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“The Propelling Machinery of a Torpedo-boat Destroyer.”<sup>1</sup>

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ALTHOUGH the torpedo-boat has ceased to be a novelty, and a speed of 30 knots per hour is regarded with indifference, a few particulars of the machinery by which this speed is attained, and of improvements suggested by recent experience, may prove of some interest. The Author proposes to confine himself to the propelling machinery of the enlarged torpedo-boat known as the “destroyer.”

*Boilers.*—The most characteristic feature of these vessels is the boiler. With the exception of H.M.S. “Havock,” “Hasty,” “Dasher,” and “Charger,” which were fitted with the locomotive-type marine boiler, all our destroyers owe their speed chiefly to what is known as the express, or small-tube water-tube boiler. The locomotive boiler which was for a long time the standard boiler for small craft had been pushed to its utmost limit; at high powers its limited grate area had to be compensated for by a high rate of combustion, to which it was not suited, and leakage at the tube-ends was frequently the result. The express boiler, however, presents conditions exactly the reverse. Apart from its superiority in point of weight, its ample grate area has obviated the necessity for such high rates of combustion, though its rapid circulation and unexposed tube ends enable it to stand the most severe forcing, should occasion demand it. Several vessels of the torpedo-gunboat class and a third-class cruiser are having their locomotive boilers removed and water-tube boilers substituted; in fact the locomotive-type marine boiler may be said to be obsolete. The types of express boiler chosen for H.M. 27-knot destroyers were the “Thornycroft,” “Yarrow,” “Normand,” “Blechynden,” “Reed” and “White.” They all consist of an upper drum, forming the steam space (“White’s” boiler has two upper drums) con-

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<sup>1</sup> This Paper was read and discussed at a meeting of the Newcastle Association of Students of the Institution on the 23rd March, 1899.

needed to lower drums, or water pockets, by a number of small tubes forming the heating surface, and, with the exception of the Yarrow boiler, by a few large pipes, commonly called "down-comers," forming passages for the downward flow of water. The grate occupies the space between the lower drums, and the products of combustion impinge on the small tubes on their way to the smoke-box.

The tubes for these boilers are now invariably of solid-drawn steel, generally 1 inch to  $1\frac{1}{4}$  inch in diameter and  $\frac{3}{32}$  inch thick. Some of the earlier destroyers had copper tubes, but they proved unreliable, and have been replaced by steel tubes. Copper loses its strength at high temperatures to such an extent as to render it unfit for the tubes of high-pressure water-tube boilers. Tubes are galvanized externally to reduce external corrosion from damp when lying up. They are cleared of soot when under steam by a jet of steam from a portable nozzle connected by a flexible pipe. Air-tight doors are provided in the casing for this purpose. With the exception of those of the Reed boiler, the tubes are expanded into their drums or tube-plates, the friction of the tube joints being sufficient to prevent the drums being blown apart by the pressure on the areas opposite the tube ends. The curved tubes used in these boilers do not exhibit any tendency to straighten under pressure as might be supposed, while straight tubes generally acquire a slight curvature. The necessity of expanding tubes into very small drums led to the invention of the Thornycroft tube expander, which is turned and fed through bevelled gearing by a shaft long enough to reach the whole length of the drum. The fire-boxes are lined at their ends with fire-brick, and the lower drums at each side of the grate are also protected with the same material. The casing usually consists of two thicknesses of  $\frac{1}{16}$ -inch sheet steel with asbestos cloth between. The fire-bars are of wrought bar-iron lightened by numerous holes and riveted in pairs with distance-pieces between.

Considering generally the elements which make for efficiency in boilers of this type, the most important is rapid circulation. Circulation of some sort is absolutely essential to prevent the tubes overheating at high rates of combustion, but the more rapid it is, the greater is the efficiency of the tubes as heating surface, owing to the greater amount of heat they are able to absorb. In this respect the express boiler has the advantage, compared with the usual forms of large tube boiler, that its tubes are comparatively short and direct, and more nearly vertical; also, each tube discharges into the steam drum independently of the

rest, and the small diameter of the tubes causes a more rapid generation of steam. The cause of circulation has been the subject of much controversy, and though opinions still differ on the theoretical side of the question, all are agreed as to the steps that should be taken in practice to secure a good circulation. In reference to the economy of the express boiler, widely varying results are brought about by apparently trivial, and in most cases, preventable causes. The first condition of economy is perfect combustion. The express boiler has a large grate, which requires a thin but even fire; if too thick in places the air cannot penetrate and the coal clinkers; if too thin, the air enters the fire-box insufficiently heated.

Most destroyers have four boilers, but some have only three, while in others there are eight. In all cases there are two stokeholds. Coal is stored in bunkers along the sides of the boiler space, and in an athwartship bunker forward. The forced draught is supplied by fans, generally having vertical shafts, and situated close under the deck. In this case they are single-breasted, being joined directly to the base of their cowls, and are driven by single-cylinder horizontal engines, the full speed of which is about 400 revolutions per minute. Double stokeholds, that is, with fires back and front, have two fans, one on each side of the ship; single stokeholds have one central fan. The air usually enters the ash-pits direct, through thin doors which swing inwards and close when there is no excess of pressure on the stokehold side. An excellent system adopted in the Yarrow boiler is to take in air through similar doors high up in an outer casing; there it is heated and helps to keep the casing cool, the hot air passing on to the fire. This arrangement provides an additional safeguard against flames being forced into the stokehold by an occurrence of back pressure.

Owing to the small quantity of water contained in these boilers and the consequent rapid evaporation, the feed system assumes unusual importance. Some form of automatic feed is generally considered almost indispensable, though one foreign government prefers to trust to the human element rather than to any mechanism. Nearly every express boiler has its own form of automatic feed apparatus, but most of them consist of a valve worked by a float either within the steam drum or in a chamber connected with it. Such an apparatus is always capable of adjustment to suit different rates of combustion, or for operating the valve by hand; in the Thornycroft regulator the fulcrum of the float is raised or lowered by a screw outside the steam drum; in the Blechynden regulator

the valve seat slides within its casing and can be adjusted by an external screw, so that the valve can be opened either automatically by the float moving the valve spindle, or at will by moving the valve seat. Both of these forms have been found to work satisfactorily in practice. Messrs. Yarrow have tried a form of automatic feed in which the steam-pipe to the feed-pump is led from a conical pan placed in the steam-drum with its upper edge at the normal water-level, the object of this being to enclose a body of water unaffected by the disturbance of the surrounding water. So long as the top of the pan is uncovered, steam is supplied to the pump, but when the pan is covered with water the pump is choked with the water that comes over in the pipe. Adjustment is effected by raising or lowering the pan, there being a joint in the pipe connecting with it. This arrangement necessitates a separate pump for each boiler. An installation of Normand boilers has been fitted, in which the steam-drums are connected by pipes below the water-level. This has the effect of steadying the water-level in each boiler, and it is only necessary to watch one boiler; but it adds to the weight and complication of pipes, as valves have to be fitted to enable any boiler to be shut off.

Opinions differ on the subject of the best place to admit the feed. At first it was usually admitted in the lower drums, but the practice soon became general of admitting it into the steam drum, chiefly with the object of assisting circulation by allowing it to flow downwards inside the boiler, and also to distribute it more evenly. Recent experiments, however, with the Blechynden boilers of H.M.S. "Pactolus" have shown an increased efficiency when the feed is admitted at the lower drums. Mr. Yarrow has described an interesting series of experiments in connection with feed-admission. He has found that by partitioning off the outer rows of tubes and admitting the feed to these first, the same number of tubes will absorb a greater amount of heat from the fire than if the feed is permitted to follow its natural course in the boiler. This result has verified the theory that the hottest gases should meet the hottest tubes, and *vice versa*, and is another illustration of the efficiency of the feed-heater placed in the uptake, often called the economizer. This efficiency is due to the fact that the difference in temperature between the cold-feed and the uptake gases is sufficient to cause a useful exchange of heat, whereas if the same gases acted on a surface containing hotter water the exchange of heat would not be worth considering. It seems rather wasteful, however, to use part of the boiler as a feed-heater, since a feed-heater requires no provision for circulation

and can consist merely of coils of small pipes. There is little doubt that the boiler of the future will receive its water from a heater at the boiling-point due to its pressure, as it has been proved that a marked economy can be obtained by heating the feed to boiling-point, even by live steam from the same boiler.

The system of feed-pipes and pumps is in duplicate, being termed main and auxiliary. The main feed-pumps are preferably placed in the engine-room, where they are under better control, and are free from the ruinous effects of coal-dust, but the auxiliary feed-pumps are placed in the stokehold to be available in case of emergency, such as the failure of the automatic feed. Filters are fitted either on the suction or discharge side of the feed-pumps, and consist of layers of brass grids covered with the filtering composition, which is easily replaced when clogged, a by-pass being fitted for this purpose. Suction-filters are the lightest, since they are not subject to pressure, but the action of the discharge-filters is more certain. The latter are fitted with relief-valves to prevent excessive pressure in the pipes owing to the filters getting clogged. A reserve fresh-water tank is fitted, generally built into the ship's frames, for making up the feed. An evaporator and distiller is also fitted for producing fresh water both for drinking purposes and for the boilers. No oil has been used in the cylinders of these engines, and no trouble has been caused by the want of it, in spite of their high piston-speed. However, enough oil always finds its way into the steam by means of the rods to render filters a necessity when express boilers are used.

Steam-pipes are now of solid-drawn steel, when of larger diameter than  $1\frac{1}{2}$  inch, and below this size solid-drawn copper pipes are allowed; the earlier destroyers had solid-drawn copper pipes considerably above this size. Flanges are screwed on for small sizes and riveted for large sizes. Bends and tees are of gun-metal or cast steel; the latter is rapidly growing in favour, as reliable castings can now be obtained much thinner than was formerly practicable, and at a reduced cost. There are usually two ranges of main steam-pipes, on opposite sides of the ship, one from the forward, the other from the aft group of boilers, having stop-valves and a cross-connection in the engine-room, as well as the boiler stop-valves and regulator-valves on the engines. They slope gradually towards the engines, and are drained by steam-traps discharging into the feed-tank. The auxiliary engines are supplied with steam by a separate range of piping having separate stop-valves on the boilers, and they can exhaust into the condenser

or through a pipe at the side of the funnel. A silent blow-off is fitted from the main steam-pipe to the condenser. Gauge-glasses continue to be of glass, though they are an endless source of nuisance and sometimes danger at high pressures. Mica has been tried, but it soon discolours; it may be said that a trustworthy means of rendering the water-level visible and resisting high steam-pressures has yet to be found. Water-nozzles are fitted in the furnace-fronts for drenching the fires. The steam-pressures employed in these vessels range between 180 lbs. and 250 lbs. per square inch. The latter is not so high as the pressure employed in the Belleville boilers of H.M. cruisers and battleships, in which the boiler-pressure is 300 lbs. per square inch, but in their case it is reduced to 250 lbs. per square inch at the engines, while no reducing-valves are used in destroyers.

*Engines.*—The type of engine adopted in these vessels has been either the three-crank or the four-crank inverted triple expansion engine. In choosing between the two types a consideration secondary only to that of weight and space is that of balancing. Since the magnitude of the inertia-forces in an ordinary steam engine varies with the mass, the stroke, and the square of the number of revolutions per minute, it will be seen that of two engines having the same piston speed and the same weight of moving parts, the one with the shorter stroke and higher rate of revolution causes most vibration, and in a destroyer the highest piston speed and the highest rate of revolution are combined. The effect of these forces is greatly magnified by the light scantlings of the hull, the stiffness of which cannot be relied upon to the extent possible in larger ships. The three-crank engine was more common in the 27-knot boats, but in the 30-knot boats the four-crank engine has in many cases taken its place, and has practically become the standard type for high-speed engines. The three-crank engine, however, has much in its favour; its twisting moment is more uniform, it takes up less fore and aft space, and has fewer working parts, with a correspondingly reduced risk of breakdown. Although three cranks at  $120^\circ$  would constitute a statical balance about the centre of the shaft if the pistons were of equal weight, dynamical stresses are set up by the successive acceleration and retardation of each set of moving parts, and though the sum of the forces set up in a given direction is nearly equal throughout the stroke to that of those set up in the opposite direction, they do not act in the same plane, and therefore constitute a couple, varying with the distance between the planes in which the resultant opposing forces act. This couple tends to cause the ends

of the engine to move in opposite directions, this tendency being greatest in the vertical plane, as the forces due to the vertically reciprocating parts are then added to the centrifugal force of the revolving weights.

Vibration in the three-crank engine has, so far, been met by balance-weights placed on the crank-webs. By this means all forces due to the revolving parts can be eliminated, but it is obvious that if the revolving balance-weights be increased till they balance the vertical forces of the reciprocating parts, horizontal forces of the same amount are introduced, and thus the effect is merely to change the vertical forces to horizontal. Indirect though this method may seem, it has met with considerable success in reducing vibration, as trials with and without balance weights have proved, and seems to show that a vessel of this type is stiffer in a horizontal than in a vertical direction, at any rate at the bed-plate, where the forces are applied. It is sometimes considered sufficient to balance the revolving parts, while a good compromise seems to be found in proportioning the forces to the stiffness of the ship in the direction in which they act, thereby reducing the maximum force exerted. The increasing preference shown to the four-crank engine is largely due to a desire to obtain a self-balanced engine, though it has the important advantage of keeping the diameter of the cylinders, and consequently the breadth of the engine, more uniform, two low-pressure cylinders, very little larger than the intermediate, being substituted for the single larger cylinder. Obviously the length of the engine is considerably increased, but it is in breadth of engine-room space rather than in length that the designer is cramped. Returning to the question of balance, though the four-crank engine lends itself to obtaining an almost perfect balance with a correct disposition of cylinders and crank angles, until quite recently engineers have been content to place the cylinders in their natural sequence, with the high-pressure crank directly opposite to the intermediate-pressure crank, and the two low-pressure cranks opposite each other, the high-pressure and intermediate-pressure cranks making an angle of  $90^\circ$  with the low-pressure cranks. In this case there are two distinct unbalanced couples set up, the one reaching its maximum when the other is at zero. The magnitude of the couples, however, is in no case as great as the couple set up by a three-crank engine of the same size, unless No. 1 crank be placed opposite No. 4 crank, which is the worst sequence possible. The opposite cranks, therefore, should be brought as close together as the cylinders will permit.

The Thornycroft engine is the outcome of an effort to get rid of even this limitation, and to reduce the couple to a negligible quantity. In this engine the two adjacent crank-pins are joined by a single web without a middle bearing, the cylinders being placed radially at a slight angle on each side of the vertical. The adjacent cranks make with each other an angle of  $180^\circ$ , less the angle between the centre lines of their cylinders, so that both cranks reach the end of their strokes simultaneously. This arrangement has not only attained its object in reducing vibration to a minimum, but reduces the pressure on the main bearings. The pressures on the crank-pins to a great extent counteract one another, and the main bearings, instead of receiving the full load due to the steam pressure, receive little more than that due to the couple depending on the fore and aft distances between the crank-pin centres. In other words, supposing the fore and aft distance between the main bearing centres to be double the distance between the crank-pin centres, the pressure on the main bearings would not be much more than half that on the crank-pins. It is not exactly half, owing to the inclination of the cylinders to one another. Further, the load on the main bearings being reduced, the load on the columns is correspondingly reduced, the fitting bolts connecting the adjacent cylinders being in shear. There is a slight tendency to horizontal vibration in this engine, owing to the sideways movement of the parts, but the effect is scarcely noticeable. Mr. Thornycroft has pointed out and illustrated by the simple means of two pieces of twisted wire that a pair of cranks without a middle bearing in transmitting a twist has not the tendency to displace the centre of the shaft that a single crank has, since any distortion in one crank-pin and any deflection in one crank-web is neutralized by a similar condition in the opposite crank. He attributes many failures of crank-shafts to their being brought out of line by the distortion of the cranks, but, considering the severe bending stresses tending to throw a crank-shaft out of line, this slight tendency seems almost trivial, especially as it cannot occur unless the cranks be not stiff enough to transmit the twist without distortion. The claim to reduced initial friction with this type of engine compared with the three-crank engine seems amply justified by progressive trials with the two types of engines, the initial friction in each case being obtained by producing the curve of indicated thrust to zero speed. This type of engine has the slight disadvantage of having very short eccentric rods for two of the valves, the other two having a good length of rod; this is caused by the link motions



being at different inclinations,<sup>1</sup> but suspended from a common weigh-shaft at the side of the engine. It is also possible that the cylinders may after a time be found to have worn slightly oval owing to their inclination from the vertical. The ordinary vertical four-crank engine has been found to run fairly steadily when the opposite cranks have been brought as close together as possible, but where they have been separated by a piston-valve balance-weights have as a rule been found necessary.

The combined piston-valve adopted by Messrs. Belliss in H.M.S. "Swordfish" and "Spitfire" must of necessity be placed between the two cylinders with which it is connected. It amounts to placing two valves one above the other on a common spindle and driven by one set of link motion, the valve-chest being common to both cylinders. If the valve-settings of both cylinders are the same, then the cranks must be opposite, or at any rate nearly so, if different valve-settings are required. This type of valve reduces the fore and aft length of the engine considerably without increasing its breadth, and obviates the cost of two sets of link motion; it has, however, the drawback of presenting a more complicated casting, which is not desirable with such thin metal, and the setting of one valve cannot be altered independently of the other; it also necessitates the centres of the opposite cranks being a greater distance apart. To reap the full benefit of the four-crank engine, the crank angles should be arranged so that there is no resultant couple and very little resultant force. It is of course desirable that there should be no resultant force, but this is not at present practicable owing to the disturbance caused by the obliquity of the connecting-rod.

With the exception of those built by Messrs. Laird, which have their engines in the middle of the ship, as being the position where the hull is least susceptible to vibration, all the British destroyers have their engines aft of the boiler space, placed side by side, with no middle bulkhead. The favourite arrangement in America seems to be to place one engine-room forward of the other and separated from it by a water-tight bulkhead, the engine space occupying the middle of the ship, and the boilers being in two groups, one forward and one aft. This arrangement has the advantage of completely isolating each set of engines and boilers, and also that the coal-bunkers, which, contrary to English practice in these vessels, are situated on either side of the engine space, may afford a slight protection to the engines,

<sup>1</sup> For the exact difference, see Thornycroft and Barnaby on "Torpedo-boat Destroyers," *Minutes of Proceedings Inst. C.E.*, vol. cxxii. p. 51.

but, on the other hand, the engines occupy a much larger portion of the ship than if placed side by side.

Returning to English practice, the condensers are placed in the wings with the ordinary type of engine, and are made long in proportion to their diameter, in order to reduce weight and also to give more room for a gangway between the engines. The length of the condenser is limited by the necessity of having sufficient clear space at one end for drawing tubes. In the case of the Thornycroft engine, which is broader and shorter than the ordinary engine, the condenser is placed aft of the engines. The centre lines of the shafts have always to be slightly inclined from the engine-room downwards, to immerse the propellers, and as a rule they are slightly inclined outwards, to bring the engines as close together as possible. Some of the earlier destroyers were arranged to secure a broad gangway between the two engines, there being no room to pass between condensers and engines. This is the best arrangement for vessels of very narrow beam, but as the screws (with the exception of those of H.M.S. "Conflict") revolve outwards, a good view of the engines is not obtainable from a centre gangway, as the piston-rods and connecting-rod top ends are to a great extent hidden by the guides. As the distance between the engines is increased, the centres of their shafts have to be raised, owing to the rise in the ship's bilge; consequently the general practice is to secure a free gangway at the outside of each engine, where the only unavoidable obstructions are the exhaust pipes to the condensers, and to bring the engines as close together as the space necessary for steam pipes will admit. In most of the 27-knot boats the air-pump is placed forward of the engines in a continuation of the crank-pit and is driven by a connecting-rod from a small crank-shaft, which forms a continuation of the main crank-shaft. Height is saved by adopting the trunk form of bucket, the connecting-rod eye working on a pin secured at the lower end of the trunk. In this arrangement the air pump occupies no room that might be otherwise useful, as the floor plates can be carried above it, a lid being fitted for inspection and oiling. As, however, the stroke of the pump is limited to 4 inches, the diameter, and consequently the clearance, is excessive. It has also proved troublesome on account of the bearings becoming heated, which is probably due to some extent to its being out of sight. For these reasons it has been abandoned in the 30-knot boats, in favour of the usual lever-driven pump, driven from the aft low-pressure cylinder and placed on the outside of the engines; it does not then obstruct the gangway as there is room to pass in

the space left for drawing the condenser tubes. In a fore and aft direction, space is most required at the forward end, as in nearly every case the hand gear and pressure gauges are brought to this end and room has to be found for two main feed pumps, two circulating pumps, an evaporator, distiller and engine, a fire- and bilge-pump, in some cases feed-heaters and separators, and an air-compressor for the torpedoes. The steering engine is always placed on the aft engine-room bulkhead, between the thrust blocks, and the electric-light engine is placed in the next compartment abaft the engine-room, which is used as a galley and a store.

The main-engine cylinders are not jacketed, the usual thickness for high-pressure cylinders being  $\frac{3}{4}$  inch. They are independent castings (with the exception of Messrs. Belliss's arrangement, already mentioned) connected by brackets top and bottom; each cylinder has its own valve chest cast with it; steam-joint connections, such as are found in the merchant service, are not permitted. Since the expansion of the line of cylinders is a condition to be reckoned with, it is usual to fit the liners between these brackets when the cylinders are hot. The framing has to yield to the expansion in any case where the cylinders are bolted together, but this method ensures the cylinders being in line under working conditions. Piston valves are always fitted for the high-pressure and intermediate-pressure cylinders, and as a rule also for the low-pressure cylinder. The high steam-pressures employed render these a necessity for the high-pressure and intermediate-pressure cylinders, while even for the low-pressure cylinder a piston-valve and chest is lighter than a flat valve and chest, though it takes up more room. It has greater freedom in running at high speeds, and if carefully fitted, the steam has scarcely time to leak past it. Piston valves are of cast iron, though aluminium has been tried, and have no packing rings, but often have a number of small grooves on the working face, in which the condensed steam collects. These grooves have been found to assist in keeping the valve tight and in lubricating the working faces. All flat surfaces, such as steam ports, are stayed with fine-thread steel stays screwed into bosses in the casting, and caulked at their projecting ends. Steam is admitted between the steam ports to the annular space round the valve, exhausting at the outer edges. The valve-chest glands are then subject to steam at a lower pressure than with the reverse arrangement. When a flat slide-valve is used, a compact arrangement is to exhaust the steam through the back of the valve chest, the usual relief ring being employed to keep the passage tight. The crank-shafts are of mild steel and are forged

in one piece, the shaft and crank pins being hollow. The bore is usually half the diameter or slightly more. The crank-webs have their corners bevelled or rounded to save weight, and balance-weights, when required, are driven on to mortices on the crank-webs and secured by strong studs. In the coupling between the crank-shaft and the thrust-shaft, "drivers" are usually employed instead of the ordinary fitted bolts, to prevent the possibility of any thrust coming on the crank-shaft. They are held by nuts in taper holes in the thrust-shaft coupling-flange, and fit easily in the holes of the crank-shaft coupling-flange, the two flanges being about  $\frac{1}{4}$  inch apart. The coupling between the thrust- and tail-shafts consists of a swelling in the thrust-shaft, into which the end of the tail-shaft fits, and is secured by one or more cotters. This is the simplest form of coupling where the tail-shaft has to be drawn outboard and access is limited. The cotters transmit both the twist and the thrust, whereas in the ordinary form of loose coupling special provision has to be made for transmitting the thrust. The tail-shaft is carried at each end by cast-steel tubes lined with white metal, the forward of which is driven into a tube built into the ship and the after into what is generally known as the A-bracket, both of these parts being bored out in position. The tail-shaft is open to the sea for the greater part of its length, but though exposed to rust, there are no brass liners to set up galvanic action. Zinc rings are fitted on the shaft at the forward end of the propeller to minimize galvanic action caused by the latter. The aft end of the tail-shaft is completely covered by the propeller nut, which in turn is covered by a light brass cone which follows the outline of the propeller boss and fills up the vacuum which would otherwise be caused there. The propellers are three-bladed, the blades being in one casting with the boss. They are of high strength bronze, such as manganese- or aluminium-bronze, or Stone's metal. With the exception already mentioned they revolve outwards, as the outward current tends to throw clear any floating *débris* or ropes, instead of drawing them inwards. In large naval vessels, which have their propellers more deeply immersed, this consideration is not so important, and the latest cruisers have propellers revolving inwards to bring the open fronts of the two engines towards the centre of the ship for convenience in handling. In a series of experiments recently described before the Institution of Naval Architects,<sup>1</sup> Mr. R. E. Froude has found that there is practically no difference in efficiency

<sup>1</sup> Transactions of the Institution of Naval Architects, vol. xl. p. 61.

depending on the direction of revolution. Experiments have proved that a high-speed propeller of small diameter, large blade area and coarse pitch is the most efficient, as the reduction of surface friction secured by the lower average velocity compensates for the coarser angle of blade. The slips obtained on successful trials in these vessels range between 15 per cent. and 8 per cent., and as a rule the best results are obtained with the higher slips. At a certain point, however, increase of slip ceases to be attended by increased thrust: This is probably chiefly due to the phenomenon now known as "cavitation," which was met with in a marked degree in the first propellers of the "Daring," as described by Mr. Thornycroft in the Paper already mentioned.

The thrust blocks are of cast-iron, and are of the solid type, bushed with white metal and water jacketed; they are generally carried on cast-steel bearers bolted to longitudinal girders of angle or channel section. These girders are sometimes of cast-, but more commonly of rolled-steel, and run the whole length of the engines from the thrust blocks to the air pump, if the latter is of the crank type. The engine bed-plates are separate castings, usually of cast-steel, but sometimes of bronze, of I section, bolted at their ends to these guides, which are themselves carried by deeper longitudinals built into the hull of the ship, the space between them forming the crank-pits. They are stiffened by frames on each side and are connected by frames directly under, and bolted to, the bed-plates. The guides are of cast-iron of the slipper type with a water-jacket behind the go-ahead face. They are bolted at their upper ends to a flange on the cylinder bottom, and at their lower ends to horizontal stays between the columns. The columns are usually of forged steel turned bright, and are stayed by horizontal stays passing through swellings in the columns, near their centres. Diagonal stays are generally also fitted. Exceptions to this type of framing are H.M.S. "Salmon" and "Snapper," in which the back columns are bronze, of bulb section and somewhat bow-shaped, the cast-iron guides being bolted to them by continuous vertical flanges. This section of column is stiffer, weight for weight, than the round column, but is much more expensive, and the same stiffness can be secured with round columns by the use of diagonal stays. The piston-rods and connecting-rods are drilled hollow to about half their external diameter, and the crossheads are in one piece with the piston-rods, the gudgeon pins being shrunk into the connecting-rod forks. The gudgeon pins are hollow and of specially hard steel. The engines are stayed to the bulkheads and to the ship's sides by

stays consisting of tubes with palms welded on each end, running from gussets close under the deck, to lugs cast on the cylinders. The two sets of engines are similarly stayed to each other. Though the slot- or locomotive-link has been adopted in some of these vessels, the usual double-bar link is preferred, as it admits of adjustment in every wearing part, gives a truer motion, and is lighter for the same strength. The eccentric-straps are of gun-metal or phosphor-bronze lined with white metal. They are ribbed between the bolts, usually by T or bulb-shaped ribs. Joy's assistant cylinder has been fitted in a few vessels of this class, and has reduced the wear on the valve-gear considerably. This device consists of a piston connected to the valve spindle, working in a cylinder, to each end of which it admits steam in turn. By regulating the amount of steam admitted, it can be made to do the work of moving the valve in each direction, the valve gear merely controlling the length of travel. The all-round reversing-gear still obtains, on account of its simplicity and compactness; the earliest destroyers were reversed by hand, but steam reversing gear was very soon introduced. The arrangements for oiling demand considerable attention in these rapidly moving engines. Centrifugal lubricators are fitted to the crank-pins and often to the eccentrics; in addition, oil is led by the usual wick siphons from oil-boxes placed at about the level of the cylinder bottoms. These boxes also supply oil for the guides, crosshead brasses and link motion. The main-bearing oil-boxes are situated lower down. Separate oil-boxes are provided for the glands, as only mineral oil must be used. These engines, having hollow shafts, are well adapted for a system of forced lubrication, such as that used by Messrs. Belliss in their type of enclosed electric-light engine, in which the oil is forced by a pump through pipes passing through the shaft and crank webs to the crank pins, and thence to the crossheads and guide slippers. Water is led from the circulating pumps by pipes laid along each side of the engines, for playing on the eccentrics, bottom ends and main bearings, and for circulation through the water jackets in the guides and thrust blocks. The condensers are built of sheet-brass plates riveted together, and stiffened by angle rings. The tubes are of solid-drawn brass,  $\frac{5}{8}$  inch in diameter and about 18 Lancashire Gauge in thickness; they are packed with the ordinary screwed ferrule and tape packing. Owing to their great length they require a central supporting plate. The circulating water flows through all the tubes together, making only one passage through the condenser. It is fed by scoops in the skin of the ship at the curve of the

bilges. When the ship is at full speed the pump has little or no work to do but to keep pace with the water, as the speed of the ship is generally sufficient to force the water through the condenser. This is not, however, an advantage; in fact, it is certain that the scoop causes a resistance to the speed of the ship, out of all proportion to the steam saved in the centrifugal pump, and the failure of some of these vessels to attain their contract speed at first has been traced to the form of scoop employed; some form of scoop is, however, a necessity, as the pump cannot suck in the water without one, and a scoop that is able to get the water into the suction-pipe at all generally gives it sufficient velocity to carry it through the condenser. The ideal scoop should give the water just sufficient velocity to carry it to the circulating pump. The circulating pumps, of which there is one for each condenser, are of the centrifugal type, and are arranged so that the flow of water is as continuous as possible; they are driven by single-cylinder engines of about  $3\frac{1}{2}$  inches stroke, the full speed of which is about 300 revolutions per minute. A small air-pump is driven off the crank-shaft of each of these engines, for clearing the condenser of water and to maintain the vacuum when the main engines are standing. It delivers to the feed-tank and can also draw from the reserve tank to make up the feed. The fire- and bilge-pump is generally of the duplex type, and sucks from boiler-room and engine-room bilges or from the sea, and discharges overboard, or to a hose-connection on deck when it is used as a fire-pump. As a bilge-pump it is assisted, when necessary, by bilge-ejectors placed in the engine-room, in the stokeholds, and in the compartments forward and aft of the machinery space. These are placed on the skin of the ship close to the deck and merely consist of a nozzle emitting a jet of steam, which draws up the water from the bilges and discharges it overboard. They are useful in the event of the bilge-pump getting choked, while they are not liable to get out of order, as they have no valves and the steam has a scouring effect.

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