CHAPTER CLXXXVI.

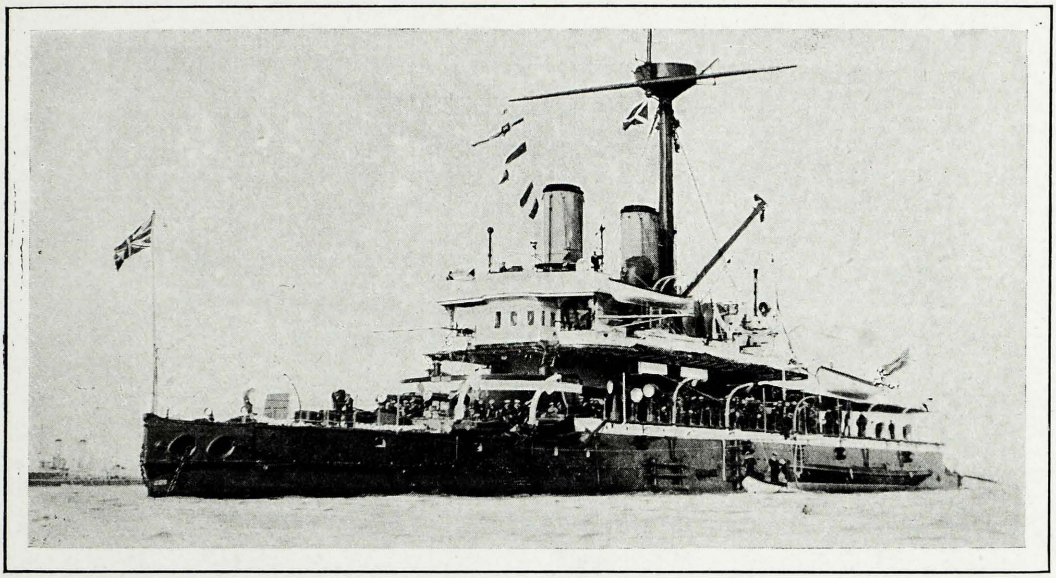
THE EVOLUTION OF NAVAL ENGINEERING.

Beginnings of Steam in the Navy—Paddle Wheel and Screw Propeller—Surface Condensers—Increasing Steam Pressures—Double and Triple Expansion Engines—Water-Tube Boilers—Invention of Parsons' Steam Turbine—The Turbinia—General Adoption of the Turbine—Advantages of Geared Turbines—Forms of Gearing, Mechanical, Hydraulic and Electrical—Coal and Oil Fuel—Forced Draught—Oil-Fired Furnaces—Internal Combustion Engines—Possibility of Application to Large Ships—Training of Naval Engineers—The Selborne-Fisher Scheme—Common Entry—The Engine Room Departments in Action.

IN the present chapter it is proposed to give an account of the engineering factors which made the ships of the British Navy, regarded as moving units, not as fighting machines, what they were at the opening of the Great War. Among these factors three were of outstanding importance on the material side, at least in the progress of the preceding 25 or 30 years : the adoption of water-tube boilers, the introduction of the steam turbine, and the use of oil fuel, whether for raising steam in boilers or for the direct production of power in internal combustion engines. But, important as they were, they must be looked upon as merely the later stages of the constant and never-ending struggle for more power with less weight of machinery and fuel which had been going on ever since mechanical propulsion was brought into the Navy, and the changes that preceded them, though perhaps dwarfed by the distance from which they must be viewed, were not less momentous in their own day.

It is interesting to note that the three great changes referred to above must all be associated with the name of Lord Fisher, for he was at the Admiralty, with the exception of an interval of a few years, throughout the period in which they were brought about. They were also all initiated during the term of office as Engineer-in-Chief of the Fleet of Engineer Vice-Admiral Sir A. J. Durston, who was appointed in 1889. Durston's principal assistant for many years before his retirement in 1907 was Engineer Vice-Admiral Sir Henry J. Oram, who had a large share in the work, and actively extended and developed it, after succeeding him as head of the engineering department of the Navy, especially by the adoption of mechanical gearing in conjunction with the turbine. Indeed, it has been said that during the ten years Sir Henry Oram held office—he retired in June, 1917, a few months after the death of his predecessor—greater progress had been made in naval machinery than in the preceding 50 years. He was succeeded by Engineer Vice-Admiral G. G. Goodwin, who as Deputy Engineer-in-Chief had been associated with him throughout his term of office.

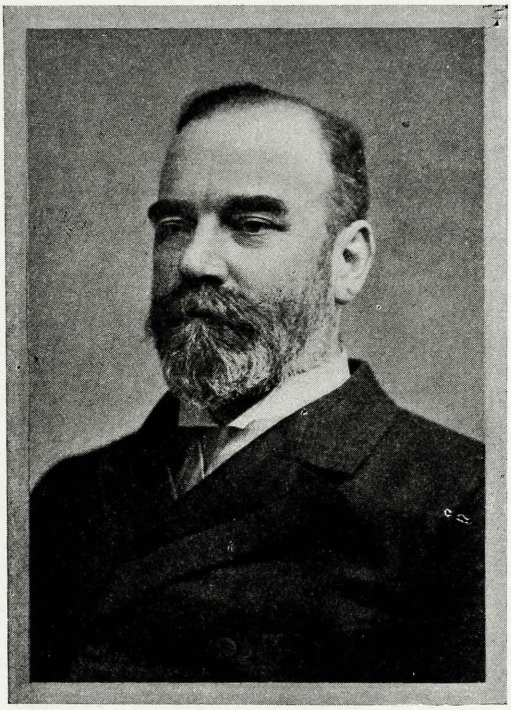
In 1914 the Navy's experience of steam was less than a century old. It was in 1820, eight years after Henry Bell's Comet, which began to ply on the Clyde in 1812, had demonstrated the commercial possibilities of the steamboat, that the Admiralty had built for



H.M.S. "DEVASTATION," 1873.
The first British Battleship without Sails.

them at Rotherhithe the Monkey, of 210 tons displacement, with Boulton & Watt engines of 80 nominal horse power. In succeeding years she was followed by sundry vessels more or less similar, but they were not, strictly speaking, warships, being used for towing and general purposes. The paddle wheels by which they were propelled were, indeed, not well suited to naval purposes. The wheels themselves were exposed to damage by the enemy's fire, it was impossible to protect the shafting and other machinery by which they were driven by placing it all below the water line, and the paddle-wheel boxes offered difficulties in connexion with the working of the guns. Nor did the paddle wheel lend itself to the application of high powers, though this objection was of little weight in the early days when the pressure of steam used was only 4 lb. per square inch and high powers were not available. Paddle-wheel warships of considerable size were, indeed, ultimately built—in the middle of the century the Terrible, a paddle-wheel steam frigate (cruiser), had a displacement of about 3,000 tons with engines that developed nearly 2,000 indicated horse power—but steam did not come into its own in the Navy until the merits of the screw propeller were recognized. Even then it was a good many years before sail was completely ousted. The ill-fated Captain, which was launched in 1869 and capsized in the Bay of Biscay in the following year, was fully rigged, with tripod masts and a large spread of sail, and the first sea-going battleship in the British Navy to depend wholly on steam for propulsion was the Devastation, of 9,060 tons, the building of which was begun in 1869.

The screw propeller reached the stage of practical test in the thirties, in the hands of F. P. Smith and Captain John Ericsson. In 1840 the Admiralty carried out trials with the

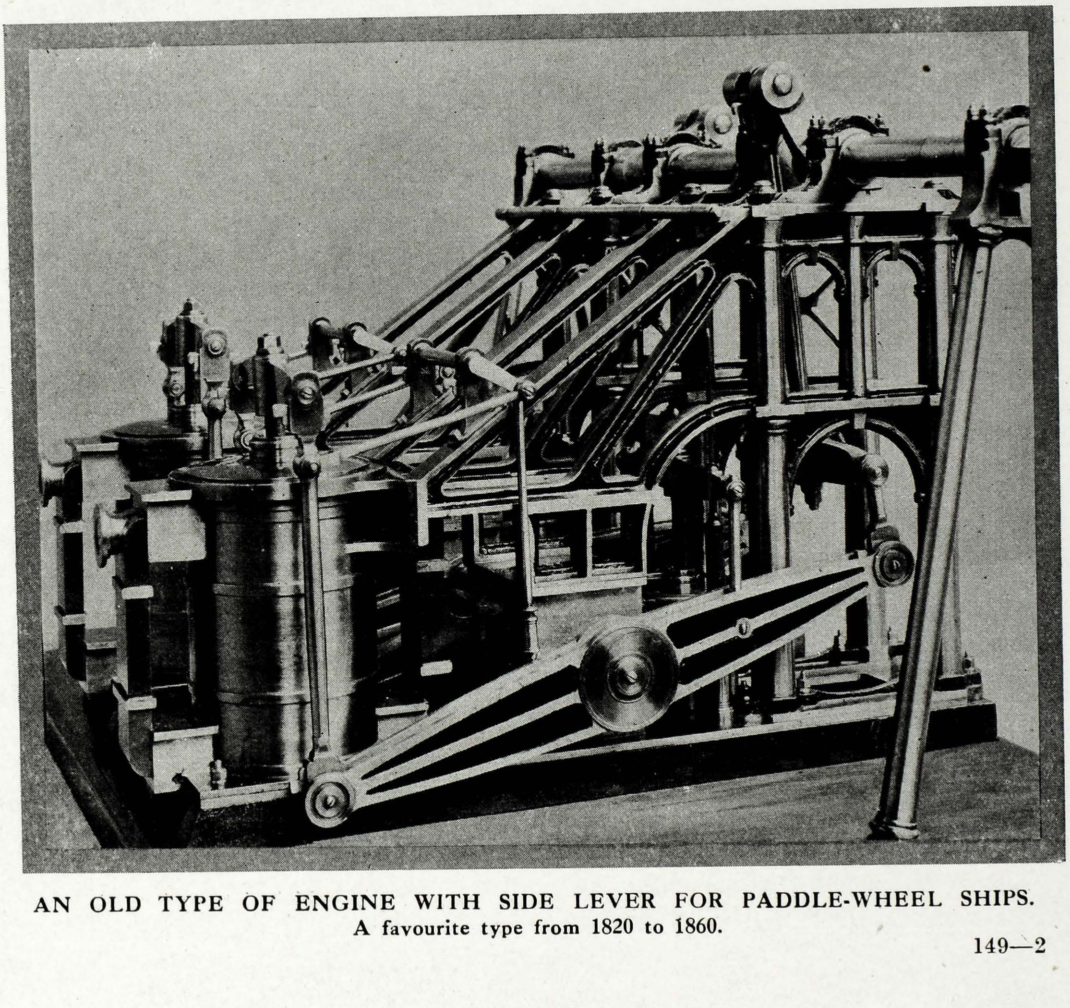


[*Elliott & Fry.*

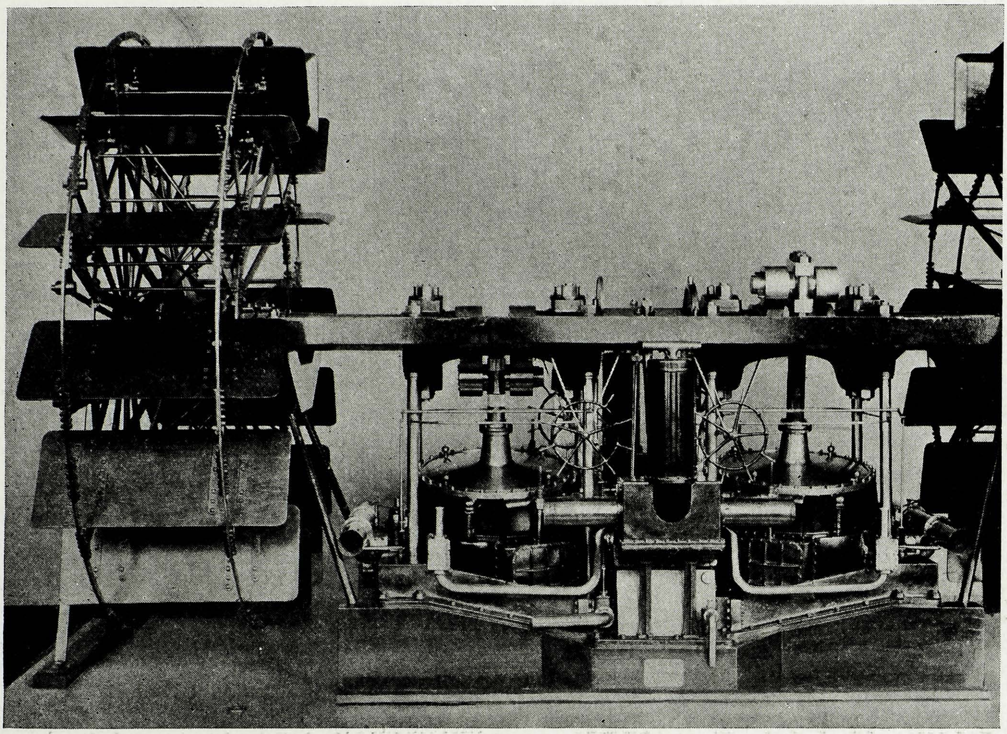
ENGINEER VICE-ADMIRAL SIR A. J. DURSTON,
Engineer-in-Chief of the Fleet, 1889-1907.

ENGINEER VICE-ADMIRAL SIR H. J. ORAM,
Engineer-in-Chief of the Fleet, 1907-1917.

Archimedes, which had been built in 1838, by private enterprise, to demonstrate the advantages of the system; but although the results were sufficiently favourable to induce Brunel, after further experiments of his own, to modify the design of his Great Britain and employ a screw propeller instead of paddle wheels, as he originally intended, they did not move the authorities to action. The force of public opinion, however, caused the question to be reopened a few years later, and in 1845 the Admiralty pitted the Rattler, of 880 tons and 200 horse power, fitted with a screw, against the Alecto, of the same size and power, but fitted with paddle wheels. At sea the Rattler proved the faster, but perhaps the most convincing test was when the two vessels, fastened stern to stern, both steamed ahead at full power, and the Alecto was hauled backwards at the rate of 2½ knots. More experiments were made between the screw steamer Niger and the paddle-wheel steamer Basilisk in 1849. In the result the superiority of the screw was so thoroughly vindicated that the paddle wheel was discarded, and by the time of the Crimean



AN OLD TYPE OF ENGINE WITH SIDE LEVER FOR PADDLE-WHEEL SHIPS.
A favourite type from 1820 to 1860.



OSCILLATING ENGINES FOR PADDLE-WHEEL STEAMER.

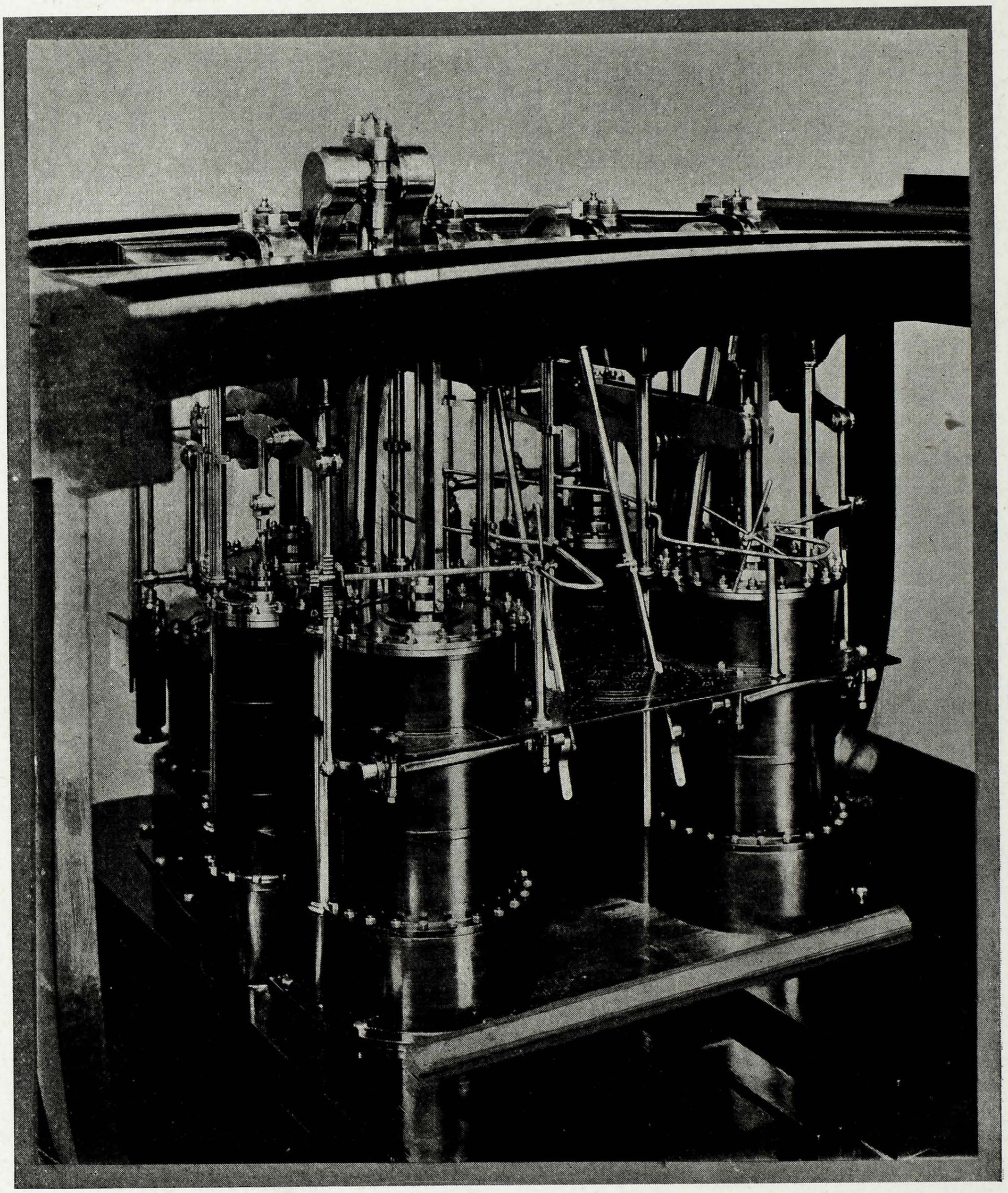
War the British Fleet contained screw vessels of all classes.

The screw as compared with the paddle wheel has the advantage of being protected from shot and shell by the water in which it is immersed, while the machinery by which it is driven is placed low down in the ship, the upper decks being thus left clear for the guns, and if it is not entirely below the water line it can be readily protected by armour. Moreover, it permits the employment of large powers, which concurrently with its adoption were becoming available through improvements partly in the boilers and partly in the engines.

In the early boilers the heat was transferred to the water from the furnace gases during their passage through a single flue, but in 1840–50 tubular boilers came into use in which the single flue was as it were split up into a number of smaller tubes, thus increasing the extent of the heating surface. This construction was more compact and weighed less, and it enabled the steam pressure to be raised to 14 or 15 lb. per square inch above atmosphere. In the next two decades the steam pressure was brought up to 30 or 35 lb. per square inch, and this increase was accompanied by, and its extension rendered possible on account of, an important change in the method of condensing the exhaust steam after it had done its work in the cylinder. In the old engines this steam was cooled and condensed by being brought into contact with jets of sea water. The condensate thus formed was nearly as salt as sea water, and while it could be used as feed water to the boilers when the steam pressures and therefore the temperature of the water in the boilers were fairly low, the case was different at pressures above 35 lb. per square inch, because at temperatures corresponding to such pressures the salts in sea water begin to be deposited and form an injurious scale in the interior of the boilers. An expedient which had been suggested in the 'thirties was therefore adopted, and the cooling water was kept separate from the exhaust steam. For this purpose either the steam was passed through a series of tubes round the outside of which cold sea water was circulated, or the water was passed through the tubes and the steam circulated outside them. The result of this method of "surface condensation" was that the condensed steam was kept free from contamination by sea water, and could safely be returned to the boilers.

The obstacle which jet-condensation presented to the use of higher pressures being thus removed, stronger forms of boiler were devised to enable them to be realized in practice, and rectangular or box boilers, not being strong enough for pressures exceeding about 40 lb. per square inch, gave way to various forms of cylindrical boiler, the pressures in which were carried up to 180 lb. per square inch. This brings the development of boiler pressure down to about the year 1889, which forms a convenient stopping point, since it not only stands on the verge of a new era in steam generation for the British Navy, marked by the adoption of water-tube boilers, but also saw the passing of the Naval Defence Act, which effected an enormous increase in the strength of the British Fleet.

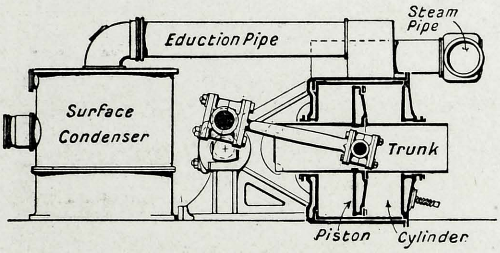
To return to the development of the engines, those first used with the screw propeller were of the same type as had latterly been employed with the paddle wheel. The earliest paddle-wheel engines were of the side-lever or beam type, but they gave place to direct-acting



FOUR-CYLINDER "MAUDSLAY" ENGINES OF H.M.S. "DEVASTATION" OF 1844.

This was a wooden paddle frigate with engines of the twin-cylinder type arranged in pairs and working on two cranks at right angles.

designs, such as Penn's "oscillating" engine, and the Maudslay "double cylinder" type. In the former the cylinder swung on hollow trunnions, through which the steam passed. In the latter there were two cylinders placed vertically side by side on the floor of the ship and working a single crosshead, an extension of which passed down between the two cylinders. The connecting rod was attached to the bottom of this extension, the object of the arrangement being to give it sufficient length.

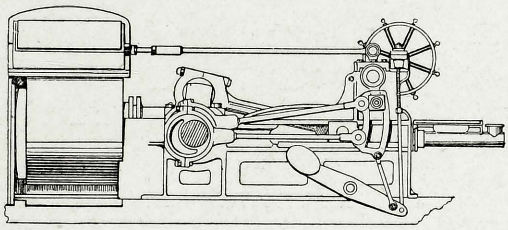


SECTION OF TRUNK ENGINE.

The screw needed a faster rate of rotation than the paddle wheel, and to enable the slow-running paddle-wheel engines to meet this condition the engineers of the day preferred to have recourse to mechanical gearing rather than to risk experiments with engines having a higher speed of revolution. A large toothed wheel was therefore mounted on the engine shaft and arranged to work into a smaller toothed wheel or pinion carried on the screw shaft. The teeth were in several rows and staggered, those of the large wheel being made of some tough wood inserted in the periphery, while those of the pinion, which were cast, were of iron.

This arrangement, which forms an interesting anticipation of that adopted later with the turbine, though in that case the purpose was to reduce the rate of revolution of the propeller shaft, not to increase it, was continued until about 1860, when with the aid of the higher boiler pressures which had then become available engines were constructed to run at sufficiently high speeds to enable them to drive the screw shaft directly. Differing from the paddle-wheel engines, the cylinders of which were placed either vertically on the bottom of the ship or in an inclined diagonal position, these were arranged horizontally. Space being limited transversely across the beam of the ship, various devices were adopted in order to get a sufficient length of connecting rod. Thus the Maudslay "return connecting rod" engine had double piston rods, one above and the other below the crank shaft, communicating with crossheads and guides fitted on the opposite side of the crank to that of the cylinder. In the Penn "trunk" engine the piston had attached to it a hollow trunk working through a steam-tight stuffing box in the end of the cylinder and the connecting rod was attached to a gudgeon pin in its centre, the arrangement being in fact similar to that followed subsequently in the motor-car engine. Later, when twin-screws came into vogue, the Humphreys direct-acting horizontal type, with the connecting rod between the cylinder and the crank, became the standard type.

The next great change in the arrangement of the engines was the introduction of the inverted vertical type, with the cylinders placed above the shaft. This type, which eventually became universal in all screw steamers not driven by turbines, was adopted for large naval ships in 1885, though the horizontal engine was retained in sloops and gun boats for a few years longer. Its advantages had long commended it to the mercantile marine, but the naval engineer hesitated in adopting it because it could not, as could the horizontal type, be placed entirely below the water line. However, this difficulty of protection was got over by the aid of armour and by carrying the coal bunkers round the engine room, so that a projectile would have to pass through a mass of coal



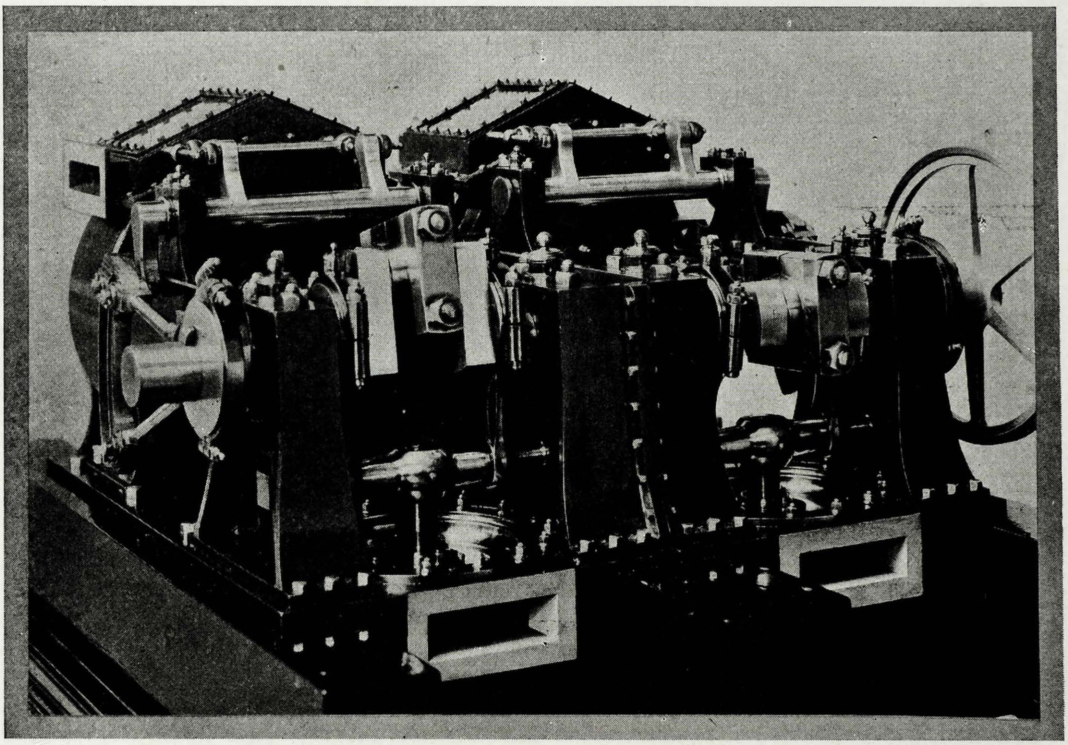
HORIZONTAL ENGINES OF H.M. ARMOUR-CLAD SHIP "VALIANT," 1862.

These engines had return connecting rods, the two piston rods of each cylinder being placed one above and the other below the crank axle.

before it could reach any portion of the engines that projected above the water line.

Meantime, again as a result of the higher steam pressures obtained through the adoption of the surface condenser and improvements in boiler construction, another great innovation was introduced in the shape of compound or double expansion engines. These were generally adopted in naval vessels, between 1870 and 1885, but again it cannot be said that the Admiralty showed unseemly haste in taking advantage of the innovation, for it had been successfully applied to marine purposes by John Elder in 1854. The steam pressure at first used with it in the Navy was 60 lb. per square inch, but gradually rose to 90 lb. about 1880 and finally to 120 lb. The principle consisted in dividing the expansion of the steam, and therefore the work it did, between two cylinders, instead of completing it in one. Sometimes the smaller or high pressure cylinder in which the first portion of the expansion took place was arranged in tandem with the larger or low pressure cylinder in which the expansion was completed, the two pistons being carried on one rod; but more generally the two cylinders were placed side by side. There were then two piston rods acting on cranks set at right angles to each other. In the case of large engines the second expansion was sometimes divided between two cylinders, because the size of a single cylinder would have become inconveniently great; in that case there were three pistons, with three cranks generally set at equal angles to each other.

With increasing steam pressures it was found advisable to extend the compounding principle to triple expansion, in which the expansion of the steam was effected in three stages, and even to quadruple expansion, with four stages, though the latter was not employed to any extent in the Navy. Triple expansion was tried in 1874 by Dr. A. C. Kirk in the Propontis, but the experiment was marred by the unsatisfactory behaviour of the boilers. Kirk was more successful in a second attempt in 1881 with the Aberdeen, employing a pressure of 125 lb., and in 1885 triple expansion engines began to be fitted in new ships for the Navy. The steam pressure was at first 130 lb., but was soon increased to 155 lb., which remained general until 1895. But in the cruisers Powerful and Terrible, which were launched in that year and ran their trials in 1896–97, there was a jump to 210 lb. at the engines, reduced from 250 lb. in the boilers, and in subsequent ships the pressures were raised to 250 lb. at the engines (300 lb. in the boilers). In those cruisers, which were of 25,000 horse power, divided between two screws, the last stage of the expansion was carried out in two equal low-pressure cylinders, so that there were four cranks. With this arrangement, which became standard for battleships and cruisers of over 10,000 h.p.,



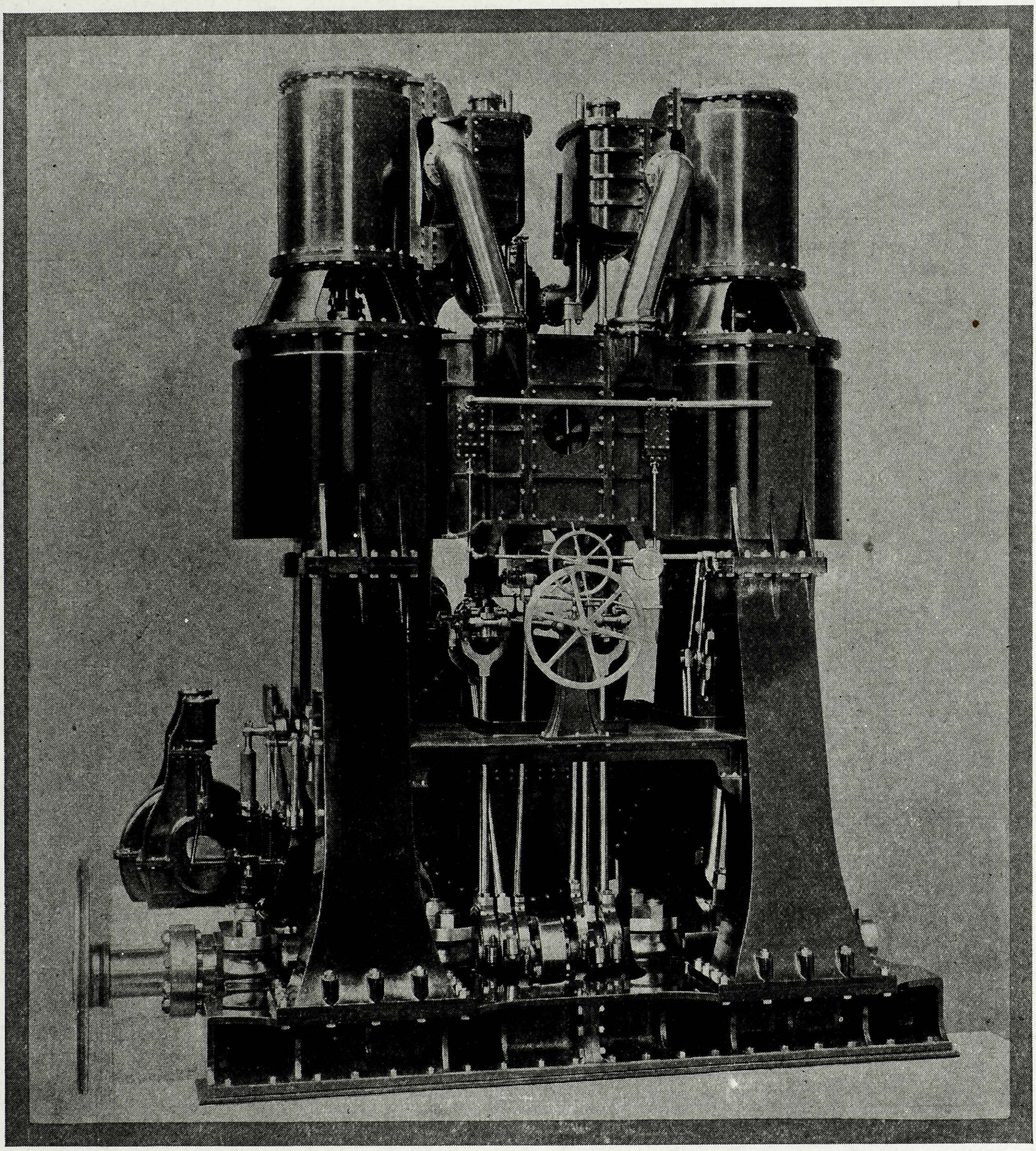
HORIZONTAL ENGINES OF H.M.S. "AJAX, 1848.

These were the first direct-acting screw engines fitted in the British Navy. The illustration is an end view, showing the two cranks at right angles.

not only could the low-pressure cylinders be kept of reasonable size, but reduction of vibration was facilitated, by placing the cylinders in such order and setting the cranks at such angles as to balance the engines as perfectly as possible.

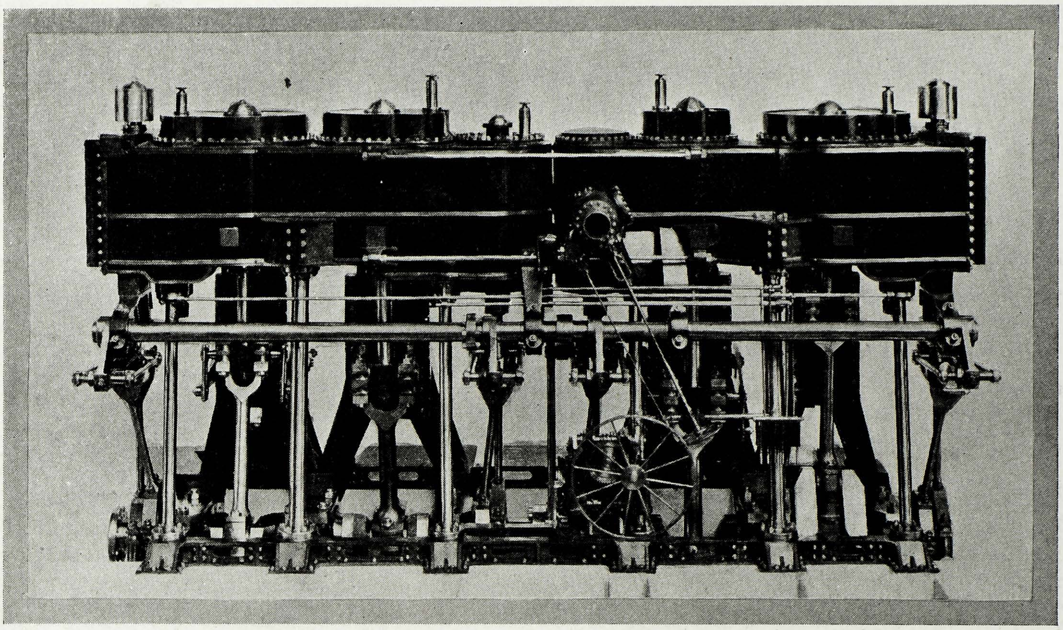
The advantages of the compound as compared with the single-stage expansion engine were summarized by Sir Henry Oram (*The Marine Steam Engine*, by Sennett & Oram) as being (1) reduction of the maximum stresses on the framing, and consequent reduction of weight and cost; (2) increased regularity of turning moment and consequent increased efficiency of the propeller in the water; and (3) more economical use of the steam in the cylinders and consequent increase of power from a given expenditure of heat. He stated that the gain in economy of fuel with even the 60 lb. compound engines over ordinary surface-condensing engines with steam at 30 lb. pressure might be taken as at least 30 per cent., and that of triple expansion engines with steam at 130 lb. to 150 lb. over compound engines with steam at 90 to 100 lb. as 15 to 20 per cent.

The following figures, taken from the same book, will give an idea of the extent to which the weight of the machinery in relation to the



COMPOUND INVERTED VERTICAL ENGINES, 1864.

The high-pressure cylinders (on top) were arranged in tandem with the low-pressure ones (below).



TRIPLE-EXPANSION INVERTED VERTICAL ENGINES.

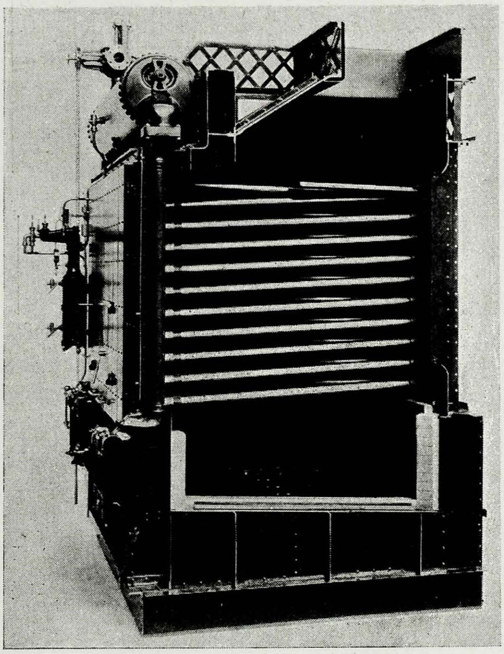
power developed was reduced by the improvements described so far :

Date	Character of Machinery	Weight per indicated horse-power. Cwt.
1832	Flue boiler, 4 lb. pressure, side-lever engine driving paddle wheel	$13\frac{3}{4}$
1850	Tubular boiler, 14 lb. pressure oscillating engine and paddle-wheel	$4\frac{1}{4}$
1860	Box boiler, 20-25 lb. pressure, horizontal single expansion engine, jet condenser and screw propeller	$3\frac{3}{4}$
1870	Box boiler, 30-35 lb. pressure, horizontal single expansion engine, surface condenser, screw propeller	3
1890	Cylindrical boiler, 155 lb. pressure, triple expansion inverted vertical engines, screw propeller	$1\frac{1}{2}$–$1\frac{3}{4}$

In a previous paragraph reference was made to the jump in steam pressure seen in the cruisers Powerful and Terrible in 1895. This jump was due to the adoption of water-tube boilers, which have already been mentioned as being one of the three great factors in the progress of naval engineering in the quarter of a century preceding the outbreak of the war. Innumerable forms of water-tube boilers were constructed, but the cardinal feature in all of them was the same—that the water is contained in the tubes round which the heated furnace gases play, in contradistinction to the old tank or fire-tube type in which the gases on their way to the funnel pass through the tubes, on the outside of which is the water that is to be heated

The water-tube boiler was not new in idea, and dates back at least to the beginning of the nineteenth century ; but in spite of the efforts of numerous inventors and constructors they retained disadvantages which were held to render them unsuitable for use in the Navy. Perhaps, indeed, too much was made of those disadvantages, because tank boilers appeared to satisfy the demands of the engine designer, and there was a natural reluctance to make drastic changes in practice until they became inevitable. By the 'nineties, however, it had become evident that the tank boiler had about reached the end of its tether, and could not well be made in large sizes to meet the requirements of the high-steam pressures needed to enable full advantage to be taken of the multiple expansion principle. The Admiralty were therefore practically forced to make the change, though their engineering advisers would have been spared much criticism and tribulation of mind had they been content, as it must be confessed they had been in the case of some other developments, to allow the mercantile marine to make the initial experiments and overcome the difficulties that are inseparable from any radical innovation. But if they had elected to tread this primrose path of least resistance the ships of the British Fleet would have had to wait long for water-tube boilers, since at the time of the Great War they had found but little favour in British merchant vessels.

The Admiralty began tentatively by fitting water-tube boilers in some of the smaller vessels, but their first large experiment was made in the Powerful and Terrible. For these cruisers they settled on the Belleville type, which had been used with satisfactory results in the French Navy for more than ten years, and they had the justification for their choice that this was the only large tube type of water-tube boiler which had been tried at sea under ordinary working conditions on a considerable scale. That some defects and difficulties

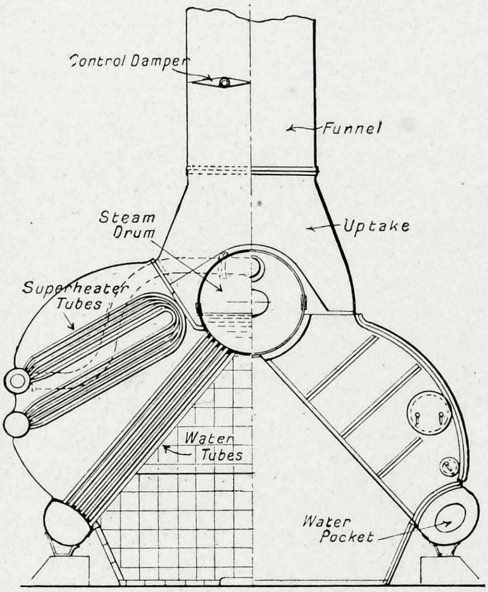


BELLEVILLE BOILER.

should be found in working a new device with which the boiler-room staffs were not familiar was not surprising—and the influence of the personal factor is shown by the fact that there were instances of these boilers proving a success in one ship, while a precisely similar installation of them in another precisely similar ship was set down a failure. The troubles which occurred were, however, seized upon by the adherents of the tank boiler, and such an outcry was raised against the Belleville in particular and the water-tube type in general that in 1900 the Admiralty appointed a committee to investigate the matter. An interim report issued in 1901 was in general unfavourable to the Belleville, which it advised should not be fitted in future new ships, but the opinion was expressed that the advantages of water-tube boilers for naval purposes were so great, mainly from the military point of view, that, provided a satisfactory type was adopted, they would be more suitable for use in the Navy than the cylindrical type. In the next two or three years the Committee carried out a number of special comparative trials with different types of boiler, and when in 1904 they issued their final report—the last of ten—they expressed themselves as satisfied that the Babcock & Wilcox type (as used in the Hermes) and the Yarrow large tube type were satisfactory and suitable for use in battleships and cruisers. For small cruisers they thought it probable that a boiler such as the Yarrow large tube type would give better results than the "express" small tube type previously fitted, while for torpedo-boat destroyers they regarded some form of boiler with small tubes closely packed as absolutely necessary to obtain the required ratio of output to weight of boiler.

In consequence of this report the Babcock & Wilcox and the Yarrow types were fitted in about equal numbers in large warships; and in 1909 Sir Henry Oram was able to declare that, although boilers had been until quite recently a constant source of anxiety to the Admiralty, serious troubles were then seldom met with. In the Babcock & Wilcox type the tubes are slightly inclined to the horizontal, and at each end are connected with sinuous headers from which pipes lead to a receiver above the tubes. Heated by the furnace below, the water rises up the inclined tubes to the upcast headers, whence it passes through the pipes to the receiver, to return down the downcast headers to the other and lower ends of the tubes. The steam is led off to the engines from the upper part of the receiver, which is kept about half full of water. In the Yarrow there is a steam receiver in the centre above and two water chambers at the sides below, the three being disposed triangularly, and the heating surface is formed by two groups of straight tubes, $1\frac{3}{4}$ inches in diameter, joining the receiver with each of the two water chambers. The Yarrow "express" type is of similar construction, except that the size of the tubes is smaller.

The three military requirements on which the Water Tube Boiler Committee laid stress as being necessary in naval boilers were (1) rapidity of raising steam and of increasing the number of boilers at work; (2) reduction to the minimum of danger to the ship through damage to the boilers by shot and shell; and (3) the

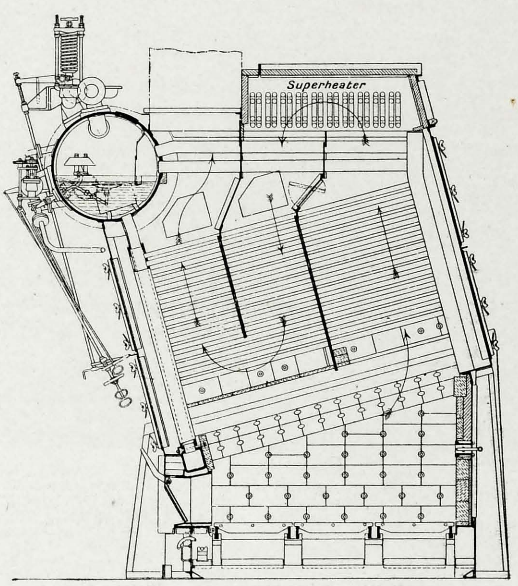


YARROW BOILER, WITH SUPERHEATER; SECTION AND ELEVATION.

possibility of removing damaged boilers in a very short time and without opening up the decks or removing the fixtures of the hull. They declared that these requirements are met by the water-tube boiler to a greater degree than by the cylindrical, and they regarded them as being of such importance as to outweigh the advantages of the latter type in economy of fuel and cost of upkeep. The rapidity with which steam can be raised—in some forms it can be done within half an hour of lighting the fires—is a consequence of the small quantity of water in the tubes, and this in turn is partly responsible for the smaller weight of the water-tube as compared with the tank type of equal power, the lightness of the component elements in relation to their strength being another contributing factor. In the course of their trials the Committee got a maximum output of 200,000 lb. of steam an hour from the Babcock and Wilcox boilers of the Hermes, or 410 lb. of steam per ton of boiler. With the Yarrow boilers in the Medea, weighing 330 tons, the output of steam was 157,000 lb. an hour, or 478 lb. per ton of boiler. But in the Minerva the tank boilers weighed 567 tons for an output of 167,100 lb. of steam under forced draught, or 295 lb. per ton, while in the Cunarder Saxonia the cylindrical boilers weighed 1,000 tons, but the output of steam was only 132,600 lb. an hour, or 132·6 lb. per ton.

Those present at the Diamond Jubilee Naval Review held at Spithead in 1897 were greatly interested in a small vessel of the torpedo-boat class which darted at enormous speed along the lines of warships after the Royal procession had passed. The patrol-boats whose duty it was to keep the lines clear were hopelessly outclassed in point of speed, and the only way in which they could check the intruder's lawless proceedings was to place themselves athwart her course and thus drive her out of the lines. This vessel was the Turbinia, built by the Hon. C. A., afterwards Sir Charles, Parsons, and embodying an invention which in a few years was destined to revolutionize the propelling machinery of the British and other navies.

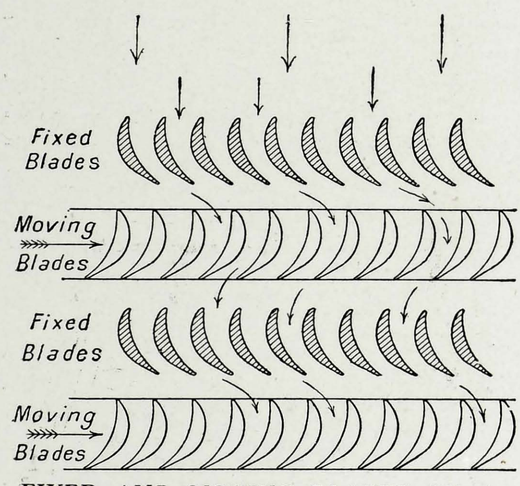
Sir Charles Parsons, the youngest son of the third Earl of Rosse, of telescope fame, a few years after graduating at Cambridge as eleventh wrangler in 1877, devoted himself to the development of the rotary steam engine. The oldest form of steam engine known, the æolipile of Hero of Alexandria (about 130 B.C.) was of this type, consisting of a hollow pivoted globe supplied with steam the reaction of which as it issued from nozzles caused the whole apparatus to rotate in the opposite direction to that of the steam outflow; but the efforts of various inventors had failed to utilize the principle in a practical way until success was reached by Sir Charles Parsons. It was in 1884-85 that as a result of many experiments he produced a rotary engine or turbine of about 10 horse-power which was successfully used for driving an electrical generator, and in the following five years some 300 of these machines were made



BABCOCK & WILCOX BOILER.

ranging up to a power of 75 kilowatts. So far as the engine or motor part was concerned, the first machine consisted of two groups of 15 successive turbine wheels or rows of blades on one drum or shaft within a concentric case. The moving rows or rings of blades or vanes were attached to the shaft, projecting outwardly from it, and nearly touching the case, while between them were rows or rings of fixed or guide blades projecting inwardly from the case and nearly touching the shaft. Thus a series of turbine elements or wheels was constituted, each complete in itself and each comprising one row of fixed blades and one row of moving blades. The steam, after doing its work on one wheel or element, passed on to the next, preserving its longitudinal velocity without shock, and gradually falling in pressure and expanding as it passed through the different rows of blades. Each successive row of blades was made rather larger than the one before in order to accommodate the increasing bulk of the expanding steam.

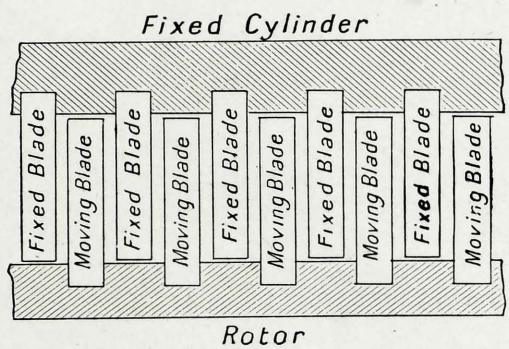
In Sir Charles Parsons' own words the steam in a turbine passes through a forest of fixed and moving blades, just as water flows from a lake of higher level (the boiler) through a series of rapids and intervening pools to a lake of



FIXED AND MOVING BLADES OF A TURBINE.

The arrows show the course of the steam.

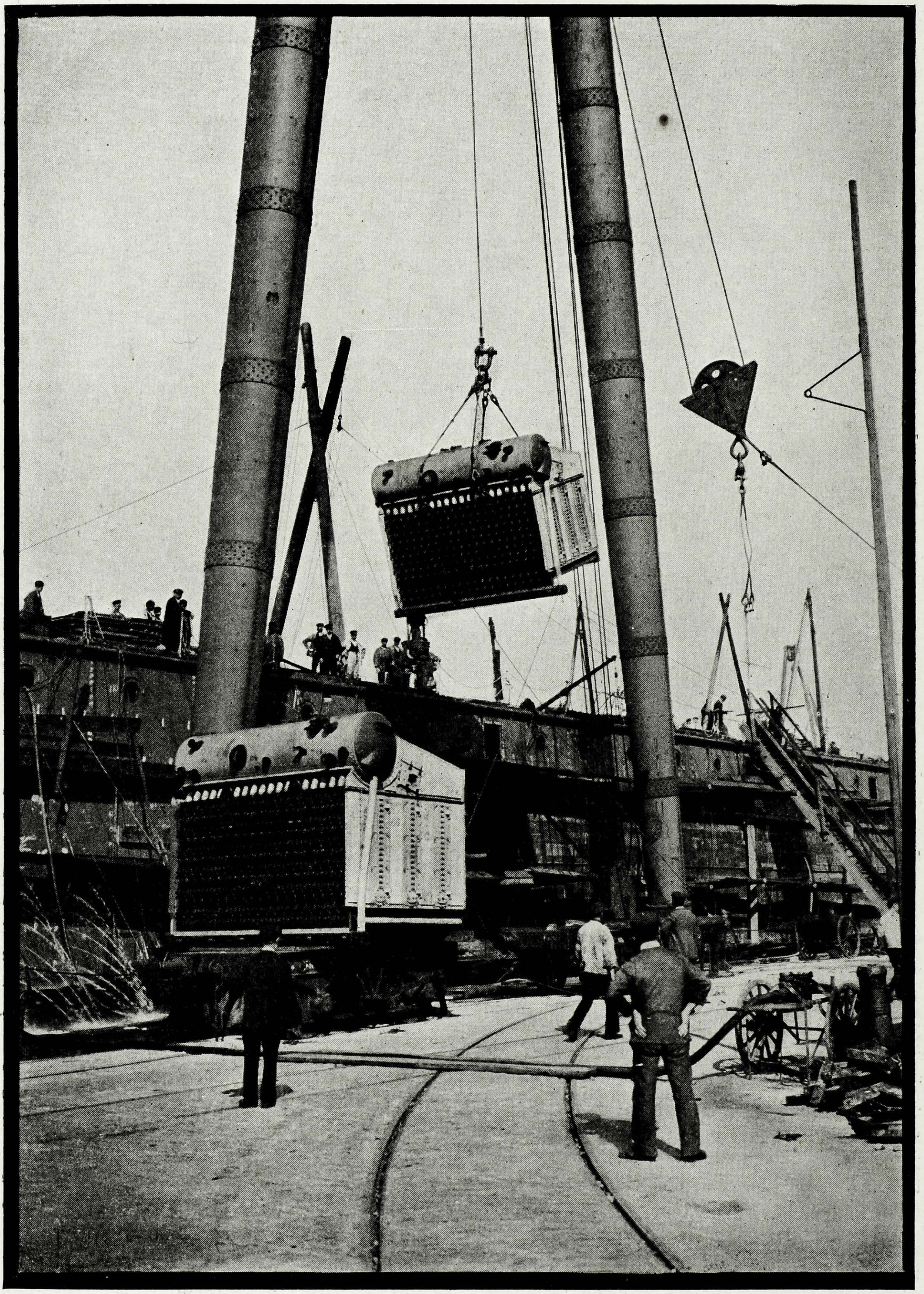
lower level (the condenser). In its flow it repeatedly gathers a little velocity from the small falls of pressure, which is as soon checked and its energy transferred to the blades, over and over again, 50 to 100 times or still oftener. The result of splitting up the fall in pressure of the steam into small fractional expansions over a large number of turbine elements in series is that the velocity of the steam is nowhere great, and thus a relatively moderate speed of rotation of the turbine suffices for the highest economy. In considering how the power is developed it must be remembered



ARRANGEMENT OF TURBINE BLADES.

that the steam flows through the turbine with a force ten times that of the strongest hurricane, and although the force acting on each blade is small, perhaps only a few ounces or in the largest blades a few pounds, the summation of these little forces mounts up to an aggregate of many thousands of horse-power in large machines. In the engines of the Mauretania and Lusitania, of nearly 80,000 horse-power, there were some 880,000 blades, varying in length from $2\frac{3}{4}$ to 22 inches, and large as these installations were they were merely the pre-runners of others of still greater power.

The Parsons turbine, like the primitive machine of Hero, was of the reaction type, as opposed to the impulse type. The latter type in its most elementary form may be regarded as a wheel provided with vanes which are blown round by the steam impinging upon them. In reaction turbines the steam, leaving a row of fixed blades at a high velocity, is guided so as to strike the adjoining row of moving blades in a series of jets, causing them to rotate. Then traversing their curved inner surfaces it leaves them as it were with a kick, which further assists in their rotation, and strikes the next row of fixed blades, from which it is again thrown off upon the succeeding row of moving blades. This process is continued through many stages of fixed and moving blades until the energy of the steam is exhausted; indeed, one of the great merits of the turbine is that it is able to utilize the energy of the steam when expanded to the very attenuated vapour densities produced by the best condensers. The reciprocating engine

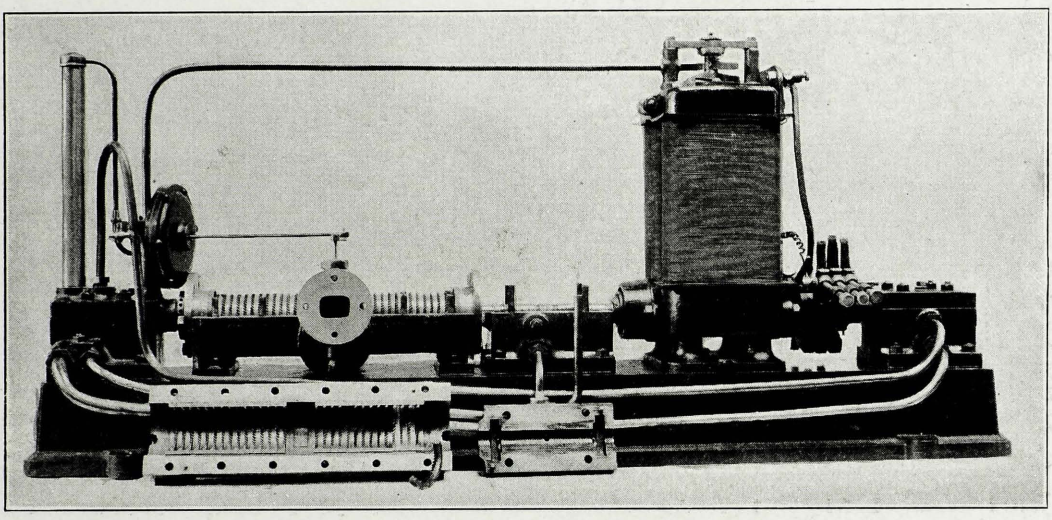


HOISTING WATER-TUBE BOILERS ON BOARD.

can take advantage of only about two-thirds of the whole range of expansion and cannot deal with very low densities of steam, one reason being, among others, that the low-pressure cylinders would have to be of such enormous size as to be impracticable. Hence in it use cannot be made of steam expanded to a pressure of less than 7 lb. absolute (about half an atmosphere). The turbine, on the other hand, can use steam at a pressure of only $\frac{1}{2}$ or $\frac{3}{4}$ lb. absolute, equivalent to a vacuum of $28\frac{1}{2}$ or 29 inches in the condenser. With turbine machinery, therefore, good condensing arrangements become imperative, for the sake of economy in steam consumption. Sir Charles Parsons recognized this fact from the first, and his jet vacuum augmenter was an important contribution to the practical solution of the problem.

and moving discs, and so on through the whole series to the exhaust, the action being the same as in the parallel flow type.

The question of the application of the turbine to marine propulsion was taken up in 1894, when a small company, the Marine Steam Turbine Company, of which Sir Charles Parsons



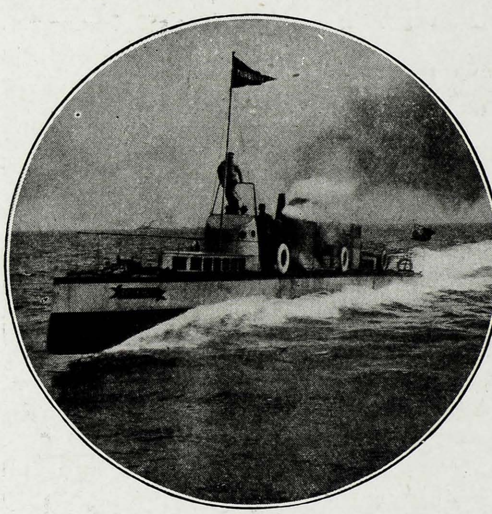
THE ORIGINAL PARSONS TURBINE, EXHIBITED AT THE SCIENCE MUSEUM, SOUTH KENSINGTON.

For the first five years after the manufacture of Parsons turbines was begun they were all constructed on the parallel flow principle, which from the first he had considered the most suitable for his purpose and on which he therefore concentrated his attention. But in consequence of a partnership dispute he lost his rights over the patents that covered it and was debarred from continuing to work on it. In these circumstances he reluctantly turned his attention to another type of turbine, that with radial flow. In this there were a series of fixed discs, with interlocking flanges at the periphery, forming when placed together co-axially a cylindrical case with inwardly projecting annular discs. On the shaft were keyed a similar series of discs, the faces of the fixed and moving discs lying a short distance apart. From the faces of the fixed discs projected rows of guide blades which nearly touched the moving discs, and in the same way from the moving discs projected rows of blades which nearly touched the fixed discs When steam was admitted to the casing, it passed outwards through the rows of fixed and moving blades between the first fixed and moving discs, then inwards towards the shaft at the back of the first moving disc and outwards again between the second fixed

was managing director, was formed with the object of carrying out exhaustive tests. The prospectus summarized the advantages to be obtained from the new system in connexion with the propulsion of ships as being increased speed, increased carrying power of vessel, increased economy in steam consumption. reduced initial cost, reduced size and weight of machinery, reduced cost of attendance on machinery, diminished cost of upkeep of machinery, and largely reduced vibration. The construction of successful land turbines had involved much more than what may be called the steam part of the problem. For example, special bearings had to be designed to suit the high speeds of rotation (the first small Parsons turbine made 18,000 revolutions a minute), the mode of lubrication had to be considered, methods of the fixing the blades in position had to be worked out, and attention given to governing and numerous mechanical details. But when it came to marine propulsion it was recognized that other fundamental problems were involved, the most important being the adaptation of the screw propeller to the high speed at which the turbine had to revolve if it was to work with reasonable efficiency and economy

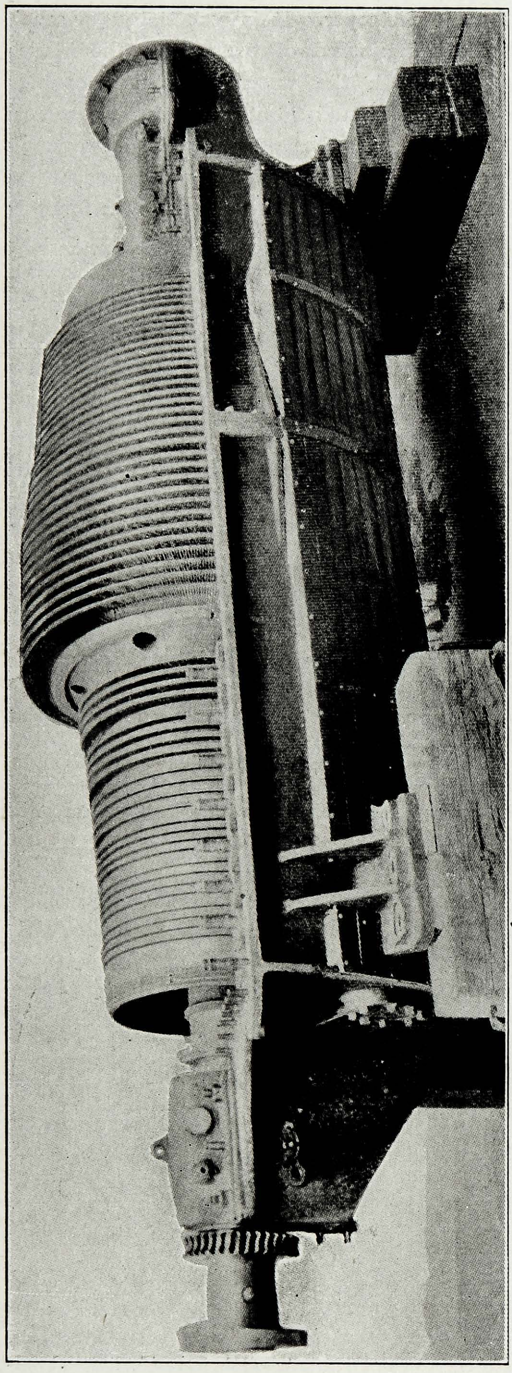
Various model experiments with propellers had already been made by Sir Charles Parsons when, in 1894, the Marine Steam Turbine Company erected works at Wallsend-on-Tyne and began to construct the Turbinia. The vessel was 100 ft. long and 9 ft. in beam, and at a draught of 3 ft. she had a displacement of about 44 tons. The boiler fitted was of the water-tube type, with straight tubes $\frac{1}{2}$-in. in internal diameter, and the heating surface was 1,100 square feet, with 42 square feet of grate area. The turbine drove a single shaft, and had to be of the radial flow type, as when it was designed Sir Charles Parsons had not recovered his patent rights over the parallel flow principle. The preliminary trial of the vessel was run on November 14, 1894, but in spite of numerous variations in the propellers—first with a single screw, and later with multiple screws—the results were disappointing, because the speed obtained, $19\frac{3}{4}$ knots, was not nearly so great as it should have been considering the horse power developed by the engine, which was ascertained to be 960 at 2,400 revolutions. It may be mentioned that to make this measurement special apparatus had to be devised. In a reciprocating engine the power can be calculated from the diagram drawn by an instrument known as an indicator, which shows the pressure within the cylinder at all points of the stroke of the piston ; but this arrangement is not applicable in the case of the turbine. Sir Charles Parsons therefore inserted a spring coupling between the turbine and the propeller shaft, and from the compression of the springs, or the extent to which the engine shaft was twisted in relation to the propeller shaft, calculated the power that was developed. Subsequently various torsion meters, embodying much the same principle, were devised. When a shaft is rotated it is twisted to an extent that depends on the quality of the steel and the load that it carries. Therefore if the amount of twisting that is caused by a certain load on a given shaft is known, and the extent to which the shaft is actually twisted when in use is measured, as it can be by a torsion meter, the power that the engine must be developing to produce that twist can be calculated. The result is usually expressed in the case of turbines as shaft horse-power.

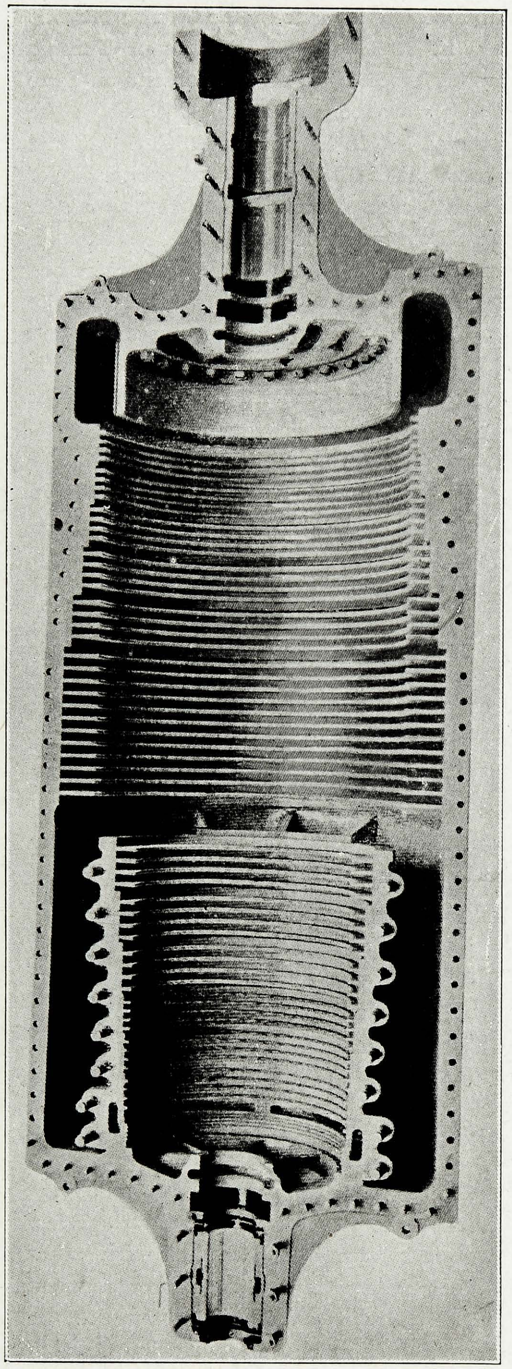
The trouble with the Turbinia in her first form was traced to a phenomenon known as cavitation, which had been noticed in 1893 by Sir John Thornycroft and Mr. Sydney Barnaby during the trials of the Daring, a 27-knot torpedo destroyer. It is caused by too much work being asked of the screw ; the blades tear through the water, producing cavities which contain no air but only vapour of water, and into which the water cannot flow quickly enough to fill them up, the result being that the power of the engine is wasted in forming and maintaining these cavities, instead of usefully employed in driving the ship forward. It was therefore resolved to divide the power in the Turbinia between three shafts instead of concentrating it on one, and to build new turbines, this time on the parallel flow principle, the rights over which had been recovered. Three separate turbines were provided, each driving its own propeller shaft, and were connected in series, so that the expansion of the steam was divided between the three instead of being completed in one. The first portion of the expansion was effected in the high-pressure turbine placed on the starboard side, the second portion in the intermediate turbine on the port side, and the final portion in the low-pressure turbine in the centre. As turbines can run in only one direction, and cannot be reversed like reciprocating engines, another turbine for going astern was placed forward of the low-pressure turbine on the central propeller shaft. Each shaft carried three screws of improved design.



THE "TURBINIA," THE FIRST TURBINE-DRIVEN STEAMBOAT, 1896.

The result of these changes was that the vessel attained a speed of $32\frac{3}{4}$ knots on the measured mile, and from tests made by Sir J. A. Ewing in 1896 it appeared that the maximum speed was obtained when the outer or wing propeller shafts were running at 2,230





PARSONS TURBINES, OUTER FIXED CASE AND INNER REVOLVING DRUM OR ROTOR.

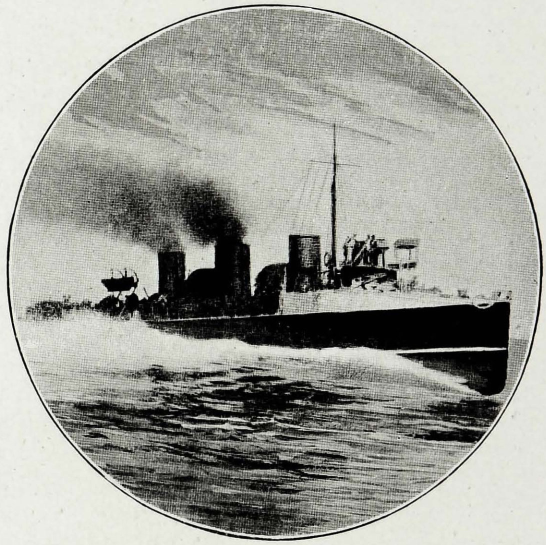
revolutions a minute, and the middle shaft at 2,000. At the Naval Review she was pressed to steam 34½ knots, representing about 2,300 horse-power. She thus developed 100 horse power for every ton of her machinery, which, including turbines, boilers, shafting, etc., weighed 22 tons, the turbines alone weighing only 3 tons 13 cwt. At 31 knots she consumed 14½ lb. of steam per horse-power, equivalent with a good marine boiler to less than 2 lb. of coal per horse-power, a result better than was obtained in a torpedo-boat or torpedo-boat destroyer with ordinary triple expansion engines. Her reversing turbine gave her a speed astern of 6½ knots, and she could be brought to rest from 30 knots in 36 seconds, and from rest up to 30 knots in 40 seconds.

After the success of the Turbinia the Parsons Marine Steam Turbine Company, an enlargement of the syndicate which had built that ship, received an order from the Admiralty for a turbine-driven torpedo-boat destroyer, the

Viper, of the same dimensions (210 ft. long, 21 ft. beam) as the usual 30-knot vessels of that class. She had four shafts, each with two screws.* Each of the outer shafts had one high-pressure turbine, the steam from which was taken to two low-pressure turbines, one on each of the inner shafts, the four turbines being of about equal power. On each of the two inner shafts there was also an astern turbine in a separate casing forward of the low-pressure turbines ; these astern turbines ran in a vacuum when not in use. With her full trial weights on board, when her displacement was 370 tons, the Viper showed a mean speed of 36·58 knots on an hour's full power trial, her fastest run on the measured mile being 37·113 knots, nearly 43 miles an hour. This latter speed meant a horse-power of about 12,300, or about double that obtained from triple expansion reciprocating engines in 30-knot destroyers of similar dimensions but only 310 tons displacement. The Viper ran ashore and was wrecked near the Channel Islands in August 1901, and six weeks later the Cobra, another somewhat larger torpedo-boat destroyer, which had been fitted with turbine engines, was lost in a storm in the North Sea.

Another destroyer, the Velox, launched in the following year, was of the same dimensions as the Viper and was fitted with the same arrangement of turbines. In addition, however, she was provided with two triple expansion reciprocating engines of 150 horse-power each, which could be coupled to her two inner shafts. The intention in fitting these was to increase economy at low cruising speeds, when the efficiency of the turbines fell off, and they were used at speeds up to 12 or 13 knots, the steam from them being passed into the main turbines. At higher speeds they were disconnected. In the destroyer Eden, launched in 1903, two cruising turbines, one high-pressure and the other low-pressure, were fitted in place of such engines, with the same object.

An extension of the use of turbines to larger ships was made in 1902, when it was decided to fit them in the Amethyst, one of four 3,000-ton cruisers then building. Here there were only three screw shafts. The central one was driven by a high-pressure turbine, and each of the side ones carried a cruising turbine forward and a low-pressure one aft, one of the cruising turbines being high-pressure and the other low-pressure. Comparison between the performance of the Amethyst and her three sister boats having triple expansion reciprocating engines was very definitely in favour of the turbine machinery. While the limit of the other ships, with the same boiler power, was about 22 3 knots, the Amethyst easily steamed at 23·6 knots, and that with a coal consumption about 10 per cent. less. At low speeds, of about 10 knots, she was, however, less economical, but at about 14 knots she came to an equality with the other vessels. The actual weight of the machinery was the same in all of them to within a few tons, but the turbines of the Amethyst



H.M.S. "VIPER," AN EARLY TURBINE TORPEDO-BOAT DESTROYER.

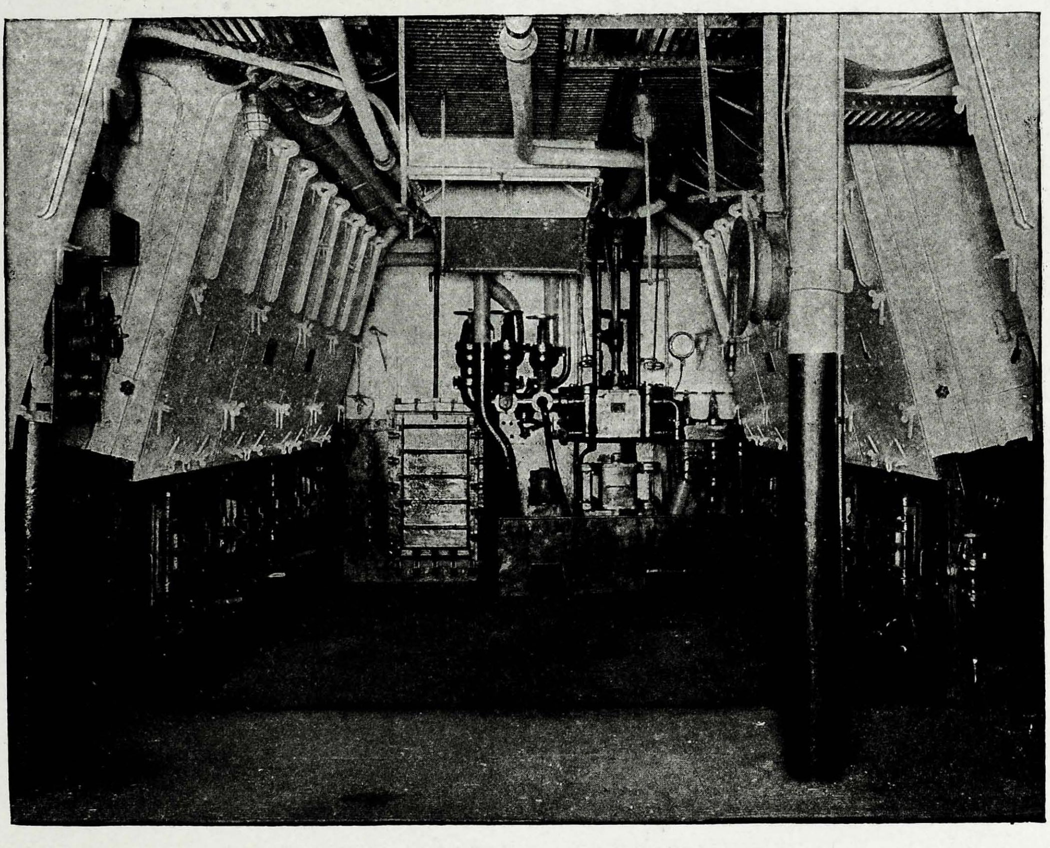
were substantially lighter in relation to their power, for at the speed of 23·6 knots it was calculated they gave 26 horse-power per ton, whereas the reciprocating engines of the Topaze, one of the sister ships, gave only 18·3 horse-power per ton.

The final triumph of the turbine came when the committee appointed by the Admiralty in 1905 recommended its adoption in the Dreadnought, and thenceforward it became the standard method of propulsion for the steam vessels of the British Navy. The reasons officially assigned for this decision were saving in weight and reduction in number of working parts ; reduced liability to breakdown ; smoothness of working ; ease of manipulation ; saving in coal consumption at high power, and therefore in boiler-room space ; saving in engine-room complement ; and increased protection from damage

* The practice of fitting more than one screw on each propeller shaft was afterwards abandoned.

by shot and shell owing to the engines being lower in the ship. That the turbine system was not without disadvantages was recognized, but it was felt that the advantages much more than counterbalanced them. From the point of view of sea-going speed there was no difficulty in deciding in its favour, and the chief question about which doubt arose was in connexion with the provision of sufficient stopping and turning power for purposes of quick and easy manœuvring. It was considered, however, that all the requirements promised to be fully met by the adoption of suitable machinery.

For the large ships the four-shaft arrangement was adopted, the outer or wing shafts being driven by high-pressure turbines and the inner ones by low-pressure turbines. For the sake of manœuvring power astern turbines were provided on all four shafts. As Sir Henry Oram recorded, previous experience indicated that turbines would yield the same power as reciprocating engines with the use of 15 per cent. less steam, and accordingly in the Dreadnought a reduction of about 15 per cent. was made in the usual boiler proportions. This action was justified by the trial results, for whereas in reciprocating engines 16 lb. per indicated horse-power would be a fair average, her steam consumption for turbines only at full speed was found to be 13·48 lb. per shaft horse-power, the initial steam pressure at the turbines being 164 lb. per square inch by gauge. In three subsequent ships, according to Sir Henry Oram, the figure was reduced to just over 13 lb. per shaft horse-power, the steam pressure being 147 lb. per square inch. In the battle-cruisers of the Indomitable class, in which the turbines of 41,000 shaft horse-power were much greater in size and revolved more slowly than those of the Dreadnought, the boilers were made about 4 per cent. smaller proportionately than in the latter ship. The economy, however, surpassed anticipations, the steam consumption of the turbines at full power being only 12·03 lb. per shaft horse-power, with an average steam pressure of 123 lb. by gauge at the high-pressure steam turbine; and without going into further details it may be said that still better results were obtained later. It will be noticed how the adoption of the turbine brought with it the advantage of permitting the boiler pressures to be greatly reduced from those of 250 or

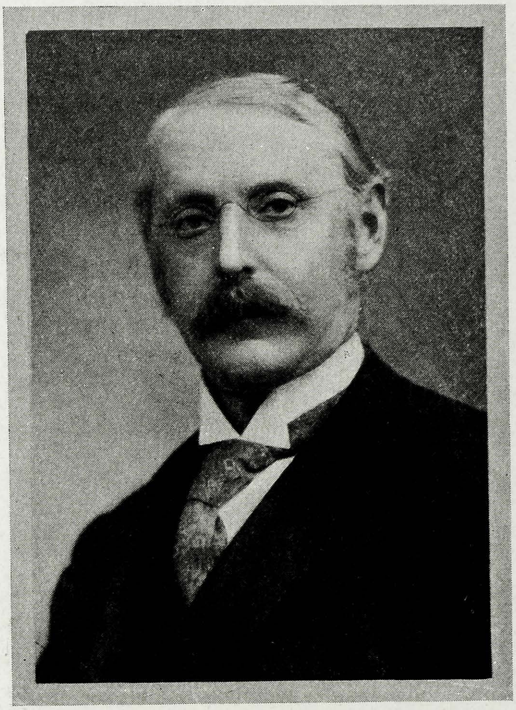


FIRE-ROOM OF A WARSHIP FITTED WITH BABCOCK BOILERS

300 lb. per square inch which had been reached in 1895 in the effort to make the most of the triple expansion reciprocating engine.

The economy in steam consumption, which was assisted by the "closed exhaust" system whereby the energy remaining in the exhaust steam from various auxiliary engines of the single-cylinder type was turned to useful account in the main turbines, was naturally accompanied by a decrease in coal consumption, which in the three Indomitable cruisers was reduced at full power to an average of just under $1\frac{1}{2}$ lb. per shaft horse-power per hour. This meant an increase in the radius of action for a given quantity of fuel, or alternatively a reduction in the quantity that had to be carried for a given radius of action. There was also a decrease in the weight of the propelling machinery in relation to power, and as time went on it was reduced, including all necessary auxiliaries, from about 140 lb. to about 100 lb. per shaft horse-power in battleships. In small fast ships like torpedo-boat destroyers, in which the machinery is of lighter construction than in large ships, striking reductions in weight were also achieved. In a destroyer with triple expansion reciprocating engines the weight of the machinery, including the water in the boilers and spare gear, was 58 lb. to 62 lb. per horse-power. The substitution of turbine engines, still with coal-fired boilers, knocked off 8 or 10 lb., but with oil-fired boilers it came down to 33 lb., and the use of steam with a moderate degree of superheat reduced it to 30 lb. A comparison of these results with the weight of 1,540 lb., which, as already recorded, was required for the development of one horse-power in a naval ship of 1832, shows the enormous improvements that were realized by the engineering branch of the Navy in the course of about 80 years.

In order to promote the economy of steam and fuel at lower speeds—an important matter seeing that warships spend much of their time in cruising at speeds which do not require the use of the full power of their engines—a cruising turbine was fitted on each of the inner shafts of the Dreadnought, but subsequently this arrangement fell into disfavour, the view adopted being that the increased economy secured by the cruising turbines was not worth the extra complication, cost and liab lity to injury entailed by their use. The alternative measures that were adopted for the purpose, such as the addition of a cruising element in the shape of an extra stage of shorter blades at the initial end of the main high pressure turbines, with by-passing arrangements, or the fitting of a velocity compounded impulse turbine wheel for the initial stages, cannot be dealt with here,

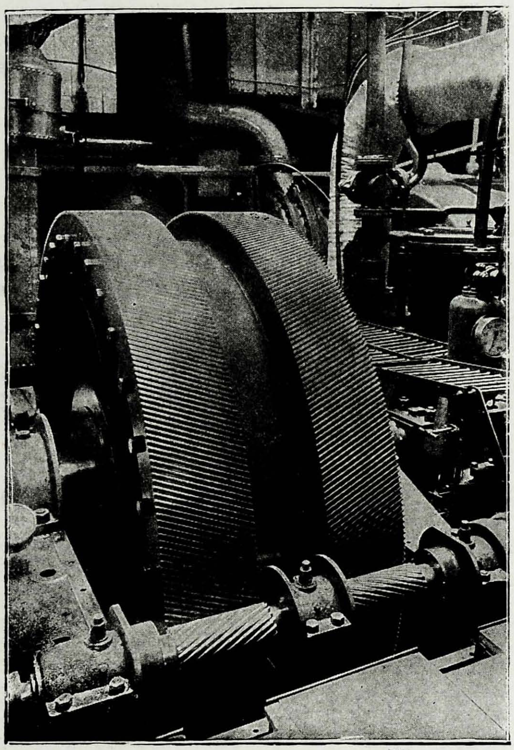


[Elliott & Fry.

THE HON. SIR C. A. PARSONS, K.C.B.
Inventor of the Parsons Turbine.

and for information about them, so far as it can be published, reference may be made to Mr. Alexander Richardson's book on the *Evolution of the Parsons Steam Turbine* and to the chapters on marine engineering contributed year by year to the *Naval Annual* by the same writer. Something, however, may be said about what Sir Charles Parsons once called the "inherent and permanent idiosyncracies" of the steam turbine and the screw propeller, since the subject leads up to the question of different forms of gearing in connexion with turbines.

In general terms it may be said that the screw propeller is essentially a slow-speed device. The steam turbine, on the contrary, is essentially a high-speed one. High-pressure steam expanding into a vacuum moves at an enormous velocity, and it is shown by theory, and confirmed by experience, that in the turbine, in order to obtain as much power as possible from a given amount of steam, the velocity of the moving blades relatively to the fixed or guide blades should be about half the velocity of the steam. In a turbine of large diameter and large power the fulfilment of this condition is compatible with a reasonably low speed of revolution, because the peripheral velocity of the moving blades is high owing to their radial length from the shaft ; but with small machines of small diameter the required blade velocity can be got only by increasing the rate of revolution of the shaft, and if the shaft is coupled



[*Engineering.*

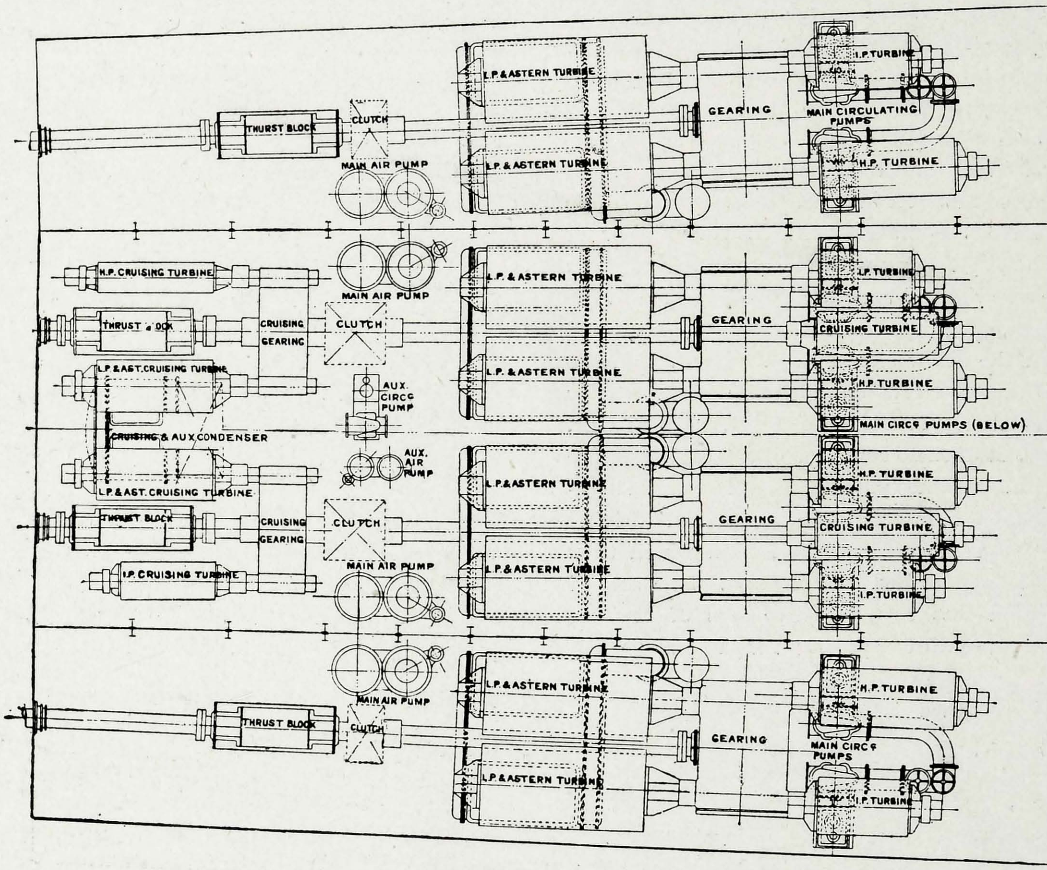
MECHANICAL GEARING OF THE "VESPASIAN."

direct to the propeller, in the usual way, the propeller revolves at excessive speed for efficiency. This was the difficulty found in the application of the turbine to vessels requiring speeds not exceeding 16 or 17 knots, but evidently it would be solved if the speed of the propeller could be reduced in relation to that of the turbine, so that both could be designed to run at speeds that would ensure good performance for both. This can be effected by gearing, of which three types are possible—mechanical, hydraulic and electrical.

Mechanical gearing, it will be remembered, was introduced in the early days of the screw propeller in order to get a faster rate of revolution than was attainable with the existing slow-running engines intended for paddle wheels. When Sir William White was Chief Constructor, he considered the possibility of applying it for the opposite purpose, of reducing the revolutions of the screws in connexion with high-speed reciprocating engines, and at his suggestion Dr. A. C. Kirk worked out a design for use in a cruiser, though it was not put into practice on account of the defects of gearing as then made. In the light of subsequent improvements Sir Charles Parsons, however, made some experiments about 1896, and in the following year a 22 ft. launch, fitted with a 10-horse-power turbine running at 20,000 revolutions a minute, was built by the Parsons Company, and provided with helical spur gearing, by which the two screw shafts were driven at 1,400 revolutions, a reduction of about 14 to 1. The speed was about 9 miles an hour. Dr. de Laval had also introduced helical gearing for reducing the very high speeds attained by his impulse turbine.

Some twelve years later Sir Charles Parsons renewed his experiments with helical gearing on a much larger scale. A cargo steamer, the Vespasian, of 4,350 tons displacement, was purchased, and after she had been thoroughly overhauled, her existing machinery, a set of triple expansion engines of about 900 horse-power, was tested for coal and water consumption in order to obtain data for comparison. They were then taken out and replaced by geared turbines, the original propeller, shafting, and boilers being retained. There was a high-pressure turbine on the starboard side, and a low-pressure one on the port side, their shafts each carrying pinions which geared into a wheel mounted on the propeller shaft. The revolutions of the turbines, 1,400 a minute, were thus reduced to 70 in the propeller shaft. At this rate of revolution, which represented the full power of the ship with the old reciprocating engines, it was found that the turbines gave an economy of 15 per cent., increased by subsequent minor alterations to 22 per cent. After the vessel had been employed for about a year in carrying coal from the Tyne to Rotterdam, and had travelled about 20,000 miles, the gear, which was entirely enclosed in a casing and continually sprayed with oil by a pump, was removed for examination, and the wear on the teeth of the pinion, which was of nickel steel, was ascertained to be less than two-thousandths of an inch. The loss in transmission through the gear was not actually measured, but on the basis of previous tests with experimental gears it was believed to be not more than 1½ per cent.

After this successful demonstration, mechanical gearing was applied to two cross-channel turbine ships belonging to the London and South-Western Railway, the Normannia and Hantonia, which were put into service in 1912. They were twin-screw vessels, and the power for each screw was derived from one high-pressure and one low-pressure turbine. The screws were designed to give a speed of $19\frac{1}{2}$ knots at 315 revolutions a minute, and the reduction gearing was so calculated that at this stated that 15 vessels, including ocean-going passenger steamships, cargo vessels, and destroyers, had been, or were being built, with geared turbines on the Parsons system and an aggregate exceeding 100,000 horse-power. He also pointed out that everyone familiar with warship design must realize the exceptional importance necessarily attaching to economies of weight, space, and consumption of steam and fuel made possible by the use of smaller quick-running turbines of high efficiency which trans-



SUGGESTED ARRANGEMENT OF TURBINES FOR A BATTLESHIP.

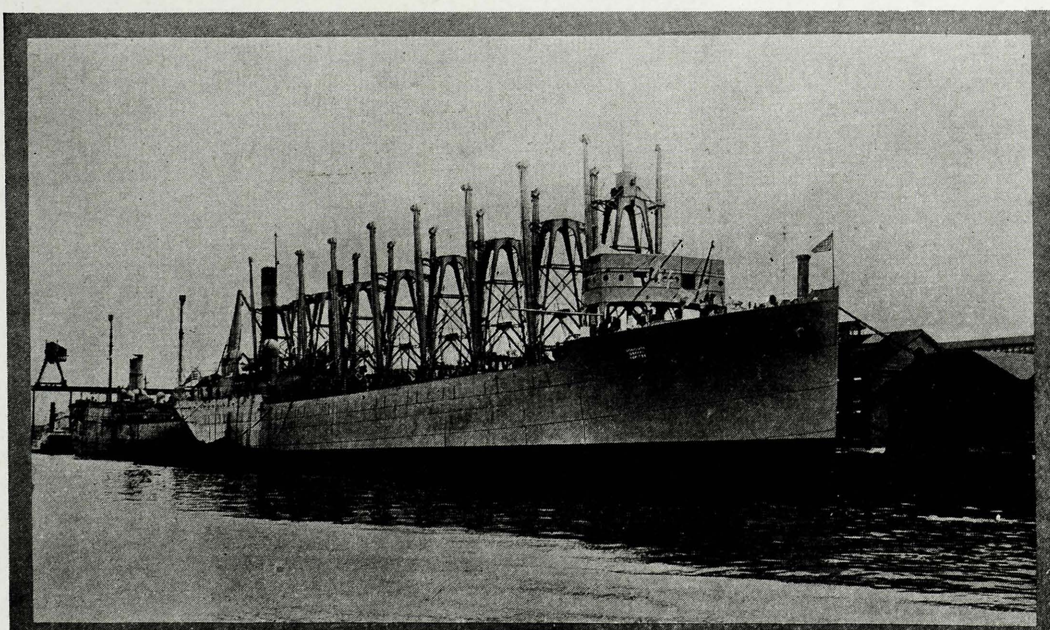
rate of revolution of the screw shafts the high-pressure turbines made 2,014 revolutions a minute and the low-pressure ones 1,392. On the six hours full-speed trials both ships slightly exceeded the designed speed with the turbines developing about 5,000 shaft horse-power. The coal-consumption was about 1·34 lb. per shaft horse-power per hour, and on six months' service at a speed of 18 knots they consumed nearly 43 tons a double trip, whereas another slightly larger vessel with direct coupled turbines, running on the same service at the same speed, used 72 tons per double trip.

In the same year as that in which these vessels were put into service, Sir William White

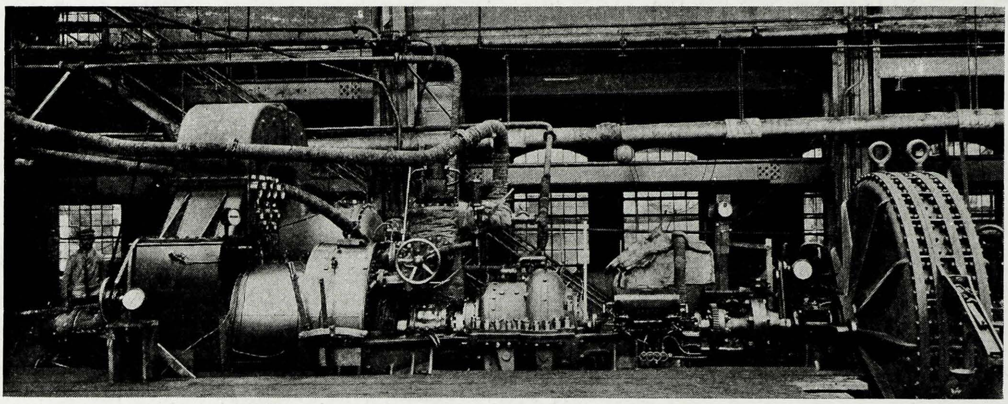
mit their power through reducing gear to the screws. This observation was confirmed by the statement made in the *Naval Annual* for 1914 that by gearing the weight of the turbines was being reduced to an amount which more than counterbalanced the weight of the gearing, and that there was a saving of space in the arrangement of the machinery. It was also mentioned in the *Annual* that geared turbines were working with a consumption of about 11 lb. of saturated steam per shaft horse-power per hour, that mechanical gearing was then fitted for the transmission of 15,000 shaft horse-power on one shaft, and that ratios of reduction as high as 26·2 of the turbine shaft to 1 of the propeller shaft were being used, ratios of 4 or 6 to 1 being employed in high-speed torpedo-boat destroyers and light armoured cruisers.

As an example of a possible method of applying and working gearing in a large ship, reference may be made to a design proposed before the Institution of Naval Architects by Sir Charles Parsons in 1913 for a four-screw battleship of about 60,000 shaft horse-power. Each screw was to be driven by a separate and independent set of turbines. To take the outer or wing shafts first, there was to be on each one high-pressure and one intermediate-pressure turbine forward of the gearing, and aft of it two low-pressure turbines, each incorporating an astern turbine in the same casing. Each of the ahead turbines was to drive a separate pinion, the four pinions of each set engaging with one wheel mounted on the screw shaft. A clutch was provided in the design, enabling the engines to be disconnected from the screw shafts when desired. On the two inner screw shafts there were similar installations of turbines, but with two additions. The first of these consisted of two high-pressure cruising turbines placed between the main high-pressure and intermediate turbines and driving direct on the screw shafts, from which they could be detached by a clutch. The second addition was two complete sets of cruising turbines (each comprising a high-pressure and a low-pressure cruising turbine, the latter combined with an astern turbine) placed aft of the main engines and driving the two inner screw shafts through gearing. A clutch enabled these cruising installations also to be disconnected at will. The object of these arrangements was to secure practically the same consumption of steam per shaft horse-power throughout the whole range of speed. At low speeds the two forward cruising turbines would be used, and at intermediate speeds the aft cruising installations, the main engines being cut out by means of the clutches. The consumption of oil fuel at full power was expected to be about 0·7 lb. per shaft horse-power per hour.

In the United States a considerable amount of attention was given to mechanical gearing for marine and other purposes by Admiral G. W. Melville and Mr. J. H. Macalpine. The distinctive feature of their system, with which Mr. George Westinghouse was also associated, lay in mounting the pinion in a floating frame. Their argument was that however perfectly the teeth might be cut, the slightest error of alignment of the pinion, which is long in proportion to its diameter, would produce great inequality of distribution of pressure along the teeth. The method they adopted for freeing the design from this delicacy of alignment was to mount the pinion bearings in a very stiff frame, supported near the middle of its length by the



THE "JUPITER," U.S. NAVAL COLLIER:
The first electrically propelled ship of the American Navy.



FÖTTINGER HYDRAULIC TRANSFORMER.

bedplate but (where the teeth were not in mesh) free to move about an axis transverse to the axes of the gear and the pinion. Thus the position of the pinion axis at any moment was partly determined by the interaction of the teeth, the result being great equality of distribution of tooth pressure. It was claimed therefore that such a floating frame gear would work satisfactorily with the pinion sensibly out of line, thus overcoming the difficulty of bad distribution of tooth pressure caused by minute errors of alignment, and that a higher average tooth pressure could be employed than with a rigid gear, reducing the weight of the apparatus in relation to the power transmitted. It may be mentioned, however, that no need for any such arrangement was found with the Parsons double helical gear, provided the teeth were cut with absolute accuracy, to ensure which special machinery was devised.

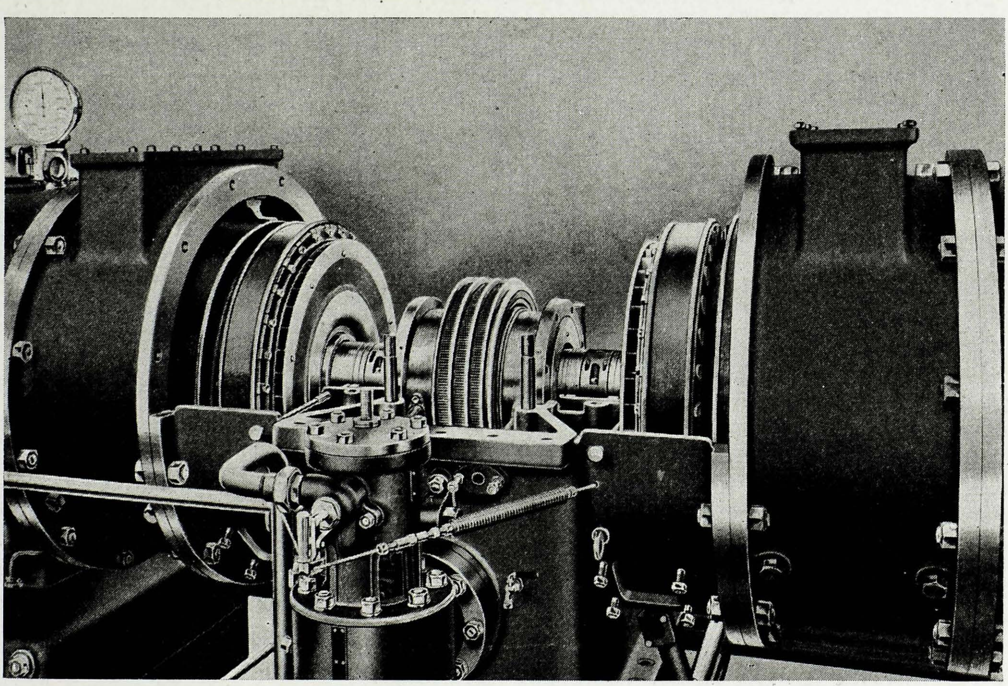
The floating frame system, which was adopted in a good many merchant ships, was fitted experimentally by the United States naval authorities in a naval collier, the Neptune, of 20,000 tons displacement, in order that comparative tests might be carried out between her and a sister ship the Cyclops, propelled by ordinary triple expansion reciprocating engines, and another sister ship, the Jupiter, having turbines and electrical transmission gear.

An example of hydraulic gearing applied to marine propulsion is afforded by a German invention, the Föttinger transformer. Here the steam turbine is coupled directly to a water turbine or pump, the hydraulic pressure developed by which in turn drives a second water turbine or motor mounted on the propeller shaft. Separate water circuits are provided for going ahead and going astern, that for the latter purpose being arranged in such a way that the direction of the water is reversed so as to drive the propeller shaft in the opposite direction. It follows that in whichever way the screws are being turned the steam turbine always rotates in the same direction and no astern turbine is required. The system, with which it was said an efficiency of 90 per cent. could be guaranteed in large installations, was fitted in the Köningen Luise, a pleasure steamer belonging to the Hamburg Amerika Line. This vessel came to England in May 1914, and ran a series of demonstration trials in the Solent for the information of Admiralty and other engineers. Less than three months later she took her place in the German Navy as a mine layer, and the sinking of her on August 5 by the Amphion and the Third Destroyer Flotilla was the first blood of the war and the first success in it of the British Navy.

As has just been recorded, electrical gearing or transmission was tried experimentally by the United States Navy Department in a collier in which electrical energy generated by a turbine-driven dynamo was used to drive electric motors on the propeller shafts. Two years' experience with this vessel led to the decision to adopt electrical gearing in the New Mexico, first called the California, a battleship with an estimated displacement of 32,000 tons, which was laid down in 1915. Here two turbines, of 37,000 shaft horse power, were to drive four propellers at 175 revolutions a minute, giving a speed of 22 knots. Each turbine was to be coupled to a bi-polar alternator, the current from which was to be taken to four electric motors, one on each shaft. These motors were to be connected for either 24 or 36 poles. At moderate speeds the plan was to use only one of the generators, and under this condition a speed of 15 knots was expected with the 36-pole connexion and 18½ knots with the 24-pole. With either connexion changes of speed were to be effected by changes in the turbine speed. The weight of the propelling machinery, apart from boilers and condensing auxiliaries, was estimated at 530 tons, and the General Electric Company, who were responsible for it, guaranteed that the steam consumption per shaft horse-power should not exceed 11·9 lb. at full speed and power, 11·1 lb. at 19 knots, 11·4 lb. at 15 knots, and 14·6 lb. at 10 knots.

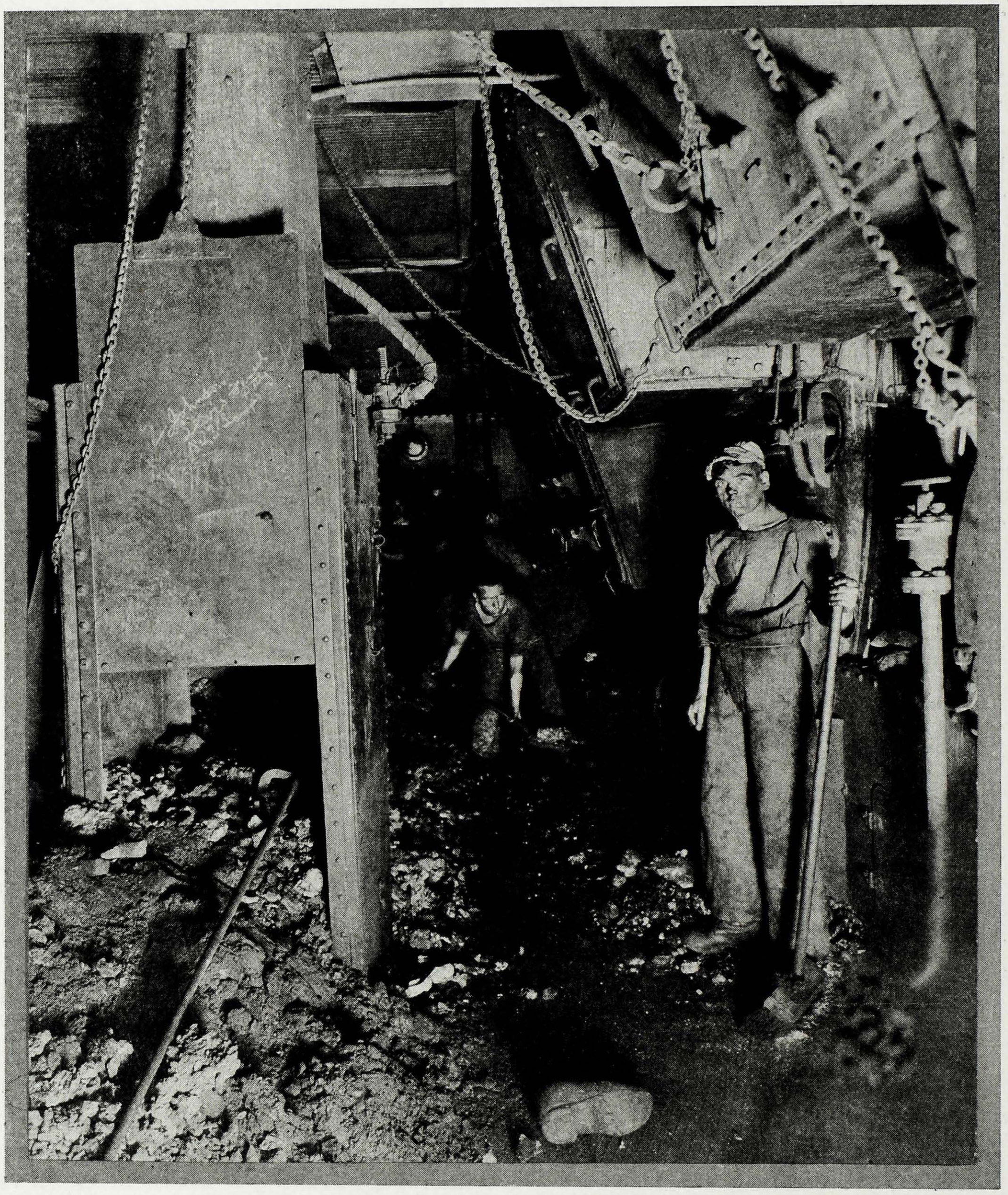
But a still bolder step was taken when it was decided to adopt electric drive on the same principle for the new American cruisers of the 1916 programme, with a length over all of 874 ft., a beam of 91 ft., a draught of over 30 ft., and a displacement of 34,800 tons. Turbines of 180,000-200,000 shaft horse power were to drive four screw shafts through electric motors, and the speed expected was variously stated at from 32 to 35 knots. Apparently space could not be found on the engine deck for the huge range of boilers required to supply steam for machinery of such enormous power, and it was accordingly arranged to place a number of them on a higher deck.

Before leaving the subject of electrical gearing, mention may be made of an interesting Swedish system, the Ljungström, which, according to the Annual Report of Lloyd's Register for 1915-16, was being applied in two mercantile vessels under construction in Great Britain, one of 1,500 shaft horse-power with a single screw, and the other of 5,400 horse-power with two screws. In this turbine there were no stationary blades, but the steam passed across two sets of blades which revolved at equal speed in opposite directions, the effect therefore being the same as if one set of blades were stationary while the other revolved at double their velocity. Each half of the turbine was directly coupled to its own alternator, producing three-phase current of a frequency of about 50 a second at a voltage of about 800. The alternators of each set were electrically locked, ensuring exactly equal speed, and consequently equal power, on each rotating half of the turbine. Two sets of turbo-alternators were provided in each vessel, and the two alternators of each set worked in parallel. They had each only one pair of poles, but the two motors to which they supplied current had each five pairs of poles and therefore rotated at one-fifth of their speed. These motors were connected to pinions with helical teeth which geared in the ordinary way into a large gear wheel



LJUNGSTRÖM TURBINES.

Upper casing removed, exposing the turbine and steam chests and the ends of the rotors.



STOKEHOLD OF A COAL-FIRED BATTLESHIP.

secured to the screw shaft, and the combination of electrical and mechanical gear enabled the turbine running at 3,600 revolutions a minute to turn the screw at 76 revolutions. The turbines always ran in the same direction, reversal of the screw being effected electrically by the motors. Variations of speed down to about 80 per cent. of the maximum were obtained by altering the supply of steam to the turbine, and for lower speeds the regulation was effected by interposing resistances in the circuit.

Britain possesses enormous reserves of coal of qualities suitable for naval purposes, and the Admiralty steam coals produced in the Rhondda Valley of South Wales are famous all over the world. Coal accordingly remained the staple fuel of the British Navy for many years, and it was not until the opening of the twentieth century that, so far as naval ships were concerned, liquid fuel in the shape of mineral oil began to enter into serious competition with the solid fuel.

During the coal period, owing to the constant increase in the size and power of the engines and consequently in their demands for steam, measures had to be taken to increase the amount of coal that could be burnt in a given time in a furnace of given size, so that the additional heat released might generate more steam without undue increase in the boiler installations. The demand for a larger supply of steam could, of course, have been satisfied, without interfering with the furnace arrangements, by providing more boilers, but this course was impracticable in warships because it would have required more space than could be spared for the purpose. It therefore became necessary to intensify the combustion by ceasing to rely simply on the natural draught produced by the funnel and supplementing it by devices that caused the fire to burn more fiercely.

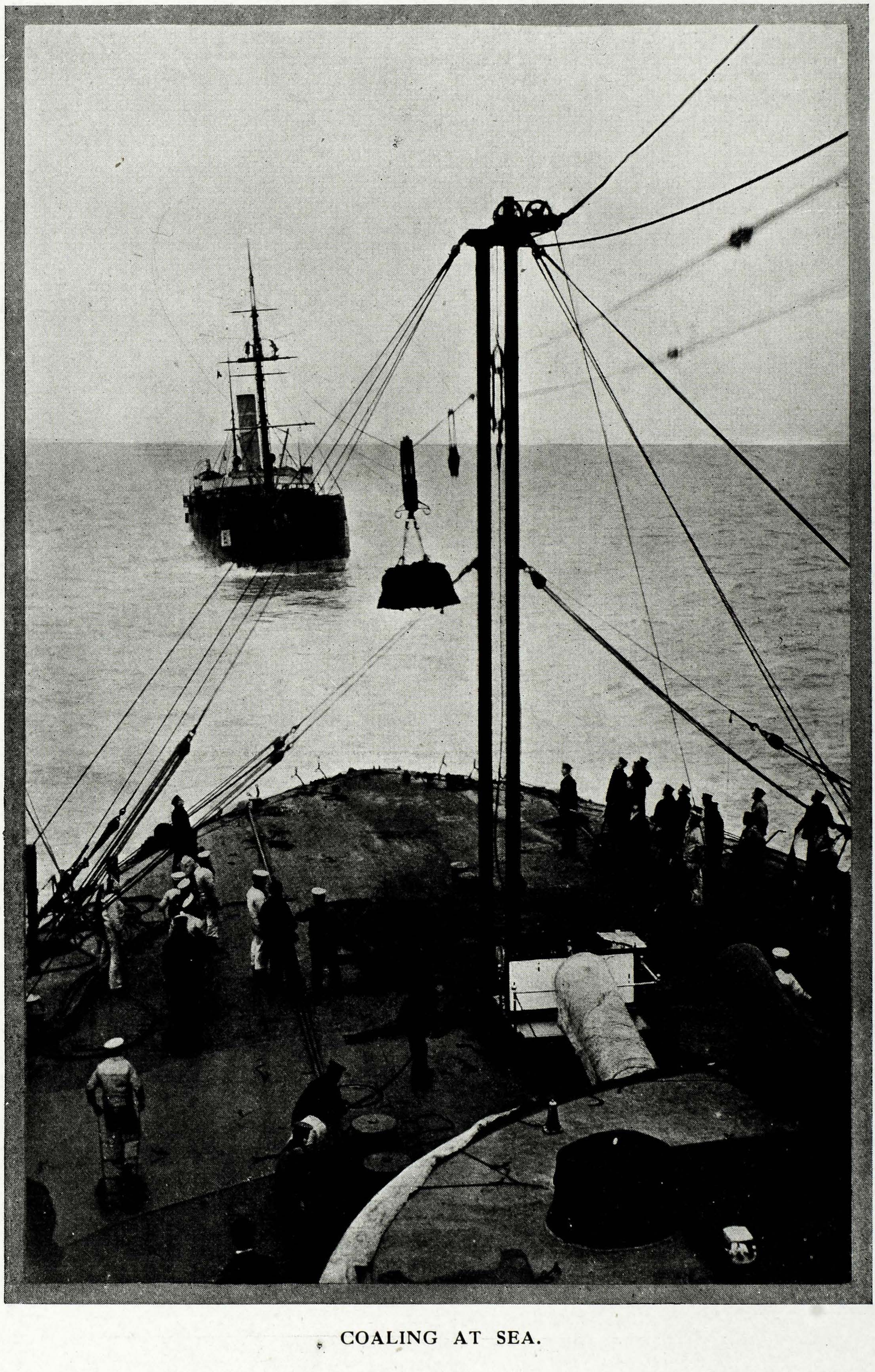
An early device of this kind consisted of a steam jet placed at the bottom of the funnel, but though effective enough it wasted too much fresh water, which is a precious commodity in a ship, Jets of compressed air, instead of steam, were also used in the same way, but were not found advantageous. Another plan which was adopted in some of the ships of the Navy was to put exhaust fans in the funnel to suck away the products of combustion, and still another was to blow air into the ashpits, which had to be closed for the purpose. In 1882 the closed stokehold system of forced draught was adopted in the Conqueror, and subsequently came into extentive use in the Navy. With this the boiler rooms were made air-tight, and a pressure of air was maintained in them by means of fans, air-locks being provided to enable men to enter or leave them without releasing the pressure. In the Conqueror this arrangement increased the power of the boilers by 68 per cent over that obtained with natural draught, with a mean air pressure of 1¾ inches, and in the Sanspareil six years later the boilers were made to develop 20 indicated horse-power for each square foot of grate area with two inches pressure of air. But it was found that forcing the boilers too much in this way gave rise to troubles such as leaky tubes, and before the tank type had been abandoned for the water tube type it was considered advisable to limit the forced draught to a figure corresponding to about 12 indicated horse-power per square foot of grate, and to increase the heating surface per indicated horse-power, which had been reduced so low as 1·7 square foot, to not less than 2½ square feet.

According to one authority the weight of coal that can be burnt per square foot of grate area per hour is approximately 16 to 20 lb. with natural draught; 25 to 28 lb. under forced draught with ½ inch air pressure; 33 to 36 lb. with 1 inch air pressure; 40 to 45 lb. with 2 inches; 55 to 60 lb. with 3 inches, and 70 to 80 lb. with 4 inches. High air pressures, however, are not economical, for though the amount of steam generated is increased, it is not increased proportionally to the amount of coal burnt. For example, in a trial with a Babcock and Wilcox marine (water-tube) boiler, nearly 25 lb. of coal were burned per square foot of grate area per hour under natural draught and nearly 11 lb. of water were evaporated per lb. of coal per hour; but under 3 inches forced draught, while the weight of coal consumed per square foot of grate area per hour increased to over 70 lb., the weight of water evaporated per lb. of coal fell to 8¾ lb.

The first attempt to use oil for raising steam in a warship was made in America by Colonel Foote in 1863. Inside the furnace of a gunboat he fitted a retort in which the oil was gasified with the aid of steam, the gas produced being burnt in the furnace. The trial trip was successful enough, but in practice the arrangement was a failure because it soon became choked with carbon. Subsequent experiments with vaporization systems were equally unsuccessful, but they were probably responsible for Admirals Fishburn and Selwyn drawing the attention of the British Admiralty to oil fuel in the 'seventies. The time, however, was not ripe for the innovation, and no measure of success was obtained until the plan of burning the oil in an atomized, or finely broken up condition, was introduced.

In 1900, when progress in this direction had been made, the Admiralty began experiments, and the memorandum of the First Lord for 1901–2 stated that a method of assisting the combustion of coal by oil fuel was being tested in the destroyer Surly. While the experiments were being carried out that vessel was a standing joke at Portsmouth on account of the dense smoke poured out from her funnels.

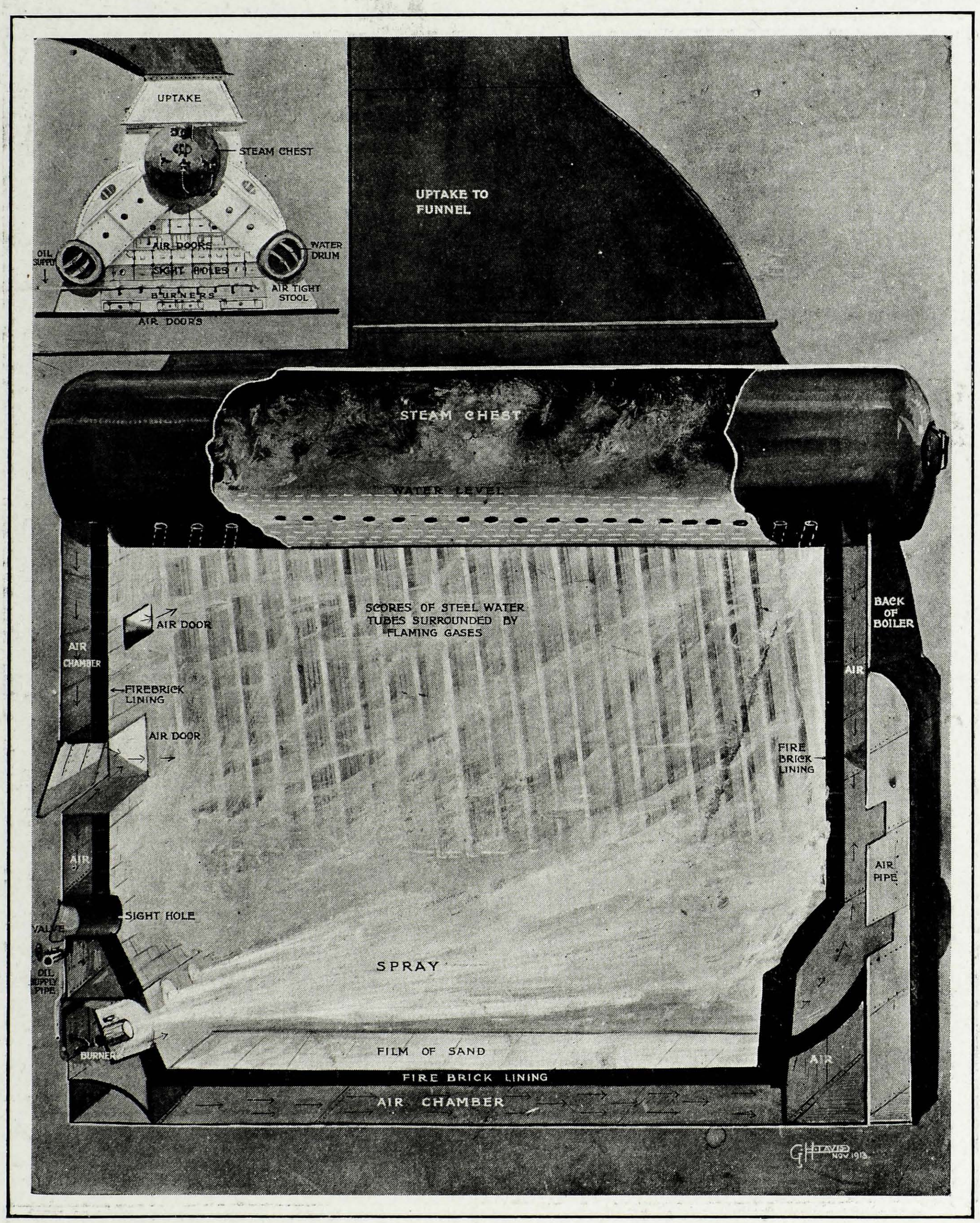
This fact illustrates one of the difficulties that were encountered in utilizing oil fuel in the Navy, for no commander wishes to make himself conspicuous to an enemy by a trail of smoke behind his ships, and the fact that Welsh steam coal with careful stoking can be burnt with little or no smoke is one of its beauties from the naval point of view. On the other hand, the readiness with which oil can be made to yield smoke has its advantages on occasion, as the Germans found in sundry instances in the war, when they disguised their precise position from pursuing British ships by



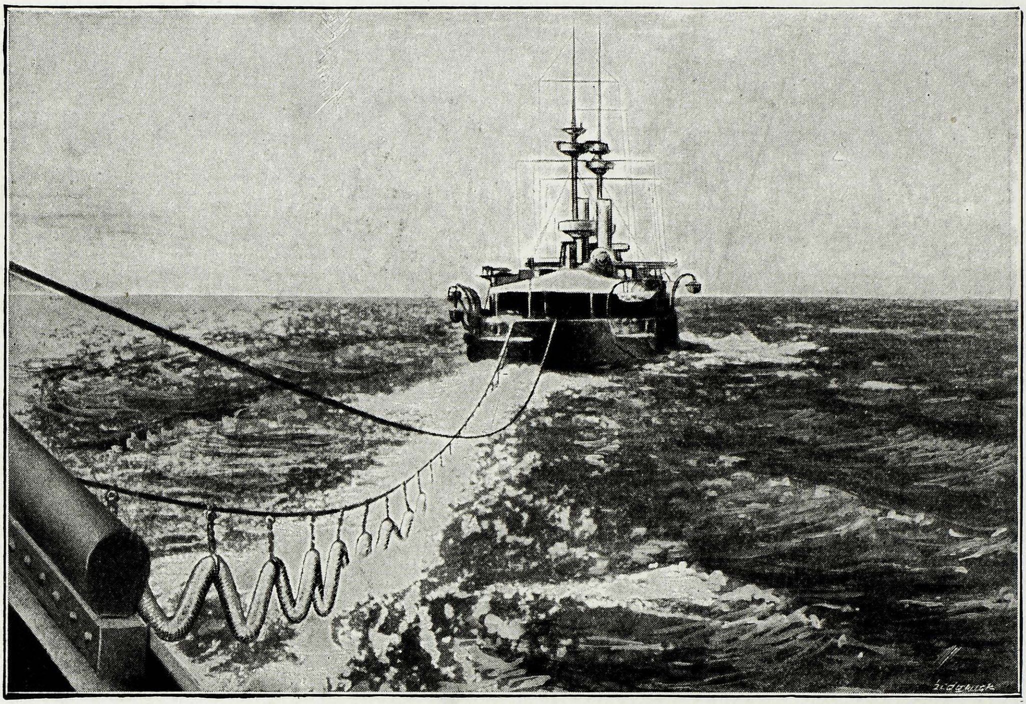
COALING AT SEA.

enveloping themselves in a thick veil of smoke.

Perseverance, however, brought success, and put Great Britain, as regards the use of oil in the furnaces of warships, several years ahead of any other Power ; in fact, almost exactly at the time that the problem of smokeless combustion was solved in this country, a Board of Naval Engineers on Liquid Fuel in America had to confess that they were not within sight of reaching the desired end. In the course of the next few years many completed ships and others that were building were adapted for burning oil in combination with coal. The naval manœuvres of 1906 afforded a striking instance of the usefulness of this course, for when the King Edward class of battleships, under Vice-Admiral Sir William May, were chased by a superior force of older vessels, under Admiral Sir Arthur Wilson, they were able to race away from their pursuers merely by turning on their oil sprays. After that time most ships in the Navy were fitted with appliances for burning oil, coal,



METHOD OF BURNING OIL IN A YARROW BOILER.

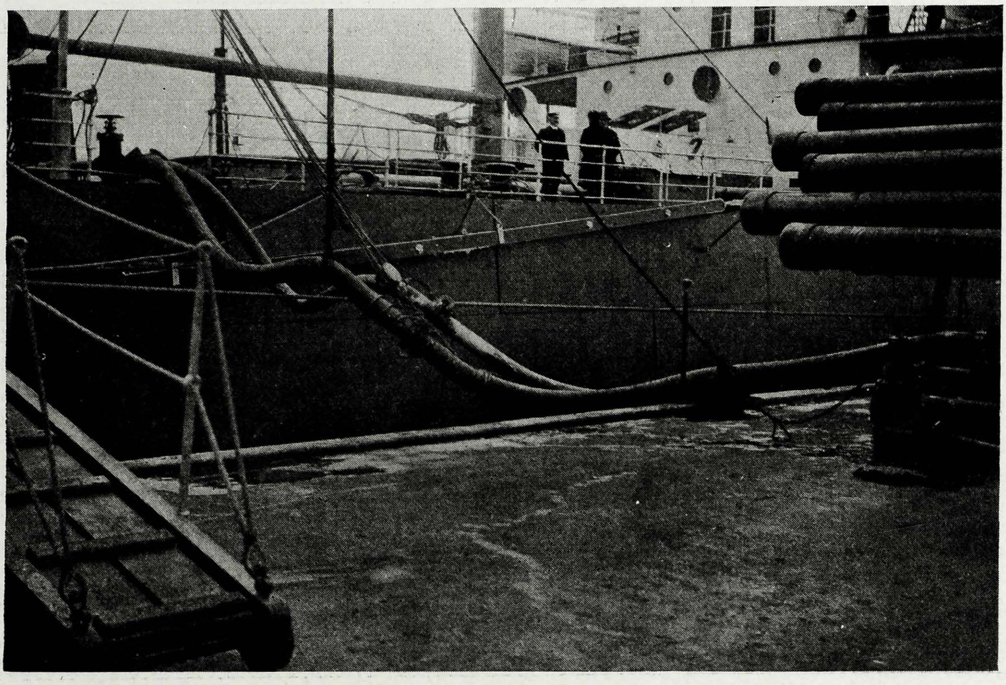


OIL BUNKERING AT SEA. [Engineering.

however, being retained as the main fuel except in the case of torpedo craft. The first flotilla of ocean-going destroyers wholly dependent on oil was created in 1909, and with the Queen Elizabeth and her sister ships of the 1912-13 programme came the "all-oil" battleship.

Very many devices have been invented for atomizing the oil, and reducing it to the condition of a fine spray or mist, the minute particles of which come into contact with abundance of air, and so are thoroughly consumed without the production of smoke. Three agents are used—steam, compressed air, and mechanical pressure. Many burners of the steam type produce a long narrow cone of flame which gives successful results in cases where there is plenty of combustion space available, but is not so suitable with the wide but comparatively short combustion spaces found with the water-tube boilers employed in naval ships. Moreover, a not inconsiderable amount of steam must be used, about 4 or 5 per cent. of the total generated, and this means a loss of fresh water which cannot be disregarded. Compressed air has theoretically the advantage that much of the air needed for combustion is supplied with the atomized oil, and the flame is shortened; but, on the other hand, the necessary air-compressors take up space which cannot always be conveniently found on a ship. The third method, in which the oil is forced out under high pressure, pulverizing itself in its escape, has found most favour for naval purposes. The oil pumping plant required is compact, and the steam used for driving it can be recovered.

Some pressure burners impart a swirling or rotary motion to the injected jet of oil mist, which materially contributes to proper combustion. If a jet of oil mist is driven into the furnace unmixed with air, it can burn only from the exterior, no air being able to enter the flame; and as the length of the flame is governed by the distance it must travel in order to obtain sufficient oxygen from the air to be completely burnt, the flare of oil mist becomes so elongated that there is not sufficient room in the combustion space for all its carbon to be oxidized and smoke results. But if instead of the oil mist and air being allowed to flow forward as more or less independent streams, they are forced to mix by giving both of them a swirling motion, or if the air is forced by other means into the oil-mist, then the length of flame is reduced and smokeless combustion is assured within the limits of the available space. Either forced or induced draught is usually adopted to provide the furnace with a sufficient supply of air. With pressure burners the oil must be preheated in order to reduce its viscosity and make it flow more freely. This can be done conveniently by



OIL BUNKERING IN PORT.

passing it through a nest of tubes which are heated externally by steam. Measures must also be taken to ensure that the oil is free from water, even a small bubble of which may interrupt the flow in the burner.

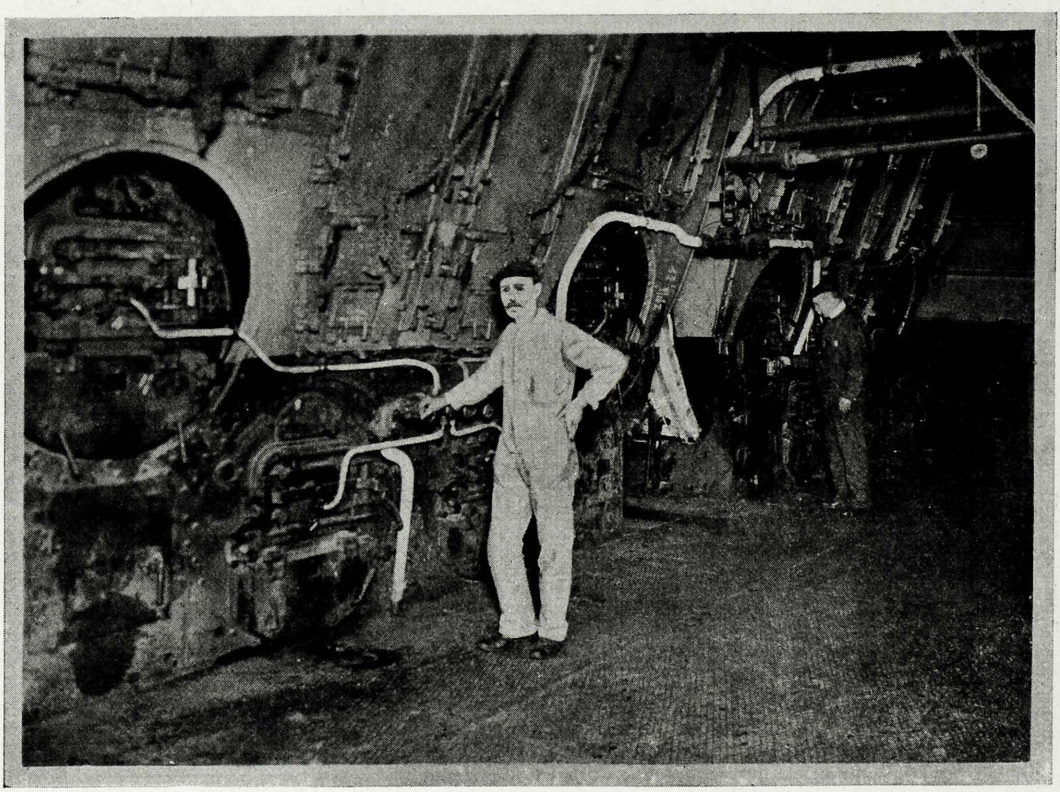
When oil is used as an auxiliary to coal the fire bars are left in place, but the furnace fronts are provided with oil burners and independent air supply valves, which are shut off when coal only is being used. When oil is to be burnt the fires are levelled, the air supply below the bars cut off, and the oil burners with air supply above the fuel bed brought into use.

The primary attraction of oil for use in raising steam in warships is that it is a more concentrated fuel than coal. Different oils and coals both vary in calorific power, but roughly it may be said that the number of British thermal units in a pound of good coal is 14,000, and in a pound of oil 20,000. On this showing 70 tons of oil are equivalent to 100 tons of coal, supposing that in practice the heat can be transferred to the water of the boiler equally effectively, and in this respect oil is held to have the advantage. For a given weight of fuel, therefore, the radius of action of a ship is proportionately increased—Mr. Winston Churchill, in his statement to Parliament on oil fuel in July, 1913, put the extent of this increase as "nearly 40 per cent." Other advantages are that the boilers weigh less and occupy less space, that oil can be carried in remote parts of the ship from which coal could not be brought to the boiler room, and also in double bottoms; and that it can be readily pumped on board through a pipe from tanks on shore or from an oil steamer, whereas the operation of coaling a ship is unpleasant even in harbour, and is at the best difficult at sea unless the weather is good. The number of men in the stokehold is reduced, because hand labour is not wanted for trimming and stoking, while those who are required work under better and less exhausting conditions. There are no ashes to be disposed of, and no coal dust in an "all-oil" ship. Superior control of the output of steam is obtained; an order for increased speed can be responded to more quickly, and a reduction in the demand for steam, such as is caused by stoppage of the engines, can be met without waste.

On the other hand, there are some disadvantages. The extra pumps and piping add to the complication of the machinery and also the weight; the protection obtained from the coal bunkers is lost in an "all-oil" ship, and the danger from fire is increased should the tanks be pierced by a shot and the oil allowed to escape. But the chief practical objection hinges upon the question of supply. The British Isles contain no great oil field—or, at any rate, none has yet been proved and worked—and though no doubt the output of shale oil is capable of increase and there are possibilities of oil being distilled from coal or peat, yet we must depend largely on imports from overseas. Mr. Churchill dealt with this question in the speech already referred to, and stated that while his advisers were of opinion that some losses by an enemy's action might be anticipated, no serious effect on our naval movements need be feared from this cause in war, if the reserves were maintained in peace and so long as the British command of the sea, on which all else depended, was effectively maintained. He outlined the ultimate policy of the Admiralty as being to become the independent owners and producers of their supplies of liquid fuel, first by building up an oil reserve in this country sufficient to make us safe in war and able to override price fluctuations in time of peace; secondly by acquiring the power to deal in crude oils as they came cheaply into the market and to treat them for naval use; and thirdly, to become the owners, or at any rate the controllers, at the source of at least a portion of the supply of natural oil required by the Navy.* But he also remarked that it was not on oil-burning ships that we depended, or were likely to depend for many years to come, for the protection of our trade routes, and from this point of view there is significance in the brightly polished shovel prominently displayed in "all-oil" ships with the inscription "Lest we forget."

Besides burning oil under a boiler and, by transferring the heat thus generated to water, producing high-pressure steam for use in a steam engine, there is another way of utilizing it for the production of power, by burning it mixed with air within the cylinder of an internal combustion engine; the heat then expands the products of combustion to many times their original volume, and the pressure thus created drives forward the piston of the engine, just as does the high-pressure steam in the cylinder of a reciprocating steam engine, and so produces

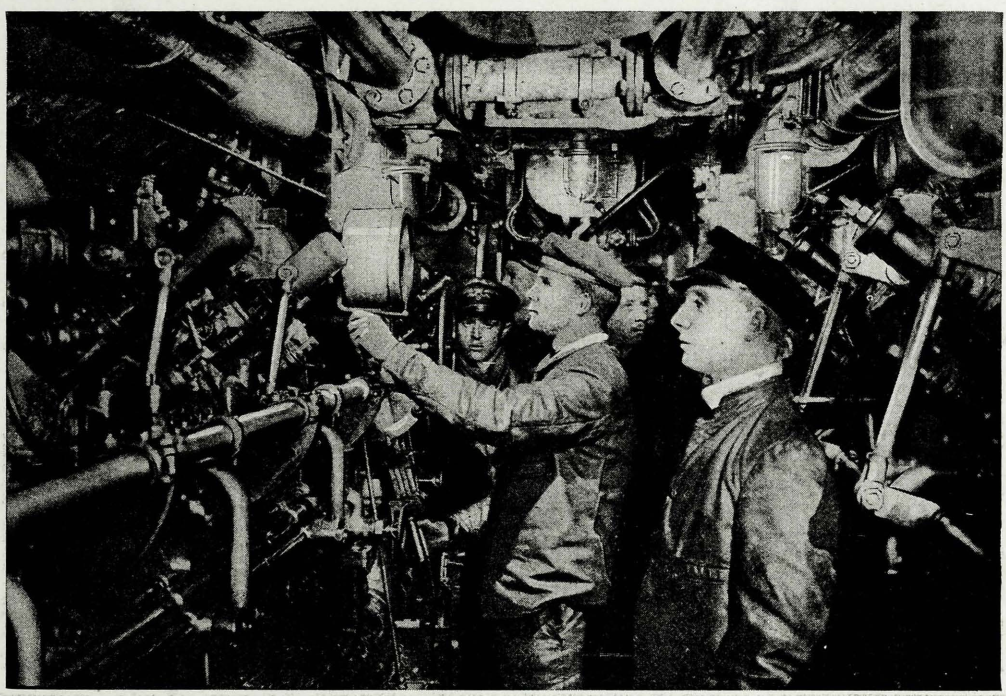
* It was in pursuance of this policy that, as the result of a favourable report by a committee sent out in October 1913 under Vice-Admiral Sir Edmond Slade, the Government were authorized in June 1914 to acquire share or loan capital in the Anglo-Persian Oil Company to the extent of £2,200,000. See Chapter LII., Vol. 3, p. 109.



OIL-FIRED BOILERS.
Photographed while the ship was running at full speed.

power. Being more direct than the other, this method might be expected to waste less heat, and therefore to be more economical ; and in fact, whereas by the middle of the second decade of the twentieth century the possibility of obtaining one horse-power per hour by the burning of about ¾ lb. of heavy oil under a boiler and using the resulting steam in turbines was at least in sight, if it had not been actually realized, at the same period one horse-power per hour could be obtained by the consumption of something like half that amount of oil in an internal combustion engine. To the naval engineer, always on the look out for means that will enable his ships to go farther with a given amount of fuel, the prospects offered by such engines, with their elimination of all the paraphernalia of boilers, would appear particularly attractive ; yet apart from motor boats and some oil tank vessels they were employed in the British Navy for the propulsion of practically only submarines.

One reason was that steam turbines could be made of large sizes, giving thousands of horse-power, so that the power required for even the largest ships could be obtained from a comparatively small number of units ; oil engines, on the contrary, although promising experiments were being made with the object of increasing their size and power, were manufactured only in comparatively small units yielding only a few hundred horse-power per cylinder. Accordingly, to get the large powers required to drive the large and fast ships of the Navy the complication and inconvenience of installing and working a great number of small units would have had to be accepted. Nevertheless, this difficulty did not deter responsible engineers from seriously taking up the problem, and various plans for the application of oil engines even to the larger naval ships were put forward from time to time.



OIL-MOTOR ROOM OF A GERMAN SUBMARINE.

For example, in 1907, Mr. James McKechnie, of Messrs. Vickers, discussed the question before the Institution of Naval Architects, more especially from the point of view of the placing and use of heavy guns. Earlier in this chapter it was noted that one advantage of the screw propeller over the paddle wheel was that it did away with the interference to the working and training of the guns caused by the paddle-wheel boxes. But even with the screw, the funnels with their uptakes impose some disadvantage, and the guns with their ammunition hoists and connected mechanism have to be placed in positions dictated by the necessary arrangement of the boilers and propelling machinery rather than by tactical considerations. If therefore by the adoption of internal combustion engines the funnels could be abolished and the decks freed from the obstructions brought about by them, considerable advantage would be gained in respect of the arrangement and working of the guns, which, for example, would have a much wider arc of training, with the result of increasing the fighting power of the ship for a given armament.

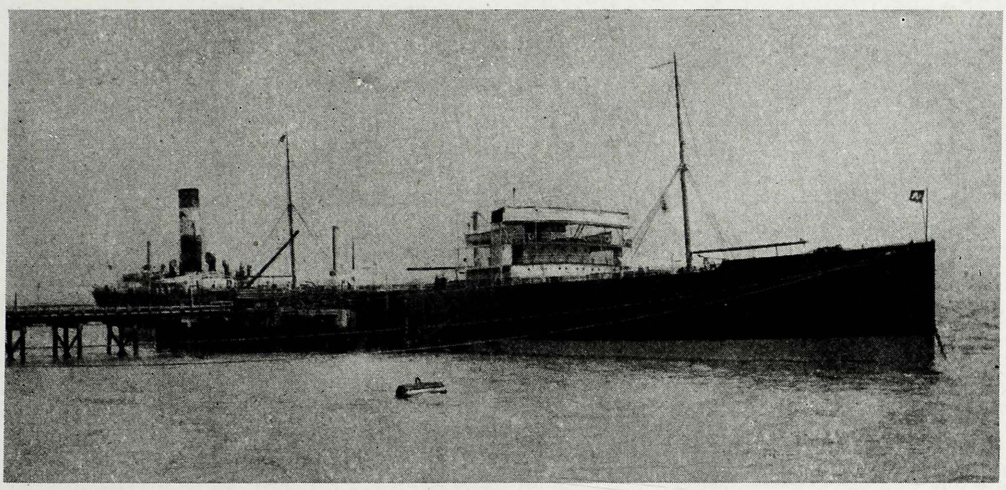
Mr. McKechnie considered a 16,000 horse-power battleship, and proposed to use a form of internal combustion engine which had been developed at the Vickers works at Barrow-in-Furness, and which could be worked either by producer gas or by oil. The ship was to be propelled by four screws, each driven by a ten-cylinder vertical gas engine, placed in the aft compartments; gas-producers of the pressure type were to occupy the central compartments, and forward of them were to be four sets of air-compressors also driven by gas engines. The weights and other particulars of the machinery, according as the ship was fitted for propulsion by steam, gas, or oil, were compared in the following table:

	Steam	Gas	Oil
Weight of machinery	1,585 tons	1,105 tons	750 tons
I.H.P. per ton ...	10·1	14·48	21·33
Area occupied by machinery, engines and boilers or producers	7,250 sq. ft.	5,850 sq. ft.	4,110 sq. ft
Area per i.h.p. ...	0·453 sq. ft.	0·366 sq. ft.	0·257sq. ft.
Fuel consumption per lb. per i.h.p. per hour :—			
At full power ...	1·6	1·0	0·6
At about quarter full power ...	1·66	1·15	0·75

Nine years later, also at the Institution of Naval Architects, Engineer Lieutenant-Commander Sillince attacked the question of applying Diesel oil engines to the propulsion of warships of different classes. For large and fast destroyers, he concluded that the weight of Diesel engines, roughly double in proportion to power developed that of the steam turbines with oil-fired boilers used in such vessels, put them out of the running, since it would not be compensated for by saving in fuel, and the case of light unarmoured cruisers was much the same. For large cruisers, of a power of the order of 70,000 shaft horse-power, and a speed of 30 knots, he decided, after working out various alternatives, that the only reasonable solution was to use cylinders of only moderate power (say, 750 to 1,500 horse-power), a considerable number of cylinders per shaft, and not fewer than four shafts—preferably six or eight With six shafts, and 12 1,000 horse-power cylinders on each, the weight would be 5,000 tons, including all auxiliaries, and with eight screw shafts, each with 12 750 horse-power cylinders, it would be 4,750 tons. It may be noted that as compared with these weights, geared turbine installations would have the advantage, though the oil engines would mean a saving in the weight of fuel to be carried for the same radius of action. For battleships, with smaller requirements of power, he concluded that with four shafts equal powers and speeds could be obtained from Diesel engines as from steam with equal weights of machinery, and that oil engines would enable the radius of action to be increased at least threefold at full speed, and fourfold at cruising speeds. But while regarding the use of oil engines for the propulsion of battleships and large cruisers as an engineering possibility, he indicated that Diesel engines had not yet been satisfactorily developed to the sizes contemplated in his calculations.

With the disappearance of sails from the ships of the Fleet—the abolition of training in masts and yards was formally announced in 1901—the task imposed on the engine-room branch became greater and greater, for just as warships were helpless without their machinery, so the machinery in turn was useless without men to work it. In 1830 the Admiralty felt it "their bounden duty to discourage the introduction of steam, as calculated to strike a fatal blow to the naval supremacy of the Empire"; in 1902 they spoke of the warship as "one huge box of engines." In the years following the Naval Defence Act of 1889 the Navy underwent enormous and almost continuous expansion. Not only was the number of ships in it immensely increased, but, as will be evident from the preceding account of the mechanical developments of that period, the efforts of the engineering advisers to the Admiralty brought about tremendous advances in the speed and power of the individual units, with consequent increase in the responsibilities of the men entrusted with their management and manipulation.

The question of providing sufficient numbers of officers and men adequately trained for their duties in the light of the mechanical character of the modern warship thus became of prime importance, and it was recognition of this fact that led to the promulgation, at the end of 1902, of the scheme of naval training associated with the names of Lord Selborne and Lord Fisher. Previously the engineers of the Navy had been a class apart, entering as students between the ages of 14½ and 16½ and separately trained in engineering, but without any training in executive duties. There had been a good deal of agitation for the improvement of their status generally, and that the problems they presented had not been overlooked is shown by the fact that in 14 years 14 Orders in Council were issued affecting the engineer officers. The Selborne-Fisher scheme, which began to come into operation in 1903, recognized a fact expressed by President Roosevelt in the words: "Every officer on board a modern vessel in reality has to be an engineer whether he wants to or not; everything on board such a vessel goes by machinery, and every officer . . . has to do engineer's work." Its object was to cast an engineering tinge over all officers, and to that end it ordained that the first years of training should be the same for all of them, whatever the direction in which they might ultimately specialize. In connexion with the effect which the scheme was intended to have in the direction of unifying the executive and the engineering branches, it is noteworthy that it was Lord Fisher who was responsible for one of the latest concessions to the engineers, in the shape of the coveted curl on the sleeve, denoting executive rank. Lord Fisher, indeed, with his marvellous prevision, was the first naval authority to recognize fully the value of the engineering side of the Navy and the necessity that all executive naval officers should have an engineering training.



[*Anglo-Mexican Petroleum Products Co.*

AN OIL-SHIP DISCHARGING HER CARGO.

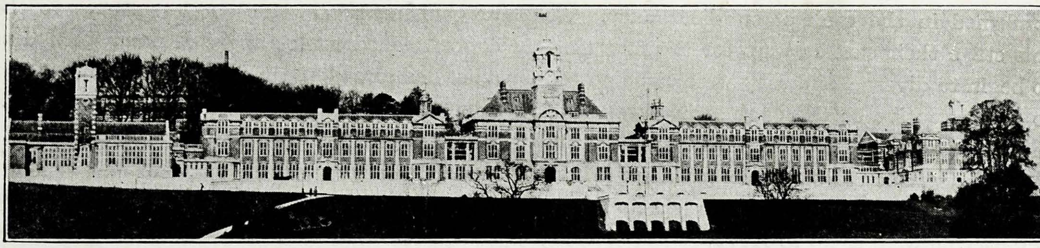
The system of common entry was therefore instituted. Under it all officers for the executive and engineer branches of the Navy and for the Royal Marines were to enter the service as naval cadets under exactly the same conditions between the ages of 12 and 13, two years earlier than the cadets under the old system. They were then to be trained all in exactly the same way until they had passed for the rank of sub-lieutenant between the ages of 19 and 20. They were to spend their first four years at the Royal Naval College, Dartmouth, receiving elementary instruction in physics and marine engineering and the use of tools and machines, and then were to go to sea as midshipmen for three years. During this period special attention was to be paid to their instruction in mechanics and the other applied sciences, and to marine engineering, under the supervision of the engineer, gunnery, marine, navigating and torpedo lieutenants of their respective ships; and after its expiry, on satisfactorily passing the specified examinations, they were to become acting sub-lieutenants. A three months' course in mathematics and navigation and pilotage was to follow at Greenwich, and then a six months' course in gunnery, torpedo, and engineering at Portsmouth; then, after passing more examinations, they were to be confirmed in the rank ot sub-lieutenant. At this stage their careers were for the first time to begin to diverge, and they were to be posted to the executive or the engineering branch of the Navy or to the Royal Marines, freedom of choice being allowed so far as possible. Those sub-lieutenants who elected to specialize in engineering were to go to Keyham Engineering College for a professional course, after which some were to go to Greenwich for a further course, and the remainder to sea. All would then, if qualified, be promoted to be lieutenants under the same conditions as the executives. This is an outline of the original scheme, more particularly as it affected the engineering branch, put forward in Lord Selborne's memorandum, but sundry modifications were subsequently made in it, without, however, changing its general character.

It was arranged under the scheme that the ranks of engineer officers should be assimilated to the corresponding ranks of executive officers, and that the former should wear the same uniform and bear the same titles of rank—sub-lieutenant (E), lieutenant (E), commander (E), captain (E), and rear-admiral (E), to which was subsequently added lieutenant-commander (E). At the same time it was thought desirable to harmonize the position of the existing officers of the engineering branch with the new order of things. Accordingly assistant engineers for temporary service and assistant engineers became engineer sub-lieutenants; engineers, chief engineers, and staff engineers became engineer-lieutenants; fleet engineers became engineer-commanders; inspectors of machinery became engineer-captains, and chief inspectors of machinery became engineer rear-admirals. The engineer-in-chief became an engineer rear-admiral, but the Admiralty reserved the power, which they exercised in the case of Sir A. J. Durston, the chief engineer at the time the scheme came into operation, and his two successors, to promote the officer holding that high post to the rank of engineer vice-admiral. The pay of engineering officers was also raised.

A scheme for the advancement of men in the engineering branch to commissioned rank from the lower deck was instituted at the beginning of 1914, nearly two years after a similar arrangement had been brought into force for the executive branch. Lord Selborne's memorandum had expressed the desire of the Admiralty to see their way to promote a certain proportion of gunners, boatswains and carpenters to the commissioned ranks, and had announced that a list had already been drawn up of 60 appointments to which those officers could be advanced. The proportion of each branch of warrant officer to be promoted to lieutenant was to be the same, as nearly as possible, as the proportion of each of those branches to the combined total of the warrant officers' list, and a proportionate allotment was promised on the same principles to the warrant officers of the engineer branch.

The rank of mate (E)—that is, mate engineering—was established in January, 1914. The arrangement was that recommended candidates finally selected by the Admiralty were, after passing a qualifying examination, to be given the rank of acting mate (E), and then to attend courses at Greenwich and Keyham. Examinations followed each course, and if the acting mates passed successfully they were confirmed in their rank and appointed to seagoing ships, where they messed in the wardroom. After a minimum period of service of two years as acting mate (E) and mate (E) they were to be promoted to engineer lieutenants, and afterwards were to be subject in all respects to the regulations applying to officers of that rank. The first list of mates (E), 12 in number, was published in December, 1914, with seniority of November 1, and the first three to pass, after the two years' qualifying service in the Fleet, were promoted to acting engineer lieutenants on November 1, 1916.

From its very nature the Selborne-Fisher scheme of training could come into full operation only gradually, and its effects could not make themselves felt for many years. Indeed, in order to keep up the supply of officers, the old system had to be maintained concurrently for a period which in the case of the engineers extended to five years; and it was not until April, 1914, that the first batch of lieutenants specializing in engineering joined the Royal Naval Engineering College at Keyham for their final year of professional training, after serving at sea as commissioned officers for two years, a portion of which time they spent, like all other officers under the new scheme, in the engine room, performing the ordinary duties of junior engineer officers. The great bulk of the engineers in the ships that fought in the war must therefore have been trained under the old system, and whatever the new methods were to



BRITANNIA ROYAL NAVAL COLLEGE, DARTMOUTH.

bring forth in the future, that at least was most amply vindicated by results.

Just as a warship's engines are buried out of sight in the depths of its interior below the water line, so few of the deeds done by those in charge of them came into the light of day. The efforts of the engine-room staffs were, however, generously recognized by the admirals in command at the three great naval battles of the Falkland Islands, the Dogger Bank, and Jutland. As regards the first Sir Doveton Sturdee said in his dispatch that great credit was due to the engineer officers of the ships, several of which exceeded their normal full speed, and he referred specially to the case of the Kent, which, thanks to the "excellent and strenuous efforts of the engine-room staff," was able to get within range of the Nürnberg and sink her. As Mr. Churchill subsequently explained to Parliament, the Kent was a vessel 13 years old, designed to go only 23½ knots, but she was forced up to 25 knots and thus was able to catch the Nürnberg, which had a speed considerably over 24½ knots.

At the Dogger Bank action Sir David Beatty said the excellent steaming of the ships was a conspicuous feature, and later Mr. Churchill added that all the vessels engaged in the action exceeded all their previous records in steaming, without exception. He continued:

> Here is a squadron of the Fleet which does not lie in harbour but is far away from its dockyards and which during six months of war has been constantly at sea. All of a sudden the greatest trial is demanded of their engines, and they all excel all the previous peace-time records. Can you conceive a more remarkable proof of the excellence of British machinery, of the glorious industry of the engine-room branch?

At Jutland Sir David Beatty said that "as usual the engine-room departments of all ships displayed the highest qualities of technical skill, discipline and endurance. High speed is a primary factor in the squadron under my command [the Battle-Cruiser Fleet], and the engine-room departments never fail." Again, Sir John Jellicoe reported that while the battle fleet was proceeding at full speed to close the battle-cruiser fleet in the same action, the steaming qualities of the older battleships were severely tested, and he attributed great credit to the engine-room departments for the manner in which they, "as always," responded to the call, the whole Fleet maintaining a speed in excess of the trial speeds of some of the older vessels. In another part of his dispatch he stated that failures in material were conspicuous by their absence, and that several instances were reported of magnificent work on the part of the engine-room staffs of injured ships. The artisan ratings, he added, also carried out much valuable work during and after the action, and could not have done better.

One other passage from his dispatch may be quoted in conclusion:

> It must never be forgotten that the prelude to action is the work of the engine-room department, and that during action the officers and men of that department perform their most important duties without the incentive which a knowledge of the course of the action gives those on deck. The qualities of discipline and endurance are taxed to the utmost under such conditions, and they were, as always, most fully maintained throughout the operations under review.

A distinguished admiral, who was a vigorous critic of the Selborne-Fisher scheme of training, once said that so far as nerve trial goes the engineer's post is an easy one. Mr. Kipling showed a much juster appreciation of the facts when he wrote the lines, "To bide in the heart of an eight-day clock The death they cannot see. . . . And die in the peeling steam."