inches, and 62⅓ inches diameter, by 42 inches stroke, constructed by Messrs. John Elder and Co., to the designs of Mr. A. C. Kirk; and those of the "Sexta," constructed at the Ouseburn Engine Works, Newcastle-on-Tyne, to the specification of Mr A. C.

(This Paper was read at the July, 1891, Meeting of the Institute of Mechanical Engineers, and is reprinted from the July Volume of Proceedings, by permission of the Author and Council of that Institution.—*Editor.*)

Franklin, then of London, with cylinders of 11 inches, 17 inches, and 24 inches diameter, by 18 inches stroke, as illustrated in Figs. 1 and 2, Plate VII. Both of these engines were commenced in 1873, and tried in 1874, and were of the three-crank type usually built now.

Since 1881 the three-stage expansion engine has become the rule, and the boiler pressure has been increased to 160 lbs. and even as high as 200 lbs. per square inch. Four-stage expansion engines of various forms have also been adopted; and many changes have been made in other respects, necessitated by increased pressure or by desire for increased economy or power. In dealing with the changes made during the last ten years, it will be best to commence with the furnace and proceed from the boiler to the engine.

Forced Draught.—Ten years ago the principle known as forced draught, so far as marine engineering in this country was concerned, had been practically confined to torpedo vessels, and the writer believes to three cruisers, each of about 2,850 horse-power, though it had long been employed in steamers on American waters. Since then it has become the rule in all vessels for naval service, and comparatively common in both passenger and cargo vessels. By this means it is possible considerably to augment the power obtained from a given boiler; and, so long as it is kept within certain limits, it need result in no injury to the boiler, but when pushed too far the increase is sometimes purchased at considerable cost.

There are several methods by which the principle may be practically applied. In the earlier cases in this country closed stoke-holds were adopted, the air being delivered into them by fans at a pressure varying from about 1 inch to 3 inches of water. This arrangement certainly has the merit of keeping the stoke-holds cool, and its details are simple; but it is dirty, and where bunker doors are not well fitted, great discomfort may be caused on deck. Possibly also it is not quite so economical as the closed ashpit system; but such exact data as exist of its working indicate that with moderate air-pressure it is at least no less economical than natural draught. In America it was customary to close in the ashpits, and take the delivery tubes from the fans into them. This, though involving more ashpit fittings, is certainly advantageous so far as cleanliness is concerned; the furnaces are also not subjected to the severe strains caused by the inrush of cold air which occurs during firing with closed stoke-holds. As often fitted it has the disadvantage of making rather a hot stoke-hold, though with sufficient precautions there is no reason why the ventilation should not be made perfect by taking the air through the stoke-holds. In the earlier American experiments (*see* Isherwood's Experimental Researches, vol. 2, trials of gunboats of "Chippewa" class, and "Fulton") the air was introduced into the ashpits by pipes at their back ends.

The principle of forced draught has also been carried out by placing a fan in the uptake, and exhausting through the furnaces. This plan has the great advantage of dispensing with the elaborate furnace fittings common to the undergrate systems; and according to the researches of Dr. Tyndall on combustion in condensed and attenuated atmospheres, it should result in a more perfect combustion, but how far this is realized in practice has not come within the writer's experience.

In regard to the economy of forced draught, an examination of Table 5 (appended) will show that while the mean consumption of coal in those steamers working under natural draught is 1·573 lbs. per indicated horse-power, it is only 1·336 lbs. in those fitted with forced draught. This is equivalent to an economy of 15 per cent. Part of this economy however may be due to the other heat-saving appliances with which the latter steamers are fitted. But independently of the economy of forced draught in coal relatively to power, it is like all economies in marine engineering, simply a question of the comparative cost of carrying a given freight at a given speed: in other words, it is a question of the total expenses of carrying the freight with the help of forced draught, as against the total expenses with natural draught. It is not a mere matter of coal consumption, which is only one of the elements that go to make up the total. Assuming indeed that the consumption of coal per horse-power is not less with forced than with natural draught, then, since with forced draught it is possible to develop a given power from a smaller boiler, and consequently with a smaller weight than with natural draught, here is at once a source of economy, because the difference in weight may be made up in freight. Such evidence as exists shows that not only is forced draught more economical as regards quantity of coal, but by its means such classes of coal may be used as would not without it be worth putting on board. It is in this direction, perhaps, that the greatest saving has followed its employment.

Thus far the following would appear to be a fair summary of the advantageous points attending the use of forced draught. First, it seems fairly well established that, if the boilers are well constructed and are provided with ample room to ensure circulation, their steaming power may without injury be increased to about 30 or 40 per cent. over that obtained on natural draught for continuous working, and may be about doubled for short runs. Secondly, such augmentation is accompanied in normal cases by an increased consumption per indicated horse-power. But, thirdly, the same or even greater power being indicated, it may with moderate assistance of forced draught be developed with a smaller expenditure of fuel, the grates, &c., being properly proportioned. Fourthly, forced draught enables an inferior fuel to be used. And, fifthly, under certain conditions of weather, when with normal proportions of boiler it would be impossible to maintain steam for the ordinary speed with natural draught, the normal power may with forced draught be ensured. In particular cases any or all of these advantages may be a source of economy; and the first of them may render possible that which would otherwise be impracticable.

As now adopted in the navy, forced draught is purely an auxiliary intended for use under special circumstances. When a maximum power and speed are required only occasionally, or when the vessel is intended for cruising in hot climates, or under such conditions of weather as to impair the natural draught power, in such cases it is a most important source of economy. Vessels of the cruiser type, which are required in case of necessity to develop say over 9,000 horse-power, while the usual cruising speed of about 10 to 12 knots requires only from 1,000 to 1,500 horse-power, are rendered possible at a reasonable cost by the adoption of forced draught. The recent troubles with naval machinery in vessels of the "Barracouta" class have done much to unsettle opinions in regard to this problem. But looked at calmly it becomes evident that the causes of those troubles are altogether apart from the question of forced draught pure and simple, and are rather questions of boiler design. So long as boilers were designed with ample spaces for internal circulation, ample capacity of furnace and combustion chamber, and so proportioned that the surfaces of the furnaces and combustion chambers were sufficient to absorb a large proportion of the heat before the products of combustion reached the tubes, and above all so that the tube plates were protected from direct impact of the intense radiant heat from the incandescent mass of the fire, no serious trouble ensued. In the recent cruisers built under the Naval Defence Act of 1889, a separate combustion-chamber to each furnace has been adopted with perfect success.

Boiler.—It is impossible to chronicle much change in the form of the marine boiler as designed for ordinary service; but both Messrs. Thornycroft and Messrs. Yarrow have given their attention to water-tube boilers, with the object of lightening weights and so rendering higher speeds attainable in small vessels. These boilers doubtless have the merit of lightness; but unless there are never less than two in one ship, so arranged that one boiler can readily be shut off, they can be of little use in ordinary service, as the failure of one tube is the failure of the whole boiler of which it is a part; whereas in an ordinary boiler a tube may give out, and cause no more trouble than that involved in inserting a stopper. If however tubulous boilers were used in numbers and separable, they might be made serviceable for the mercantile marine, and might give the shipowner a few more tons dead weight, and so make remunerative what might otherwise be a loss. One of the great advantages, however, of boilers of this type, namely the small weight of water they carry, is attended by what might prove a serious drawback, inasmuch as they have to be fed and worked with greater care; whereas the large cylindrical boiler, which contains a large reserve of water, will admit of a little irregularity. But to set against this, there is the probability that the damage might not be so serious in the water-tube boiler, if the water were allowed to become low. Moreover, by the use of slow working independent feed-pumps there is no reason why this possible source of trouble should not be overcome.

Though no particular change can be recorded in the general design of the marine boiler, the change of material used, and the great advance which has taken place in the application of tools to boiler-making, cannot pass without notice. As a material for boilers, iron is now a thing of the past, though it seems probable that it will continue yet awhile to be the material for tubes. Steel making has moved on apace, so that now plates can be procured of 132 square feet superficial area and 1½ inch thick. Mechanical appliances have been greatly improved. All flanging, tapping, tubing and staying, and in some works practically all riveting, are the work of machines; and a practical caulking machine seems not quite an improbability. On the other hand, for purely boiler work, a punching machine has happily become obsolete in marine engine works. In view of these facts, and of the ever-increasing knowledge of the structure, the Board of Trade and

Lloyd's have relaxed some of the rules by which manufacturers were "guided," if not perhaps somewhat hampered; and have made considerable modifications in their scantlings. It is questionable, however, whether these bodies might not with safety still further modify their rules, and reduce the thickness of shells, and lower the tests relatively to working pressures. For some years past boilers have been built for the Royal Navy with shells 18 per cent. thinner than required by the Board of Trade and Lloyd's rules, and the test pressure, instead of being double the working pressure, is only 90 lbs. above it; and these boilers have proved perfectly satisfactory in respect of strength. While 18 per cent. lighter, it must not be supposed, in the case of thick plates at least, that they are weak in proportion; because the difficulties of manufacture and probabilities of defects in the plates increase so rapidly with thickness, that it is doubtful whether the difference of weight represents with any degree of approximation the difference of strength. This appears to be the view of the Board of Trade, whose rules require all heavy plates to be subjected to special tests. This subject was introduced by Mr. Richard Sennett at a meeting of the Institution of Naval Architects in 1888; and Mr. John Scott, of Greenock, liberally taking action in the matter, subjected to hydraulic pressure a boiler shell built to Admiralty requirements, with the result that he proved with sufficient clearness that the elastic strength of the structure was capable of standing at least double the working pressure for which the boiler was designed. Without further discussing this question at the present, it appears to the writer that the time has arrived when the Board of Trade and Lloyd's should reconsider their rules in these respects.

The increased pressures of steam have also caused attention to be directed to the furnace; and have led to the adoption of various artifices in the shape of corrugated, ribbed, and spiral flues, with the object of giving increased strength against collapse, without abnormally increasing the thickness of the plate. As is well known, a thick furnace-plate is viewed by many engineers with great suspicion; and, meanwhile, the advisers of the Board of Trade, perhaps with great wisdom, have fixed the limit of thickness for furnace-plates at $\frac{5}{8}$ inch; but whether this limitation will stand in the light of prolonged experience remains to be seen. It is a fact generally accepted that the conditions of the surfaces of a plate are far greater factors in its resistance to the transmission of heat than either the material or its thickness. In 1878 the writer made a number of experiments on the transmission of heat through brass and iron boiler-tubes, the results of which went to show that just so long as the surfaces were perfectly clean, the brass tubes were considerably more effective; but immediately they were reduced to the ordinary working condition of boiler-tubes there was no appreciable difference in their efficiency. In 1867 Isherwood tried experiments with plates of $\frac{1}{8}$ inch, $\frac{1}{4}$ inch, and $\frac{3}{8}$ inch thickness; and he found that the thickness made no difference in the result, so far as he was able to detect. From the measured rate of the transmission of heat through thin plates and along bars of metal, it has been estimated that the resistances of the surfaces when fairly clean are about $97\frac{1}{2}$ per cent. of the whole for a $\frac{1}{2}$ inch steel or iron plate: so that, granted a plate free from lamination, thickness being a mere secondary element, it would thus appear that a furnace plate might be increased from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch thickness without increasing its resistance more than $1\frac{1}{4}$ per cent. So convinced have some engineers become of the soundness of this view, that they have adopted flues $\frac{3}{4}$ inch thick. Amongst those who have had the courage to take this step is Mr. Alexander Taylor, of Newcastle-on-Tyne, who reports that after five years' work such flues have given unqualified satisfaction.

In the matter of mere size, there has not been much increase over boilers made many years ago; on the contrary, the increased pressures adopted have tended to cause a reduction in size. It is questionable whether such large boilers as those of the "Wyoming" and "Wisconsin," of 16½ feet diameter and 23 feet length, will ever again be produced. On the other hand, as the higher pressures have caused thicker scantlings, the larger boilers have become very heavy. The boilers of the R.M.S. "Empress of India," which were 16 ft. 3 ins. diameter by 19 ft. 6 ins. long, weighed 85 tons each, without furnace fittings or mountings of any description.

Engine.—The change from the principle of two-stage expansion to that of three and of four stages has been attended with corresponding modifications in the engine. Though the first two of the three-stage expansion engines were of the three-crank type which has now become the standard, yet in the earlier east-coast engines, which were introduced by Mr. Alexander Taylor in 1881, the engine was simply the two-crank engine with another high-pressure cylinder added tandem to the first cylinder, Fig. 3, Plate VIII.; and for a year or two favours seemed divided between the three-crank engine and the two-crank tandem, the first cylinder being tandem sometimes with the second and sometimes with the third. In recent years, the tandem triple seems to have disappeared, except in cases of tripling old engines.

But perhaps the desire to economise in length of engine has given rise to more varieties of arrangement than any other single cause. For this purpose, combined with the aim of making them more accessible, the valves have been removed from the fore and aft centre line, and placed behind or in front, and worked either by one of the numerous forms of radial valve-gear or by the link-motion and levers. It is true that by such an arrangement the length over the cylinders can be diminished; but as the extent to which the distances between the centres can be reduced is limited by the lengths of the shaft bearings, and the thicknesses of the cranks and couplings, little can be gained below the cylinders by this means. However, where length of hatch is important, such an arrangement has its value, as have also the two arrangements of cylinders shown in Figs. 4 and 5, Plate VIII. In Figs. 6 to 11, Plates VIII. and IX., are illustrated a variety of arrangements of three-stage expansion engines. In the application of the three-stage expansion principle to paddle engines, Mr. Rodger's arrangement of oscillating engine, Figs. 12 and 13, Plate X., is most interesting, and has been found to work most satisfactorily.

Of four-stage expansion engines, the oldest type is that made by Messrs. Denny and by the Barrow Shipbuilding Co., Fig 17, Plate XI., which consists simply of two pairs of cylinders working tandem. Messrs. Richardson, of Newcastle, adopt a four-crank engine, Fig. 18. Messrs. Fleming and Ferguson's, Fig. 20, consists of two pairs of cylinders working two cranks by means of a pair of triangular frames; this is similar in principle to Mr. Bernay's engine, Fig. 19, illustrated in the discussion upon Mr. Thornycroft's paper on high-speed steam navigation (Institution of Civil Engineers, vol. lxvi, 1881, page 147).

Two of the most common types of triple engines are those shown in Figs. 21 and 22, Plate XII., with the cylinders arranged in the sequence—high, intermediate, low; the condenser forms part of the engine framing, and the pumps are placed at the back of the condenser, and worked by levers. In the smaller engines, Fig. 21, the cylinders are rigidly bolted together; but in the larger, Fig. 22, they are free, and connected only by a pair of bar stays fixed to their centres. This is customary in order to prevent the extension of the distance between the centres when the engines are heated; but it is a point which appears more important in theory than in practice, and it is doubtful whether the greater rigidity of the bolted cylinders in the smaller engines is not a much more important feature in the ordinary work.

In the navy, where, owing to the necessity for arranging all machinery below the water line in unprotected vessels, the horizontal engine formerly reigned almost supreme, vertical engines are now almost uniformly adopted, and the necessary protection for the cylinders is obtained by an armoured hatch. In the latter designs the larger engines are made open-fronted, Figs. 23 and 24, Plates XIII. and XIV., with standards of cast steel at the back and wrought steel pillars in front. Feed, bilge, and circulating pumps are worked by separate engines. For the air-pumps also separate engines have sometimes been adopted, and they possess great merits for manœuvreing purposes, as the vacuum can be maintained and the condenser kept clear of water while the main engines are standing, and the latter are thus ready to answer more instantly any order which may be given. With the three-crank engine, however, this is of less importance than with the two-crank type.

In modern cruisers, which are designed with the view of steaming upon emergency at a very high speed, and ordinarily at about half that rate, the engines become much too large for the power developed at slow speeds, and, in consequence, are not economical under the ordinary condition of working. In larger vessels this difficulty is met by separating each set of propelling engines into two sets of half the capacity, the one forward of the other, and so arranged that the forward set may be disconnected and the after set left to do the work. The propelling engines of the Italian cruisers "Lepanto," "Italia," "Re Umberto," and "Sardegna," and of the British cruisers "Blake" and "Blenheim," have been arranged on this plan. In smaller cruisers no such plan has been adopted, so far as the writer knows, nor would it be convenient with the limited room available; but something almost equivalent might without much difficulty be contrived, such as using the high and intermediate cylinders as a two-cylinder compound engine, and disconnecting the low-pressure cylinder, which would require to be placed forward. Such an arrangement is shown on Figs. 25 and 26, Plates XV. and XVI. A similar arrangement, the writer learns, has recently been proposed by Mr. Macfarlane Gray (Institution of Naval Architects, Transactions 1891, page 63).

The general details of the engine have not undergone many modifications, but still they have not remained without change.

Piston-Valves.—Since higher steam-pressures have become common, piston-valves, which were referred to in the discussion upon Mr. Marshall's paper (page 491), have become the rule for the high-pressure cylinder, and are not unusual for the intermediate. When well designed they have the great advantage of being almost free from friction, so far as the valve itself is concerned. In the earlier piston-valves it was customary to fit spring rings, which were a frequent source of trouble and absorbed a large amount of power in friction; but in the writer's recent practice it has become usual to fit springless adjustable sleeves, such as are illustrated in Figs. 14 and 16, Plate X. For this plan he is indebted to the suggestion of Mr. James Thompson, of the Pacific Steam Navigation Co. These sleeves have all the advantages of the solid ring, so far as their freedom from friction is concerned; and in case of leakage they can with ease be adjusted by lining up at their joints. In smaller engines the same springless ring has been used for the pistons of the high-pressure and intermediate cylinders. It may not give such absolute steam-tightness as the spring ring; but any little leakage can be picked up in the low-pressure cylinder, and such very slight loss of efficiency as may be due to this cause should be fairly well compensated by the diminished friction of the valves. For low-pressure cylinders the writer is not much in favour of piston-valves; if fitted with spring rings their friction is about as great and occasionally greater than that of a well balanced slide-valve; while if fitted with springless rings there is always some leakage, which is irrecoverable. But the large port-clearances inseparable from the use of piston-valves are most objectionable; and with triple engines this is especially so, because with the customary late cut-off it becomes difficult to compress sufficiently for ensuring economy and smoothness of working when in "full gear," without some special device.