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The History of the Opposed-Piston Marine Oil Engine (*continued)

By

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Doxford Opposed-Piston Marine Oil Engine. (1912/1914).

The successful progress of the development of the Doxford marine oil engine was largely due to the energy and perseverance of Karl Otto Keller, who was born in Zürich in 1877 and died in Sunderland in 1942.

Like the other outstanding pioneers of the opposed-piston engine, Fullagar and Junkers, his early engineering experience was centred on the design of large gas engines and his work was characterized by meticulous attention to the smallest detail of design and construction.

Mr. Keller came to England in 1903 and after spending two years on large gas-engine development at Messrs. Kynoch, Birmingham, followed by short periods at Messrs. D. Napier and Sons, Acton, and Messrs. Thornycroft, Basingstoke, he was engaged by Messrs. Wm. Doxford and Sons, Ltd. to investigate the possibility of adopting producer gas engines for ship propulsion.

This work was abandoned in 1908 when it became evident that there would be great difficulty in building a gas producer to meet the requirements of marine service, and for the next three years he was employed by Messrs. Reavell, Ipswich, on the design of small petrol and paraffin engines. He returned to Messrs. Doxford in 1911 as chief draughtsman and designer in their oil-engine department.

The first experimental Doxford oil engine was designed in 1910 and was a single-cylinder single-piston two-stroke cycle valve scavenging engine with a bore of 19·5in. and a stroke of 37in. The normal rating was 250-b.h.p at 130 r.p.m., representing one unit of a 1,000-b.h.p. four-cylinder marine oil engine. The engine operated on the Diesel constant-pressure cycle with air injection of fuel. The compression and combustion pressures were both 500lb. per sq. in.

The design was undertaken after a careful study of the best Continental practice, and every effort was made to provide the ruggedness necessary for trouble-free operation in marine service.

The experimental work carried out on the single-cylinder unit indicated that the engine was capable of exceeding the designed performance, but disclosed several design weaknesses; notably, weakness of the cylinder head due to the presence of large valve pockets; the difficulty of transmitting heavy combustion loads through the framing and main bearings; and the rather high oil consumption. All these troubles were common to orthodox two-stroke cycle engines of that time, and after about five months' experimental work it was decided that a drastic change of basic design would be necessary if a two-stroke engine possessing the reliability necessary for marine service was to be produced within a reasonably short development period.

With this in mind, the firm, though aware of the disappointing results which had followed Continental efforts to produce a large opposed-piston marine oil engine, decided that in the opposed-piston principle lay the ultimate solution of the troubles experienced with the single-piston unit. The use of opposed-pistons eliminated the cylinder heads and provided even better scavenging than was obtained with the port and valve arrangement of the earlier engine; while the heavy combustion loads were no longer transmitted through the engine framing but were carried by a forged steel chain comprising the three-throw crank element, the side and centre connecting rods and the upper piston transverse beam. Furthermore, the main bearings were relieved of all load except that due to the deadweight of the moving parts, and the framing had only to withstand the relatively small side pressures from the crosshead guides.

The first experimental Doxford opposed-piston oil engine was designed in 1913 and was a single-cylinder unit with a bore of 500 mm. and a stroke of (2 x 750) mm. The unit had a normal service rating of 450-b.h.p. at 130 r.p.m. and represented one cylinder of a proposed 1,800-b.h.p. four-cylinder marine engine. The engine is shown diagrammatically in Fig. 22 and in greater detail in Fig. 23.

Development work started in the test-bed in July, 1914 with air-injection of fuel. Two fuel valves were used, one at the front and the other at the back of the cylinder with their centre lines slightly tangential to the bore so that the expansion energy of the blast air caused a certain amount of swirl during the injection period. Each fuel valve discharged its oil mist through two saw-cut orifices spaced 50 mm. apart, producing two sheets of finely atomized oil, one just above the lower piston crown and one just below the upper piston crown. When the pistons separated, the air trapped in the combustion chamber was drawn rapidly through these sheets of oil mist and, combined with the swirling action, produced intimate mixing of fuel and air.

The injection-air pressure was 1,500lb. per sq. in. which was higher than in contemporary air-injection engines. This higher pressure, combined with earlier fuel admission than was usual in contemporary engines, provided the increased rapidity of combustion necessary with an opposed-piston arrangement, where expansion was more rapid than in single-piston arrangements operating at the same piston speed as each piston of an opposed-piston assembly.

During November and December, 1914, this experimental engine completed a 35-days' continuous full-power endurance trial under the supervision of Lloyd's Register of Shipping. Throughout this trial the engine averaged 470-b.h.p. at 115 r.p.m. and 90lb. per sq. in. b.m.e.p. The mechanical efficiency was 75 per cent. and the brake thermal efficiency was about 31 per cent., giving a fuel consumption of 0·43lb./b.h.p/hr. which compared favourably with values of 0·47 and 0·49 for contemporary four- and two-stroke cycle single-piston engines respectively. The engine completed 12-hours overload test without difficulty, developing 700-b.h.p. at 150 r.p.m. with a mean brake effective pressure of 105lb. per sq. in. The mean piston speed was 740ft. per min., and the rating corresponded to the low figure of 26 cu. in. of swept volume per b.h.p. A noteworthy feature of these trials was the remarkable flexibility of the engine. There was no difficulty in operating quite smoothly at speeds of 35 r.p.m. or even less. Normal starting was readily accomplished with a blast-air pressure of 1,000lb. per sq. in., and there was no difficulty in running with a blast pressure as low as 300lb. per sq. in. The ability to run an opposed-piston engine at very low speeds with blast-air injection was interesting, because one of the disadvantages of this system when used with single-piston engines was its inflexibility due to the uncertainty of ignition at light loads due to the cooling effect of the blast air.

These experimental results fully justified the builder's decision to proceed with a full-scale engine as soon as possible, but the 1914/1918 war prevented an immediate start on this project. During the war years, however, some experimental work was undertaken, notably the construction of a single-cylinder high-speed experimental unit intended for submarine work. This engine was acquired by the Admiralty and was the first Doxford engine to have a differential stroke, the cylinder dimensions being 370 mm. bore with a lower

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*For the first part of this paper, see Vol. LVIII, No. 9, Oct. 1946 issue of Transactions, pp. 171-184.

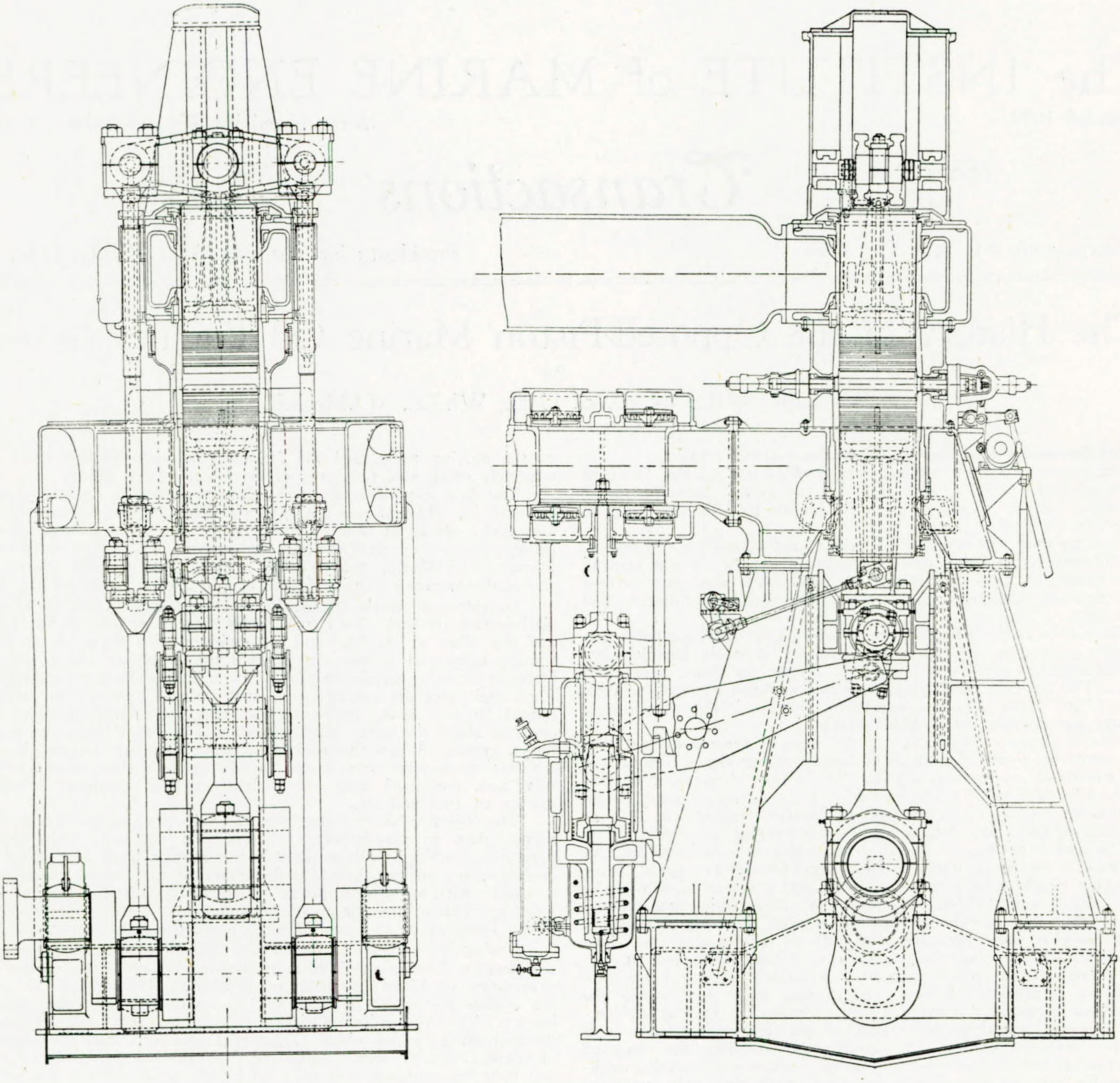

FIG. 23.—*Doxford experimental oil engine—1912-14.*

piston stroke of 390 mm. and an upper piston stroke of 330 mm. The engine developed 400-b.h.p. at 360 r.p.m., which was a considerable advance on the 100-b.h.p. per cylinder units in use at that time. The war ended before development had reached the stage where full-scale construction could be undertaken, and with the coming of peace the project was abandoned. A more fruitful item of research during the war years was the conversion of the 1914 experimental engine to direct-injection of fuel.

It is perhaps not generally appreciated that in common with other pioneers, Diesel himself attempted to use direct injection and it was due to his failure to produce a satisfactory system that he turned to air injection, the method which he had previously employed for his experiments with coal dust. The air-injection system worked well, largely because it provided a fuel spray giving good atomization, excellent penetration, and a certain amount of turbulence. But it added an expensive high-duty air compressing plant to the engine, which absorbed from 7 to 10 per cent. of the indicated horse power. Moreover, the cooling effect of the blast air made the engine rather inflexible due to uncertainty of ignition at light loads. The air-injection system, however, provided a good practical solution for the early troubles with direct injection and once it was adopted there appeared to be considerable reluctance to depart from it.

Indeed it was not until about 1930 that there was any general trend towards direct injection, while even as late as 1935 many large single-piston engines were still operating with air injection.

It is therefore all the more remarkable that the Doxford engine operated with direct injection from the beginning of full-scale development in 1919.

The principle underlying the accumulator system of direct fuel injection is described by Brandstetter in his patent No. 24411 of 1905. This inventor proposed to deliver oil from a fuel pump to a metering chamber containing a spring-loaded plunger arranged in parallel with a mechanically-operated fuel injection valve. The oil pressure forced the plunger back against the resistance of the spring until the correct amount of fuel had accumulated. At the appropriate moment the injection valve was lifted by a cam, allowing the accumulated oil to be forced into the combustion chamber by the spring pressure. Brandstetter also suggested that a flexible diaphragm could be used instead of the plunger.

Vickers appear to have been the first, however, to bring the direct-injection system to a state of practical development for large engines.

The Vickers' experiments on direct injection commenced in 1908 and the results were applied to a pair of engines originally designed for air injection. These engines completed shop trials in 1910 and in the same year Vickers obtained a patent (No. 27579) for their spring-loaded accumulator system.

In the original arrangement each cylinder had a separate cam-controlled valve delivering to an open spray valve in the cylinder, an accumulator spring plunger, and a fuel supply pump. Fuel was delivered by the pump to the accumulator where the required quantity of fuel was stored.

At the appropriate moment the cam opened the fuel valve and the plunger was forced rapidly downwards by the spring so that the contents of the accumulator chamber were discharged through the open spray valve into the cylinder.

This system was subsequently improved by the introduction of a flattened piece of pipe for the accumulator (Patent No. 26227 of 1911) which acted as a reservoir and reduced the fluctuation of fuel pressure, but owing to dribble at the open nozzle, the cam-operated valve in the cylinder cover was reinstated as in air injection. By 1916, as the result of further experimental work and service experience, it was discovered that still smaller fluctuations of fuel pressure, combined with greater ease in balancing the powers delivered by individual cylinders, could be achieved by using a battery of fuel pumps delivering into a common fuel supply pipe feeding cam-operated spray valves, one on each cylinder.

This system was named the common rail system (Patent No. 102281 of 1916), and regulation was obtained by varying the quantity of fuel delivered by the pump to the common rail, thus controlling the amount of fuel delivered through the spray valves. At the same time, the duration of injection of the spray was adjusted to maintain pressures high enough to give effective spraying.

Returning to opposed-piston engine development, an accident which occurred to the Doxford single-cylinder experimental engine in 1916 not only underlined the desirability of changing to direct injection, but may be said to have sounded the death knell of air injection on Doxford engines. While running a heavy overload trial at 165 r.p.m. with air injection, the piston of the high-pressure stage of the blast-air compressor seized and brought the engine to rest in a few revolutions, fortunately without damage, though the experience was somewhat alarming to the test-bed staff.

In the initial experiments with direct injection the compression pressure was the same as with air injection, namely, about 600lb. per sq. in. It was soon discovered, however, that with direct injection more time was required for burning the fuel. This was obtained by lowering the compression pressure to enable the fuel to be injected earlier without causing an undesirable increase of maximum pressure. The compression pressure was reduced in stages until in 1917 a satisfactory compromise was found with a compression pressure of about 300lb. per sq. in., and a maximum pressure of 600lb. per sq. in., values which have remained practically unaltered to this day. The cam-controlled fuel valves were arranged to begin lifting about 25 degrees before firing centre, with a profile which provided a small but gradually increasing lift from the instant of opening to firing centre. In this way a small amount of fuel was injected before firing centre to warm up the combustion space preparatory to the injection of the main charge. The fuel valves closed about 25 degrees after firing centre, the large hump on the fuel cam being located between firing centre and the instant of closing. Thus the main charge of fuel was injected into a preheated combustion space with consequent increase of combustion efficiency.

This method of injection produced an indicator diagram radically different from the conventional Diesel or constant-pressure diagram, since a small part of the fuel was burnt at substantially constant volume. This cycle became known as the dual-combustion cycle, and the fuel consumption of the single-cylinder experimental engine was 0·34lb./i.h.p./hr. with direct injection, compared with 0·32 with air injection. Satisfactory tests were also carried out on this engine with mean pressures up to 140lb. per sq. in., while there was no difficulty in obtaining smooth operation at speeds down to 22 r.p.m., with a clean exhaust.

With air injection, about 7 per cent. of the indicated horse power was absorbed in compressing the blast air, whereas only about one-twelfth of this power was required for satisfactory operation with direct injection. There was also a further substantial gain in mechanical efficiency with direct injection due to the reduced compression pressure and the consequent reduction of loadings on rubbing surfaces. The overall result, even after making allowance for the fact that some of the power absorbed by compression of the blast air was regained on subsequent re-expansion, was that the mechanical efficiency of 75 per cent. with air injection was increased to 82 per cent. with direct injection.

The fuel consumption on a brake horse power basis was therefore 0·42 and 0·43lb./b.h.p./hr. for direct and air injection respectively.

This represented an appreciable fuel economy coupled with a substantial reduction of first cost, weight, complication, and maintenance troubles.

As with air injection, two fuel valves were used, one at the front and one at the back of the combustion space. Each valve had a nozzle plate carrying a series of jets, water-cooled to prevent choking, and arranged so that they produced a fan-shaped spray across the combustion space in horizontal planes. The front and rear valves were staggered so that the two horizontal fan-shaped oil sprays were injected close to the surfaces of the flat-topped upper and lower pistons, thus trapping the bulk of the air in the combustion space between them. When the pistons separated at the commencement of the expansion stroke, the air was drawn swiftly through the oil sprays, producing intimate mixing and excellent combustion. The valves were fitted with cam-controlled needles which were lapped into the valve body, thus eliminating packing. An additional distinctive feature of the construction was the use of a pilot ram slightly larger in area than the fuel needle and subjected to the same oil pressure. In this way an unbalanced hydraulic pressure was produced which held the needle firmly on its seat until the pilot ram was lifted by a lever operated from the fuel cam. This method of valve control produced a very neat construction since it avoided the use of the large return spring which would otherwise have been required. The pilot ram was also lapped into its housing to avoid packing, and a small spring at the free end of the ram served to close the valve when the fuel pressure dropped to zero. Fuel was supplied from a three-ram pump driven by a slider crank mechanism of robust proportions to avoid side thrust on the rams which, like the fuel valve needle and pilot ram, were lapped into their housings to avoid packing. Without these special precautions against side thrust it is probable that trouble-free operation of the pump would not have been obtained. The fuel was delivered to a common rail at a pressure of about 8,000lb. per sq. in., and two small air vessels, initially charged with air at a pressure of 1,000lb. per sq. in., were provided in the delivery line to minimize pressure fluctuations.

In the full-scale engines the air-charged vessels were not used, since it was found that there was sufficient resilience in the fuel system and in the oil itself to store the energy required for proper atomization and penetration during injection. In this connection there is still a fairly widespread tendency to regard liquids as incompressible, and cast iron as more rigid than steel. A comparison of the respective moduli of elasticity should dispel these illusions. The values of the bulk moduli of elasticity expressed in lb. per sq. in. are about 24,000,000 for steel, 12,000,000 for cast iron, and 200,000 for fuel oil. These figures indicate that a steel engine frame is much more rigid than a cast iron frame having the same scantlings; while fuel oil is compressible to the extent that a column of oil enclosed in a pipe is compressed by about 1in. in every 100in. for each 2,000lb. per sq. in. of applied pressure.

Other noteworthy features of the single-cylinder experimental engine were the composite piston heads, and the high operating temperature of the piston and cylinder cooling-water system. The composite piston head consisted of a water-cooled outer cast-iron portion carrying the piston rings, and an inner forged steel portion which formed the flat-topped piston crown. The cast-iron portion provided a hard, well-cooled, wearing surface for the piston rings, while combustion loads were transmitted through the strong forged-steel inner portion to the piston rod. Moreover, the forged-steel crown was made very thick to provide a hot surface next to the combustion space. The running temperature of this surface was in the neighbourhood of 500 to 550°C., *i.e.* a dull-red heat. This materially assisted combustion and enabled even the heaviest grades of fuel to be burnt without difficulty, despite the relatively low compression pressure.

The cooling water outlet temperatures were about 65°C. for the cylinder jackets and about 70°C. for the pistons, with a temperature rise of about 10°C. between inlet and outlet to ensure an adequate flow of water through the system. The cooling-water passages round the liner and through the pistons were made fairly narrow to obtain a high flow velocity and hence good heat transmission, while the exceptionally strong form of combustion chamber peculiar to opposed-piston engines, through the absence of large holes for inlet and exhaust valves combined with the use of shrunk-on steel jackets and reinforcing rings of forged steel, enabled an exceptionally thin cylinder liner to be used which not only assisted heat transmission but materially reduced thermal stresses.

For starting purposes the cooling water was preheated by steam to a temperature of about 60°C., since it was found that cold starting was not always certain with all grades of fuel. This feature, far from being a handicap, ensured that no severe internal stresses were imposed in the engine structure through sudden changes of temperature, and tended towards reducing wear by bringing all rubbing surfaces to a reasonable working temperature, with running clearances properly adjusted, before any heavy loads were imposed on them. Furthermore, it was estimated from the results of subsequent development work on full-scale engines that it would not be unreasonable to expect a reduction in fuel consumption of the order of 3 to 5 per cent. due to increasing the jacket water temperature from 35 to 70° C. under constant speed and load conditions in an engine developing 600 to 700-b.h.p. per cylinder.

Broadly speaking, therefore, the use of the highest practicable cylinder and piston cooling-water temperatures not only enabled almost any grade of fuel to be burnt, but yielded an appreciable gain in combustion efficiency, minimized wear of rubbing surfaces, and reduced the loss of heat to the cooling water so that more heat was rejected to exhaust, thus facilitating the use of the exhaust gases in an exhaust-gas boiler.

Vickers Duplex Opposed-Piston Engine. (*Patent No. 165861 of 1920*).

This interesting arrangement is shown in Fig. 24. The stroke of each piston was 15in. and the bore was 14in. for the front and 14·5in. for the rear cylinder.

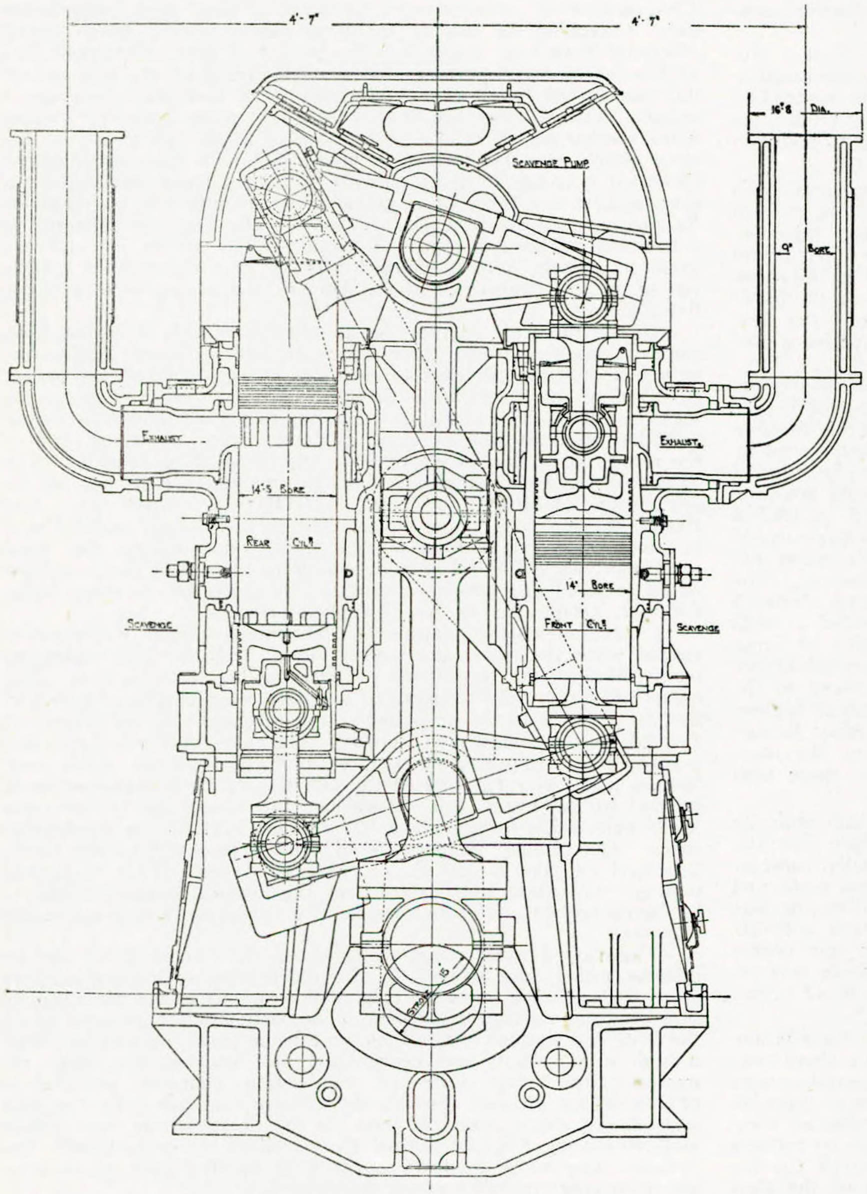

FIG. 24.—*Vickers duplex opposed-piston oil engine—1920.*

The engine was designed to develop 500-b.h.p. at 300 r.p.m., but the maximum output actually attained on the test-bed was 400-b.h.p. at 240 r.p.m.

The engine never got beyond the test stage of development.

Groves Opposed-Piston Oil Engine. (*Patent No. 230914 of 1923*).

This opposed-piston mechanism is shown diagrammatically in Fig. 25 and a comparison with Figs. 14 and 18 indicates that the arrangement represents an ingenious modification of the Junkers tandem cylinder gas engine of 1901 and the Junkers tandem cylinder oil engine of 1910/1912.

In the Groves assembly the two intermediate pistons used by Junkers are replaced by a single piston connected to the centre crankpin of a three-throw crankshaft by a piston rod which passes through the lower piston. The arrangement therefore reduces to a three-piston assembly with the three pistons working in a single cylinder. The upper and lower pistons are connected to the side crankpins by side connecting rods hinged to transverse beams. Scavenge ports, operated by the upper and lower pistons, are provided at each end of the cylinder, while there is a single row of exhaust ports at the centre of the cylinder, controlled by the centre piston. The two rows of scavenge ports are connected by a pipe.

Compared with the Junkers tandem design the Groves arrangement provides a considerable reduction of overall height. As in the Junkers arrangement, the pistons are cushioned at the ends of their outer strokes, and the work absorbed in compressing the charge is transferred directly without having to pass through the crankshaft. Weaknesses of the design are the presence of the centre piston rod in the lower combustion space—a feature of all double-acting engines—and the great disparity between the weights of the reciprocating parts of the side and centre drives. The latter point might be rather troublesome when attempting to obtain primary balance of the moving parts without having to use an abnormally short stroke for the outer pistons, in which case they become little more than piston valves for port control.

Junkers 24-Cylinder Opposed-Piston Engine—1939.*

This two-stroke cycle oil engine consists of four cylinders arranged in square formation with a crankshaft at each corner of the square. The crankshafts are connected to pinions which mesh with the teeth of a gearwheel on the transmission shaft. A 2,000-b.h.p. liquid-cooled engine of this type was projected by Junkers in 1939. This engine, which is shown in Fig. 26, had 24 cylinders, *i.e.* four banks of six cylinders each, and each crankshaft rotated at 3,000 r.p.m. The estimated specific weight was 1lb. per b.h.p. and the overall dimensions were 3·3ft. dia × 6·0ft. long, making it an extremely compact unit. It is of interest to note that the 24 cylinders give 24 evenly-spaced firing impulses per revolution of the crankshafts so that when turning at a crankshaft speed of 3,000 r.p.m., there are 72,000 impulses per minute, giving a very smooth flow of power. Several engines of this type, having cylinders 80mm. bore × (2 × 120) mm. stroke, are reported to have completed periods of successful test-bed running, and a larger experimental engine having cylinders 105 mm. bore × (2 × 160) mm. stroke, is reported to have been nearly completed at the end of the war. This engine was designed to develop 4,500 b.h.p. at 3,200 r.p.m. with an installed weight of 5,950lb. or 1·32lb. per b.h.p. The mean piston speed was 3,360ft. per minute.

Mukherjee Rotary Piston Engine. (*Patent No. 545760 of 1940*).

Fig. 27 is a diagrammatical sketch of this unit which consists of four pistons working in a single cylinder formed as a torus. The cylinder is stationary and the pistons are connected in diametrically-opposite pairs to two discs, *i.e.* pistons *A* and *B* in the lower diagrams in Fig. 27 are mounted on one disc, while pistons *C* and *D* are mounted on the other. The two discs are connected by concentric shafts to a pair of double-ended levers, both ends of each lever being slotted to engage the crankpins of a pair of two-throw crankshafts each with cranks at 180°. The crankshafts are mounted in bearings carried in a flywheel, which in turn is mounted concentrically with the disc

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*A similar layout of crankshafts and cylinders was proposed in 1926 by Causan.

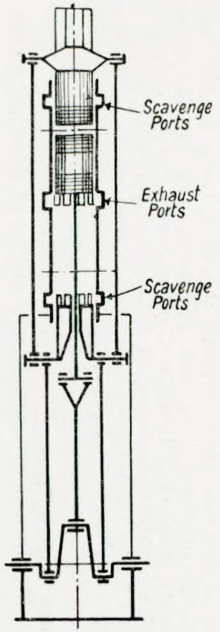


FIG. 25. GROVE'S OIL ENGINE. 1923

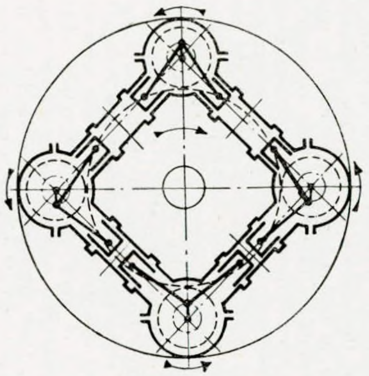
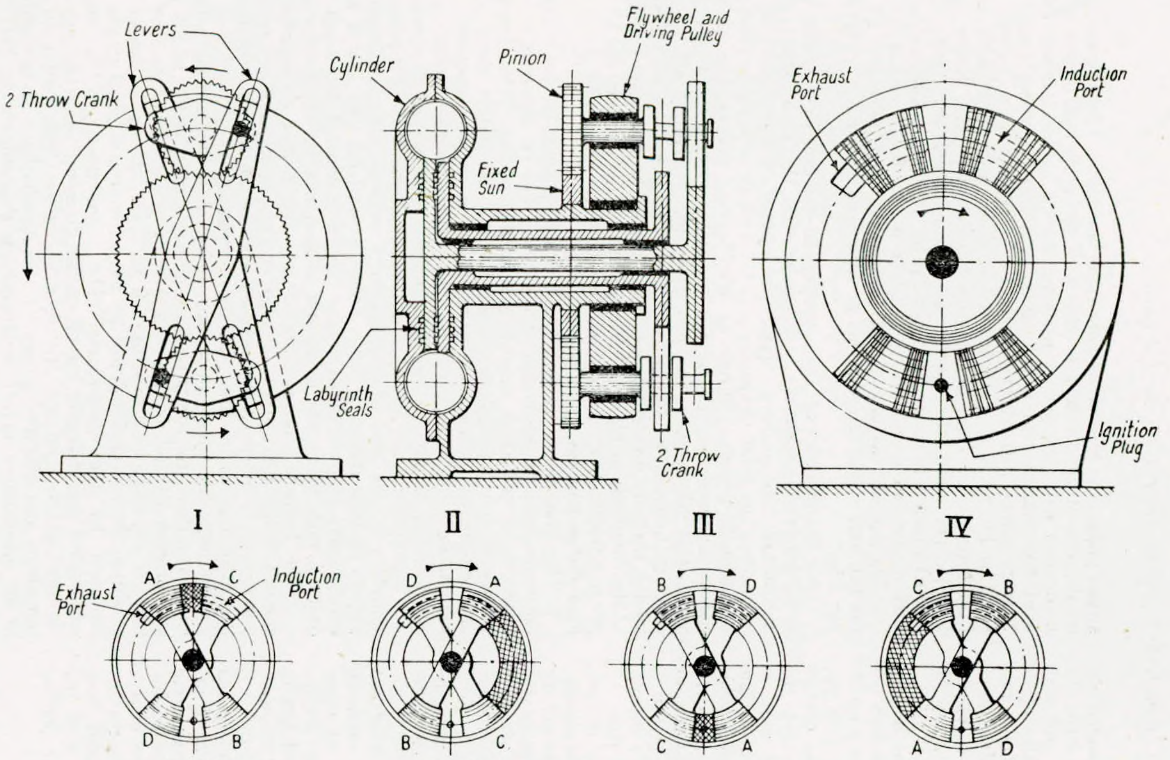


FIG 26. JUNKERS 24 CYLINDER OPPOSED-PISTON OIL ENGINE 1939



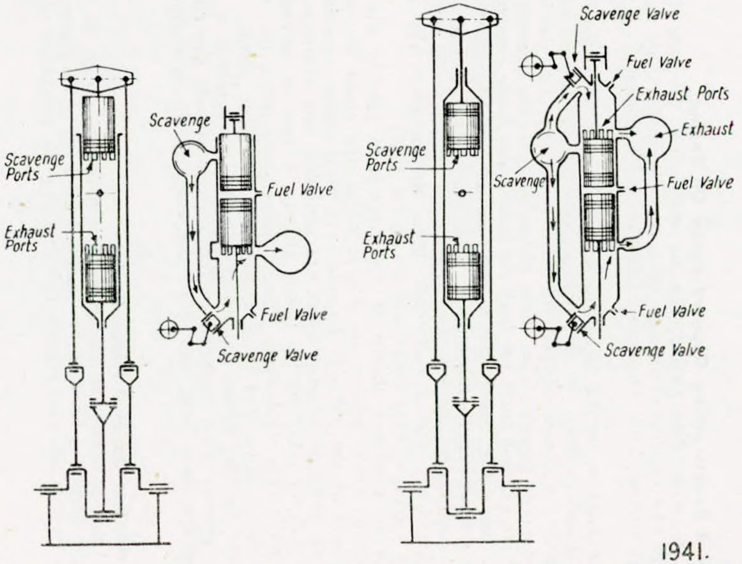
EXHAUST 0°

INDUCTION 90°

COMPRESSION 180°

EXPANSION 270°

FIG 27 MUKHERJEE ROTARY PISTON ENGINE. 1940



1941.

FIG. 28. SUN-DOXFORD DOUBLE ACTING OPPOSED-PISTON ENGINE.

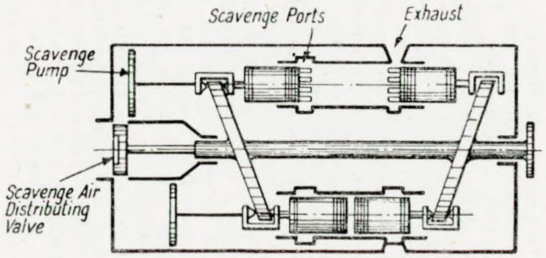


FIG. 29. STERLING OIL ENGINE

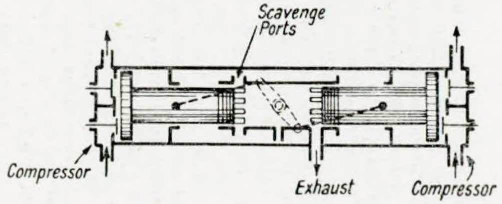


FIG. 30. FREE PISTON ENGINE

shafts. Each crankshaft carries a pinion which engages a sun-wheel fixed to the engine casing. The crankshaft pinions are half the diameter of the fixed sun-wheel, so that when the flywheel, and with it the levers and pistons, makes one revolution the crankshafts make two revolutions relatively to them. The levers therefore make two oscillations for every revolution of the piston assembly, *i.e.* the spaces between the pistons are contracted and expanded twice in each revolution. The cylinder has an ignition plug, an induction port, and an exhaust port in the positions shown in the diagram.

The working cycle is shown in the small diagrams at the bottom of Fig. 27, and in the following description attention is fixed on the space between pistons *A* and *C,* shown cross-hatched. In the position shown at *I* the exhaust port has just been closed by piston *A* at the end of the exhaust stroke and the induction port is just being opened by piston *C*. During the ensuing 90° rotation of the flywheel, the space between the pistons expands, drawing a fresh charge until at position *II* piston *A* has just closed the induction port. During the next 90° rotation of the flywheel the space between the pistons contracts, compressing the charge until at position *III* ignition occurs. During the next 90° of flywheel rotation the space between the pistons once again expands until just before position *IV* is reached piston *C* opens the exhaust port and permits the exhaust products to escape. The cycle then repeats. Power is taken off at the flywheel rim.

Thus the arrangement constitutes a four-stroke cycle process which is carried out in each of the four spaces between the pistons during every revolution of the flywheel. There is no doubt that if the troubles associated with the sealing of the pistons and sides of the discs can be overcome, and if a mechanically sound coupling arrangement can be provided, this type of engine would provide an extremely compact power-unit.

The unit can be made into an air compressor or hydraulic pump by driving the flywheel from an external motor, in which case two inlet and two outlet ports would be provided.

Experimental work on an engine of this type was carried out during the war by Professor Lutz at one of the German research establishments. In the Lutz engine there were two groups of three pistons in the cylinder, and the coupling between the two groups was arranged so that a four-stroke power cycle was carried out in each of the spaces between the pistons during two-thirds of each revolution of the assembly. During the remaining one-third of each revolution each space carried out an air-compression cycle, additional ports being provided in the cylinder for this purpose. The compressed air was mixed with the exhaust gases from the power cycle and the mixture was fed to a gas turbine, *i.e.* Lutz used the engine as a power-gas producer and no power was taken from the engine for driving an external unit. A single-cylinder unit with pistons about 6·5in. dia. was built and tested, but its development was regarded as a post-war project. The principal difficulties with the experimental engine were associated with the sealing of the pistons and discs.

Sun-Doxford Double-acting Opposed-piston Oil Engine.

Fig. 28 shows diagrammatically an interesting proposal for a double-acting two-stroke cycle opposed-piston engine disclosed by The Sun Shipbuilding and Drydock Company, Philadelphia, U.S.A., in 1941.

In the diagram on the left-hand side of Fig. 28, only the lower piston is double acting. In this arrangement the lower end of the cylinder forms a conical-shaped combustion chamber for the lower side of the lower piston. The lower piston controls the opening and closing of the exhaust ports for both the centre and lower combustion chambers, while the upper piston controls the scavenge ports for the centre combustion chamber only. The supply of scavenge air to the lower combustion space is controlled by a piston valve actuated by swinging links and a bell-crank lever driven from the main crankshaft through bevel gears and a vertical shaft.

In the arrangement shown at the right-hand side in Fig. 28, both upper and lower pistons are double-acting, the upper as well as the lower end of the cylinder forming a conical-shaped combustion space. Two rows of exhaust ports are provided, one controlled by the lower and the other by the upper piston. A row of scavenging ports for the centre combustion space is placed just below the upper row of exhaust ports and is controlled by the upper piston. The scavenge air for the upper and lower combustion chambers is controlled by piston valves actuated in the manner already described.

No records have been traced of the building of an engine of this type.

Sterling Crankless Opposed-Piston Engine.

This American design is shown diagrammatically in Fig. 29. The cylinders are arranged between two inclined discs or swash-plates and each cylinder contains two pistons driven from the periphery of the swash-plates by Michell slipper-type bearings. The engine operates on the two-stroke cycle principle with the scavenge pumps arranged in tandem with one set of working pistons. The Sterling engine is used for marine and industrial applications, a typical unit having four cylinders with eight pistons 4·25in. bore x (2 x 5·45in.) stroke, rated at 135-b.h.p. at 1,200 r.p.m. for continuous duty, with an overload capacity of 150-b.h.p. at the same r.p.m. The piston speed is 1,100ft. per min., the mechanical efficiency 85 per cent., and the mean indicated pressure 95lb. per sq. in. at the overload rating. The fuel consumption on average load is 0·4 to 0·45lb./b.h.p./hr.

The specific weight of this engine is about 30lb. per b.h.p. and the full load rating corresponds to from 5 to 6 cu. in. of swept volume per b.h.p.

An examination of the dynamics of the crankless engine reveals some interesting features. Assuming that the main shaft revolves at constant and uniform speed, the motion of the pistons is simple harmonic; the total momentum of the pistons is zero, *i.e.* there is no resultant longitudinal thrust on the bearing collars due to inertia; the total kinetic energy of the pistons is constant, *i.e.* the pistons assist the swash-plates in providing the equivalent of a steadily rotating flywheel to smooth out cyclic irregularities of speed; and, finally, the only unbalance due to the inertia of the pistons is a couple in the longitudinal plane which can be readily balanced by an appropriate adjustment of the dimensions of the swash-plates.

Free-Piston Engines.

The free-piston arrangement which figured so prominently in the early days of gas-engine development has re-appeared in modern times as a crankless opposed-piston mechanism. The present-day scheme is shown diagrammatically in Fig. 30, where there are two opposed-pistons driving compressors. The engine operates on the two-stroke cycle principle with the pistons controlling the exhaust and scavenging ports as in conventional opposed-piston mechanisms. The compressed air left in the clearance spaces of the compressor cylinders at the end of the outward strokes serves to return the pistons on their inner strokes. The motion of the two sets of reciprocating parts is synchronized by a simple system of links and levers, or by a rack gear, which has not to transmit any major forces.

The Pescara, Junkers, and Sulzer free-piston arrangements are engines of this type, and it is usual to provide an auxiliary cushioning piston and cylinder at each end of the engine to assist in returning the main pistons on their inward strokes.

Perhaps the most interesting proposal in connection with these engines is their use for power-gas generation. Briefly, in the power-gas process the oil engine, whether of conventional or free-piston type, is supercharged to from 70 to 85lb. per sq. in. under which condition the power developed by the oil engine is equal to the power absorbed by the compressor. The compressed air is used for scavenging and charging the oil-engine cylinder, while the exhaust or "power" gas is used for driving a gas turbine, the output of which represents the effective power of the installation. It is pointed out in an informative article published on this subject in 1941(17) that the oil engine is equivalent to the combustion chamber of a constant pressure gas turbine.

As the supercharger pressure in the oil-engine cylinder is made larger and larger, the volume swept by the pistons becomes smaller and smaller until in the end a limiting case is reached where the swept volume is zero. This limiting case represented the operating conditions of a constant-pressure gas turbine. Compared with the simple constant-pressure gas turbine, the power-gas scheme offers the possibility of using existing materials to the best advantage by confining the high pressure and temperature portion of the working cycle to the oil-engine cylinders where the construction has been developed over a long period to meet these conditions. The relatively low pressure and temperature part of the cycle is performed in the exhaust-gas turbine which is specially suitable for handling the large volume of gases involved in an efficient and compact manner.

The author of this article estimates that with existing materials a thermal efficiency of about 40 per cent. (fuel consumption 0·35lb./b.h.p./hr.) can be obtained with the power-gas process, compared with only 18 per cent. (fuel consumption 0·77lb./b.h.p./hr.) for a simple constant-pressure gas turbine without a heat exchanger, in its present state of technical development.

According to the latest published information a large power-gas unit is now undergoing tests at Messrs. Sulzer's Works. This unit consists of three power-gas generators with cylinder dimensions 400mm. bore × (2 × 600/660)mm. stroke, running at 350 cycles per min. with an output equivalent to 7,000 b.h.p. at 265/295lb. per sq. in. b.m.e.p. An exhaust gas driven pre-compressor delivers air to the compressor cylinders of the free-piston engines. (*The Marine Engineer,* Nov., 1945, p. 576).

Some Modern Types.

Fig. 31 shows single-cylinder elements of three present-day types

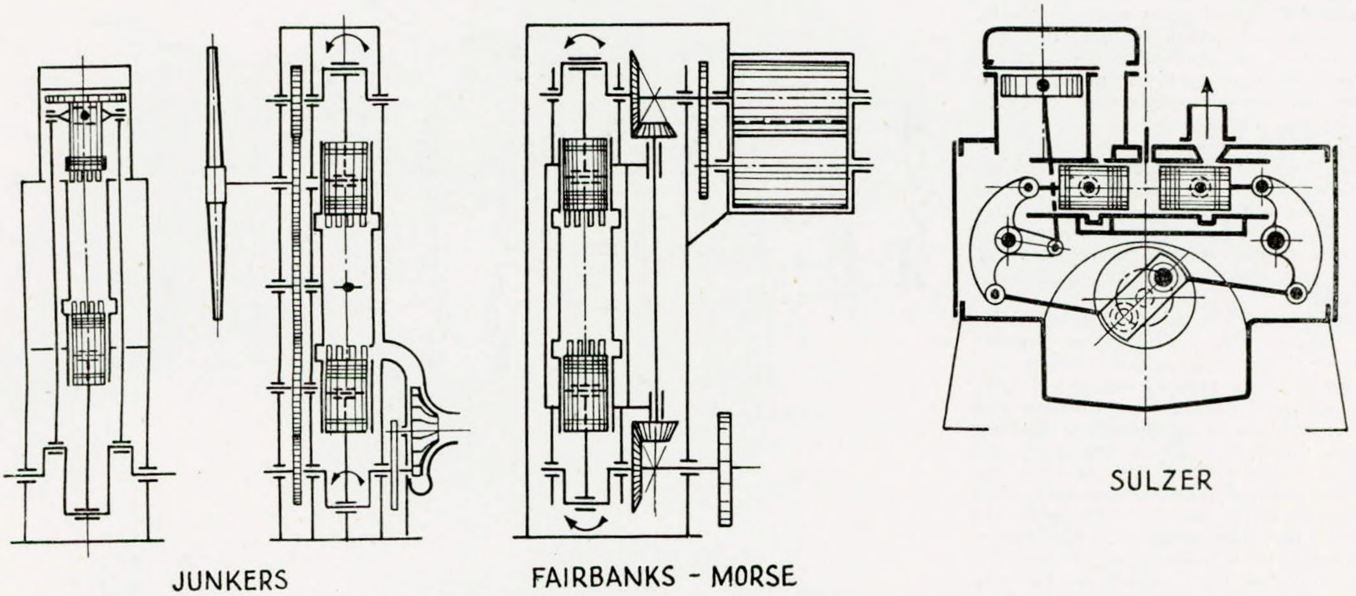


FIG. 31.—*Junkers, Fairbanks-Morse, and Sulzer oil engines.*

of opposed-piston engine, namely, the Junkers industrial engine with scavenge pump in tandem with the upper piston; the Junkers aero-Diesel engine; the Fairbanks-Morse engine with scavenge air supplied by a "Rootes" type blower; and the Sulzer arrangement with the power and scavenge pump pistons driven by levers and links.

SUMMARY OF OPPOSED-PISTON DEVELOPMENT AFTER 1900.

The year 1900 witnessed the beginning of the purposeful development of the high-powered oil engine, and by 1910 progress had advanced to the stage where the oil engine had begun to receive serious consideration as a prime mover for marine installations. In 1910 the first sea-going motorship, the *Vulcanus,* a small craft of 1,180 tons gross, was completed in Holland, the main engine being a Werkspoor four-stroke cycle Diesel engine developing 650 indicated horse power. In 1911, however, the 7,500 tons deadweight motor ship *Selandia* was completed by Burmeister & Wain. This ship was fitted with two 1,250 indicated horse power six-cylinder four-stroke cycle Burmeister & Wain engines, and may be regarded as the pioneer ocean-going motor ship.

During this period the opposed-piston mechanism was not forgotten and, following a considerable amount of experimental work, Junkers produced an opposed-piston marine oil engine developed from the Oechelhauser and Junkers gas engine, which was installed in a twin-screw Hamburg-America Line cargo ship.

These engines were of the more ambitious tandem cylinder type, and probably for this reason the venture was not a success. In 1912, however, a second attempt was made, this time with only a single cylinder on each crank, but this venture was also unsuccessful.

In 1913 the first experimental Doxford opposed-piston oil engine was designed, and test-bed development commenced in 1914. Some details of the initial experimental work on this engine have already been given, and an account of subsequent developments is given later.

The Fullagar oil engine was first introduced in 1915, and during the early 1920's several Fullagar marine oil engines were manufactured and put into service. Interest in this type of engine for ship propulsion languished when Messrs. Cammell Laird & Co., Ltd., decided to abandon its development. The manufacture of Fullagar oil engines was continued by The English Electric Company, however, and is described later.

A number of interesting opposed-piston mechanisms were proposed during the period under review, including the twin crankshaft

Some Notable Opposed-Piston Cylinders.

Type of engine	B.h.p. per cylinder	Bore mm.	Stroke mm.	R.p.m.	Piston speed ft./min.	B.m.e.p. lb./sq. in.	Mech. efficiency	Weight per b.h.p.	Cu. in. per b.h.p.	Fuel Consumption lb./b.h.p./hr.
Two-cycle single-acting	1300	725	1300+950	123	1050	74	86	138	44	0·36
Two-cycle single-acting highly super-charged	340	190	2×300	750	1475	170	—	—	3	0·35
Two-cycle single-acting aero-engine	110*	105	2×160	2300	2400	110	—	2·5	1·5	0·36
	165†	—	—	3000	3150	125	—	1·7	1·0	0·40

* Continuous.
† Short time.

Notes.

(*1*) The piston speed is the mean speed for the piston having the longer stroke.

(*2*) The values for (cu. ins./b.h.p.) are based on the swept volume.

(*3*) The highly supercharged engine is the unit proposed by Sulzer working at a supercharger pressure of 28.4lb. per sq. in. abs., and employing an exhaust-gas turbine coupled to the engine. A four-cylinder engine to this design developed 1,370 b.h.p. (1-hour rating), and completed 3,000 hours running without trouble.

(*4*) The single-acting and aero-engine are the Doxford and Junkers designs respectively.

(*5*) The figures given in the table are taken from published information.

arrangement of Lucas with the shafts connected by bevel gears and a layshaft, an arrangement which features in some present-day mechanisms; the Groves double-acting opposed-piston arrangement, which represented an ingenious modification of the Junkers tandem scheme; the Sun-Doxford double-acting opposed-piston engine: the Sterling crankless opposed-piston scheme in which the piston assemblies were driven by swash-plates and Michell slipper-type bearings; and the free-piston type of engine used for air compressors and for power-gas schemes.

The preceding table gives some of the salient data relating to notable opposed-piston designs, from which it is evident that this type of engine has fully justified the large amount of time and money spent on its development. Interest in this type of engine is unabated, and several post-war proposals are based on the use of the opposed-piston mechanism in one form or another. Probably not least of the achievements of the type is the fact that the Junkers two-stroke cycle opposed-piston aero engine is the only heavy oil engine so far produced which has become a standard power plant for aeroplanes.

Development of the Fullagar Opposed-piston Engine.

In 1931 The English Electric Company re-designed their 14in. bore×(2×16in.) stroke "Q" type cylinder as a direct-injection unit, with a standard B.S.I. rating of 245 b.h.p. per cylinder at 300 r.p.m. During succeeding years a considerable number of these engines was put into service in many parts of the world, and this type, with detail improvements, is still in production.

Prior to the conversion of the "Q" type engine to direct injection in 1931, a larger size of Fullagar engine having a bore of 19in. and a stroke of (2×22in.), known as the "R" type, was developed with a 12-hours B.S.I. rating of 438 b.h.p. per cylinder at 214 r.p.m. The first unit had air injection, but direct injection was used subsequently. The "R"-type engine is shown in Fig. 32, and units developing up to 3,500 b.h.p. in eight cylinders have been in successful operation for a number of years. A point of interest is the use of separate double-acting scavenge pumps of conventional design mounted on the upper crosshead guides and driven directly from the upper crossheads, as shown in Fig. 32. In the smaller "Q" size engines the upper crossheads were enclosed so that they acted as displacers supplying scavenge air to the working cylinders at a pressure of about 2·5lb. per sq. in. gauge.

Although the basic design of the Fullagar engine has remained virtually unchanged during the quarter of a century it has been in production, detail refinements have been introduced to improve mechanical design and engine performance. An indication of the improvement in performance achieved over the years is afforded by the steady reduction of specific fuel consumption. The early Fullagar engines built in 1924, had an optimum fuel consumption of 0·44lb./b.h.p./hr. By 1930 fuel consumptions of the order of 0·415lb./b.h.p./hr. were regularly obtained, and five years later the optimum consumption had been reduced to 0·385lb./b.h.p./hr. Further improve-

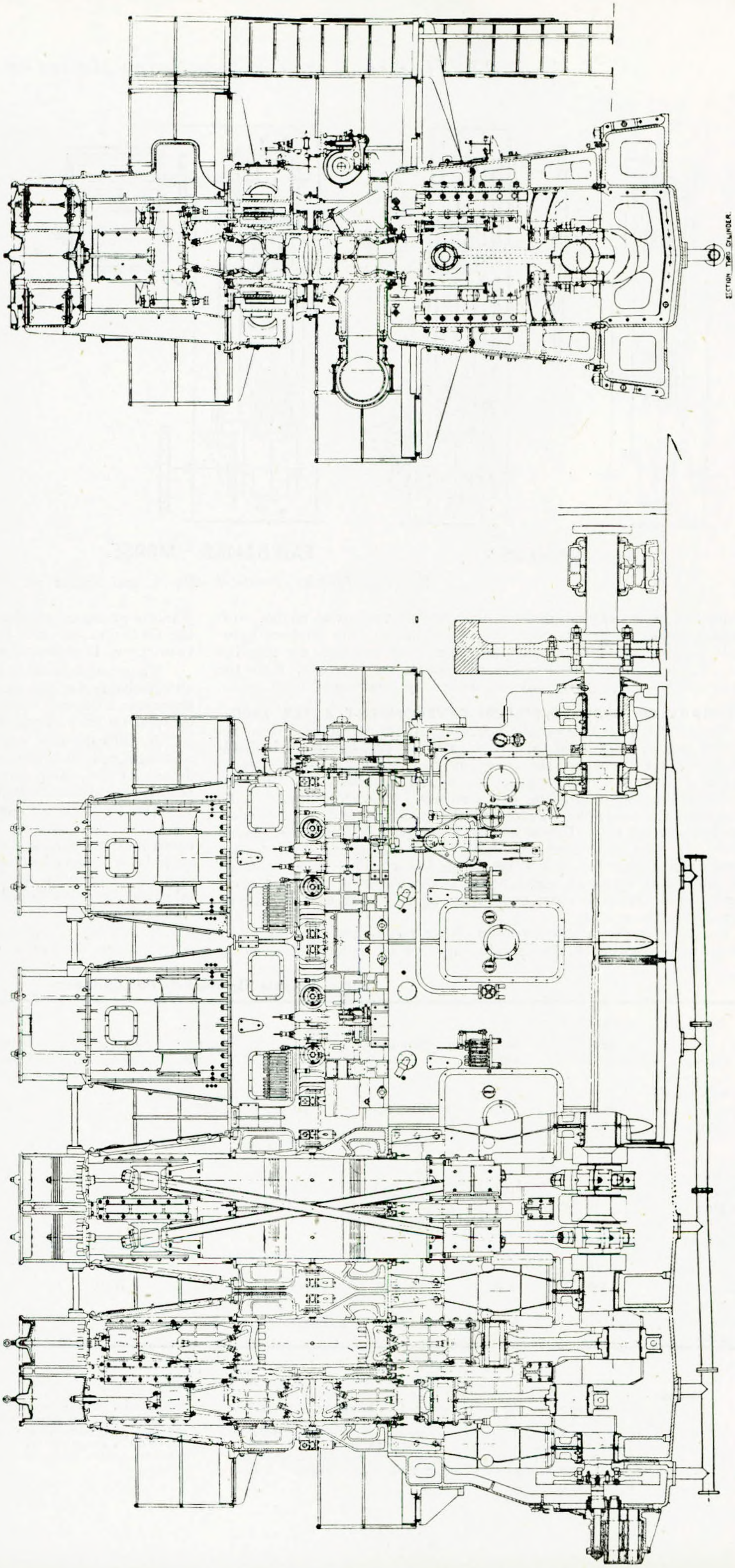


FIG. 32.—*English Electric "R" type Fullagar oil engine.*

ments were made in subsequent years, despite an increase of rotational speed from 250 to 300 r.p.m., and the present-day figure under commercial operating conditions is about 0·375lb./b.h.p./hr. at rated output, and 0·370lb./b.h.p./hr. at three-quarter load. These consumption figures were obtained with Anglo-American fuel, but Fullagar engines in service are operating satisfactorily on many heavy grades of fuel. Operating experience over a considerable number of years indicates that the engine possesses a high reliability factor which renders it suitable for industrial applications where economical results must be obtained without excessive maintenance. Fullagar engines usually run for periods of about 25,000 hours between overhauls, while cases have been recorded where an engine has been operated for more than twice this period without any attention other than routine maintenance. This severe treatment did not cause any serious damage to the engines concerned, and after overhaul they were ready for further continuous service. During the war years several Fullagar-engined power stations fell into enemy hands, and it was of considerable interest to learn, after the liberation of the countries concerned, that the engines were kept in service during the entire occupation period, and successfully met very heavy demands. The Fullagar engines installed at the Guernsey Power Station represent a typical example. These engines were kept in service by the British staff by adopting such expedients as the manufacture of piston rings from cast-iron water-pipe sockets, and scavenge valve discs from motor-car body panels.

It is difficult to speculate on the future prospects of the Fullagar engine. It is not surprising, however, in view of its long record of successful and economical performance, to find that an appreciable number of engines are in course of production at the present time, and that orders for units of this type are still being received. Perhaps the most significant feature in this connection is that about 60 per cent. of the engines constructed have been repeat orders.

Development of Doxford Opposed-Piston Engines.

The first full-scale Doxford opposed-piston marine oil engine was designed in 1919, with four cylinders 580 mm. bore and a stroke of 1,160 mm. for each piston, rated at 2,700 b.h.p. at 77 r.p.m. This rating corresponded to a piston speed of 585ft. per min. for each piston, and a brake mean effective pressure of 93lb. per sq. in. The engine was installed in the first Doxford motorship *Yngaren,* built for the Transatlantic Steam Ship Company of Gothenburg, and trials were run in June, 1921. Five engines of the same type were built between 1919 and 1924, and considering the novelty of the design the teething troubles were negligible. An indication of the performance obtained from these early engines is given by the trials on different types of marine oil engine carried out under the supervision of the Marine Oil-Engine Trials Committee, appointed in 1922 by the Institution of Mechanical Engineers and the Institution of Naval Architects with representatives from the Admiralty and the Institute of Marine Engineers, to carry out tests of oil engines and oil-engined ships (8), (9), (10), (11), (12), (13). These tests are summarised in the following table, where the thermal efficiencies are based on the gross calorific value of the fuel.

Summary of Oil Engine Trials (1923-1930).

Reference	Type of Engine	Fuel system	Rating	Weight lb./b.h.p.	Cylinder capacity cu. in./b.h.p.	Mechanical efficiency	Thermal Efficiency	
							I.p. basis	B.h.p. basis
Marine Oil-Engine Trials Committee. 1st Report, 1923	6-Cyls. 4 SCSA. Single piston	Air injection	1250 b.h.p. at 125 r.p.m.	405	86·0	77·0%	37·7	29·0
Ditto 2nd Report, 1923	4-Cyls. 2 SCSA. Single cyl. (steam assisted)	Direct injection	Oil + steam 1250 b.h.p. at 120 r.p.m.	273	44·0	90·0%	41·0	37·0
			Oil only 1140 at 120 r.p.m.	300	48·0	90·0%	37·0	33·5
Ditto 3rd Report, 1924	4-Cyls. 2 SCSA. Opposed-piston (Doxford)	Direct injection	2900 b.h.p. at 87 r.p.m.	285	52·0	87·5%	38·3	33·5
Ditto 4th Report, 1924	6-Cyls. 2 SCSA. Opposed-piston (Fullagar)	Air injection	2700 b.h.p. at 86 r.p.m.	305	66·5	80·5%	41·0	33·0
Ditto 5th Report, 1923	6-Cyls. 4 SCSA. Single piston	Air injection	1020 b.h.p. at 125 r.p.m.	330	88·0	66·0%	48·0	31·5
Ditto 6th Report, 1930	6-Cyls. 4 SCSA. Single piston supercharged	Air injection	2750 b.h.p. at 138 r.p.m.	203	52·5	84·0%	39·0	32·8
Prof. C. J. Hawkes, 1929	3-Cyls. 2 SCSA. Opposed-piston (Doxford)	Direct injection	Marine duty 800 b.h.p at 150 r.p.m.	235	37·0	87·0%	42·7	37·1
			Land duty 1020 b.h.p. at 185 r.p.m.	185	29·0	87·3%	42·0	36·6

All the tests were carried out under strict supervision by independent authorities and they indicate the superiority of the opposed-piston arrangements over contemporary single-piston engines with respect to mechanical efficiency, brake thermal efficiency, specific weight, and b.h.p. developed per cu. in. of swept cylinder volume.

The three-cylinder opposed-piston engine tested by Professor C. J. Hawkes in 1929 was the smallest of the Doxford range, having cylinder dimensions 400 mm. bore×(540+760) mm. stroke. This engine was introduced in 1928 and was designed for both industrial and marine applications. The compression and maximum combustion pressures were higher than in the larger engines, namely 425 and 700lb. per sq. in. compared with 300 and 600lb. per sq. in. respectively. The higher compression pressure enabled to engine to be started from cold if required, a feature which was introduced to enable tankers fitted with this engine to comply with the regulations controlling the carriage of low flash-point spirit in certain harbours.

The story of the development of the Doxford engine has already been told in some detail elsewhere (18). In the present paper, therefore, only a brief summary of the principal lines of development will be given.

Engine Dimensions and Performance.

As already mentioned, five engines to the original prototype design were constructed between 1919 and 1924. All these engines had four cylinders with a bore of 580 mm. and a stroke of (2×1,160 mm.). Scavenge air was supplied by a centrally-situated crank-driven scavenge pump and the engine rating was increased from 2,700 b.h.p. at 77 r.p.m. and a fuel consumption of 0·44lb./b.h.p./hr. in 1919 to 2,900 b.h.p. at 87 r.p.m. with a fuel consumption of 0·41lb./b.h.p./hr. in 1924.

This increase of engine rating combined with structural changes of which the principal items were the reduction of the number of engine columns from sixteen to twelve and the shortening of the thrust and flywheel shaft, resulted in a reduction of specific weight from 330lb./b.h.p. in 1919 to 285lb./b.h.p. in 1924.

Between 1924 and 1927, several new cylinder sizes were introduced, including a series of three-cylinder engines with cylinders 540 mm. bore and (2×1,080 mm.) stroke developing 1,760 b.h.p. at 90 r.p.m.; and a series of four-cylinder engines with cylinders 680 mm. bore and (2×1,360 mm.) stroke developing 5,000 b.h.p. at 90 r.p.m. The three-cylinder engines had a specific weight of 300lb./b.h.p. and the remarkable low fuel consumption of 0·35lb./b.h.p./hr. with Anglo-Persian Diesel oil of 0·9 specific gravity and 0·375lb./b.h.p./hr. with British Mexican boiler fuel of 0·95 specific gravity.

The larger engines had a specific weight of 260lb./b.h.p. and were remarkable as representing the only marine oil engines then in service giving 1,250 b.h.p. in a single cylinder. It was also noteworthy that this power was developed in a cylinder less than 27in. in bore. The piston speed and brake mean effective pressure were 800ft. per min. and 92lb. per sq. in. respectively.

During this period the first twin-screw installations were constructed to the order of the Commonwealth and Dominion Line. Two engine sizes were used for these installations, namely, a four-cylinder engine with cylinders 540 mm. bore×(2×1,080 mm.) stroke, and a four-cylinder engine with cylinders 580 mm. bore×(2×1,160 mm.) stroke. The smaller engines developed 2,400 b.h.p. each at 95 r.p.m. and had a specific weight of 260lb./b.h.p., while the larger developed 3,000 b.h.p. each at 95 r.p.m. and had a specific weight of 255lb./b.h.p.

These were followed in 1926 by the introduction of the balanced-type of engine, largely as the result of losing an important contract because of some criticism of engine balance, a subject which is discussed in greater detail in an earlier* paper.

The balanced-type of engine was characterized by the use of different strokes for the upper and lower pistons to obtain primary balance, in conjunction with a special crank sequence to obtain secondary balance. The first balanced engines had a bore of 600 mm. and a stroke of (760+1,040) mm. and developed 2,800 b.h.p. at 110 r.p.m. in four cylinders with an overload capacity of 3,400 b.h.p. at 120 r.p.m. The normal rating corresponded to a brake mean effective pressure of about 81lb. per sq. in., with a fuel consumption of 0·38lb. per b.h.p. per hour while the overload brake mean effective pressure was 90lb. per sq. in. with a fuel consumption of 0·41lb./b.h.p./hr.

Four of these engines were installed in the quadruple-screw luxury liner *Bermuda* under a contract from Messrs. Furness Withy & Co., which laid special emphasis on freedom from vibration.

The balanced design produced such a marked improvement of the already smooth-running qualities of the engine that after 1926 the production of the equal-stroke type was discontinued. From 1926 to 1933 the major features of the engine remained substantially unaltered, and in 1931 a large twin-screw installation was produced comprising two four-cylinder balanced engines with cylinders 700 mm. bore×(1,220+880) mm. stroke, each engine having a service rating of 4,725 b.h.p. at 120 r.p.m. The mean piston speed was 825ft. per min. (lower piston 960ft. per min. and upper piston 690ft. per min.), specific weight 220lb. per b.h.p. and fuel consumption 0·377lb./b.h.p./hr. Two of these engines were installed in the motorship *Otaio* built by Messrs. Vickers-Armstrong Ltd. for the New Zealand Shipping Co., Ltd.

In 1933, a radical alteration was made to the structure of the Doxford engine by the introduction of electrically-welded fabricated-steel construction.

The opposed-piston principle appeared to be ideal for the successful employment of a welded structure, since the main combustion and inertia loadings are not transmitted through the engine framing. This was confirmed by the immediate success of the fabricated structure which not only provided a substantial reduction of weight and overall dimensions, but produced a more rigid structure due to the greater elastic modulus of steel compared with cast-iron.

Another advantage, not fully appreciated at that time, but which has become very evident during the war years, was the greater resistance of the steel structure to shock loads.

The first engine of this type was installed in the single-screw motorship *Devon City,* and had four cylinders 600 mm. bore×(980+1,340) mm. stroke rated at 2,900 b.h.p. at 92 r.p.m. Cast-iron was retained for the bedplates of these engines, but by 1936 sufficient confidence had been established in the welded structure to enable it to be extended to the bedplate.

The introduction of the welded structure resulted in the achievement of a specific weight of 185lb./b.h.p. for single-screw and 140lb./b.h.p. for twin-screw engines, and this type is now the standard construction for all Doxford engines.

In 1929, a thorough technical investigation into the possibility of recovering heat from the exhaust gases by means of an exhaust gas boiler was initiated. Due to the exceptionally good scavenging achieved in opposed-piston engines the excess air, even in the earliest Doxford engines, did not exceed 30 per cent. of the swept volume of the working cylinders at a time when contemporary single-piston engines were using about double that quantity. This resulted in a higher exhaust temperature which, taken in conjunction with the high cooling water temperature used in the engine, implied that more recoverable heat was available in the exhaust gases. Experimental work soon indicated that the quantity of excess air could be reduced to 20 or even 10 per cent. without loss of combustion efficiency, and since the exhaust temperature increased with reduction of excess air, being about 320° C. for 30 per cent. excess, 375° C. for 20 per cent. excess, and 430° C. for 10 per cent., the availability of the heat was correspondingly increased.

It was therefore decided to reduce the size of the scavenge pump so that only 20 per cent. excess air was supplied to the main cylinders, giving an exhaust-gas temperature of 375° C. which was found sufficient to generate about 1lb. of steam per b.h.p. with a mean indicated pressure in the engine cylinders of 85lb. per sq. in. The steam pressure was 120 to 150lb. per sq. in. and the outlet temperature from the boiler flue was about 200° C. Concurrently with these developments designs were prepared for driving all the auxiliaries from the main engines, *i.e.* forced-lubrication pumps, jacket and piston cooling-water pumps, and sea-water pumps. This confined the duty required from the exhaust-gas boiler at sea to the supply of steam for steering, electric lighting, steam heating, and occasional general-service pumping. Full-scale experiments soon proved that this duty was well within the capacity of an efficient exhaust-gas boiler Thus, a vessel of 9,000 tons deadweight with an engine of about 1,500 b.h.p. operated for nearly two years with only very occasional demands on the independent oil firing of the boiler. Incidentally, an entirely independent oil-fired furnace with tubes separate from the exhaust-gas tubes was provided so that oil firing could be carried out independently or concurrently as required. A low-pressure air system of oil firing was used so that very small quantities of oil could be burnt per hour when required. By 1931, six vessels were in service with exhaust-gas boilers, and extensive service experience confirmed the ability of the system to operate regularly at sea with a fuel consumption of only 0·35lb./b.h.p./hr. *for all purposes.*

Up to date there are over 200 vessels operating on this system.

The first five-cylinder Doxford engine was constructed in 1935, only two years after the first four-cylinder engine with welded framing had been completed. Two of these five-cylinder engines, with electrically-welded fabricated steel bedplates and framing, were built in 1935 by Messrs. Barclay Curle & Co., Ltd., and installed in the twin-screw motorship *Dilwara* for the British India Steam Navigation Company. The cylinder dimensions were 560 mm. bore×(980+700) mm. stroke, and each engine had a normal rating of 3,000 b.h.p. at

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*"Oil Engine Dynamics with Special Reference to the Opposed-Piston Engine". Trans. Inst. Marine Engineers, Vol. LVIII, Part 5, June, 1946, pp. 73-101.

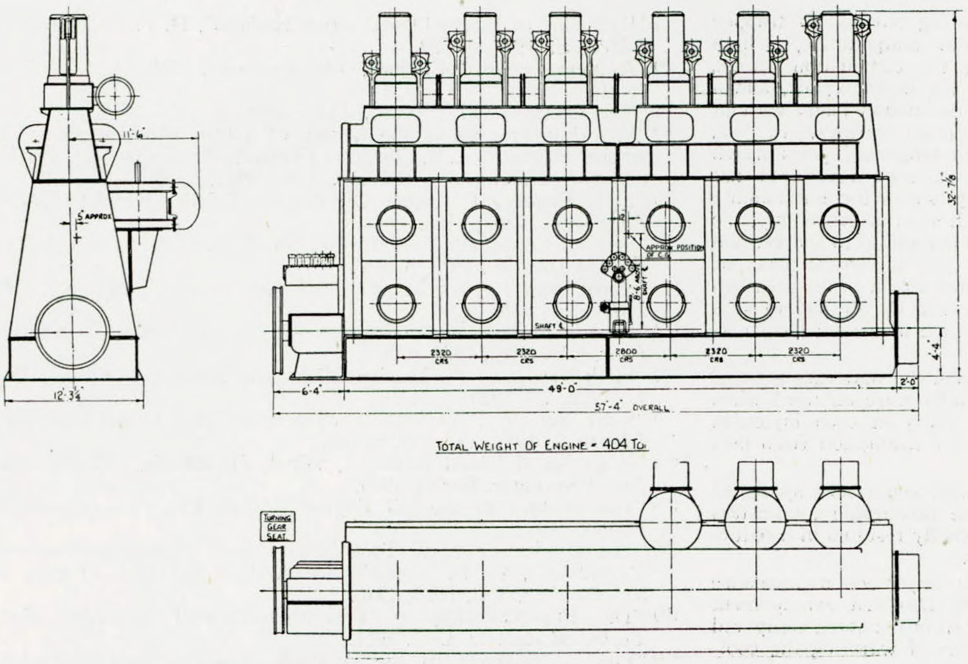

FIG. 33.—*Six-cylinder Doxford opposed-piston oil engine with lever-driven scavenge pumps. Cylinder dimensions 670 mm. bore×(1,340+980) mm. stroke; 6,800 b.h.p. at 116 r.p.m.*

120 r.p.m. with a maximum rating of 3,265 b.h.p. at 128 r.p.m. Test-bed trials gave a fuel consumption of 0·355lb./b.h.p./hr. at the normal rating, with a mechanical efficiency of 89 per cent.

Probably the most outstanding achievement up to date, however, is the completion, in 1939, of four five-cylinder Doxford engines for installation in the quadruple-screw passenger liner *Dominion Monarch* built for the Shaw Saville & Albion Company by Messrs. Swan, Hunter and Wigham Richardson, Ltd. Two of the engines were built by Doxford and two by the shipbuilders. The cylinder dimensions were 725 mm. bore×(1,300+950) mm. stroke, and each engine was rated at 6,500 b.h.p. at 123 r.p.m. with a mean indicated pressure of about 85lb. per sq. in. and a mean piston speed of 910ft. per min. (lower piston 1,050ft. per min., upper piston 770ft. per min.). The output per cylinder was therefore 1,300 b.h.p. and the vessel was the highest-powered motorship in the Mercantile Marine. The specific weight was 138lb. per b.h.p. and the fuel consumption was 0·36lb./b.h.p./hr.

Several engines of this type were built for single- and twin-screw vessels by Messrs. Doxford, Messrs. John Brown & Co., Ltd., and Messrs. Swan, Hunter & Wigham Richardson, Ltd. In 1945 the same cylinder dimensions were used for a six-cylinder engine, built by Messrs. Swan, Hunter & Wigham Richardson, Ltd. Fig. 33 is a general arrangement of one of the six-cylinder engines.

An indication of the progress made since 1921 is given in the following table.

Development of Doxford Opposed-Piston Engine.

R.p.m.	Year	Cylinders			Power		Fuel cons. lb./b.h.p./hr.	Piston Speed		Wt./ b.h.p.	Cu. in./ b.h.p.
		No.	Bore	Stroke	Per cyl.	Total		Lower	Upper		
77	1921	4	580	(2×1160)	675	2700	0·44	585	585	330	55
120	1937	5	725	(1300+950)	1300	6500	0·36	1030	750	138	44
116	1945	6	670	(1340+980)	1133	6800	0·36	1030	750	138	44

In the early days of development of the opposed-piston marine oil engine the items which probably received more criticism than any others were the novelty of the crankshaft construction, and the alleged excessive height of the engine.

In some quarters the crankshaft was even regarded as an unpractical departure from orthodox marine practice, and it was partly to allay nervousness and counteract such criticism that the first twenty-five four-cylinder engines were built with four-piece crankshafts, *i.e.* a separate three-throw section for each cylinder connected by short bobbin pieces which formed the bearing journals. Incidentally, it may be of interest to recall that the first four-cylinder crankshaft was made by Sir W. G. Armstrong Whitworth & Co. at their Elswick Works, in 1920. The finished weight was about 50 tons.

With this arrangement the bedplate was made or sufficient depth to enable a broken section of the crankshaft to be lowered into the crankpit, leaving space for a spare length of plain shafting to be inserted in its place. These precautions proved to be quite unnecessary and within ten years the four-cylinder four-piece shaft was replaced by a two-piece shaft, while a single-piece shaft was used for three-cylinder engines, changes which contributed largely to the reduction of weight achieved during this period. Two important precautions which were taken at the start of development have, however, been retained. These are the provision of external oil pipes for the lubricating oil supply system and the use of spherical bearings on all crankpins and journals. The use of external oil pipes for conveying pressure oil from the journals to the crankpins eliminated the possibility of oil seeping into the shrunk joints between the crankpins and crankwebs. That such seepage does occur with drilled holes with consequent undermining of the shrink grip has been proved by examination of contact surfaces of built-up shafts which have been dismantled.

With regard to the alleged excessive height of the engine, two factors which the critics overlooked when comparing the height of the opposed-piston arrangement with that of contemporary single-piston engines were, firstly, that for a given overall height the stroke of an opposed-piston engine is greater than that of a single-piston engine and, secondly, the headroom necessary for removing the pistons of an opposed-piston engine is only about 16in. in the largest sizes. This makes it possible to place the engine below deck beams only 40in. above the cylinder tops, leaving sufficient room for an electric crane. In this connection it is of interest to recall that Messrs. Doxford were probably the first to realize that an electric crane was an essential feature of every large oil-engine installation. With the help of the crane it is possible to remove the upper and lower pistons from one cylinder in fifteen minutes, and this is accomplished without breaking any high-pressure joints.

Now that opposed-piston engines have been successfully installed in a great variety of ships ranging from small motor coasters to quadruple-screw luxury liners, there is hardly any need to dwell on this question of overall dimensions.

An interesting characteristic, however, is the fact that for a given total stroke the overall height of an engine with unequal lower and upper piston strokes exceeds that of an engine with equal lower and upper piston strokes by the difference of the lower and upper piston strokes of the unequal-stroke arrangement. This implies that the overall height of a single-piston engine having the same stroke as the total stroke of the opposed-piston engine exceeds that of an opposed-piston engine with equal lower and upper piston strokes by an amount which is equal to the total stroke of the opposed-piston arrangement less an allowance for the absence of the upper piston head.

Other important achievements during the development period under review were steady improvement in specific fuel consumption, and a steady reduction of cylinder-liner wear.

As already mentioned, the engine had, from the start, characteristics which were favourable for the realisation of the four requirements for efficiency set down by Beau de Rochas in 1862. These characteristics included a combustion chamber free from large apertures and having a favourable ratio of cooling surface to trapped volume, the highest practicable cooling-water temperature, a high speed of separation of the pistons during the combustion stroke, uniflow scavenging with no hot spots near the incoming air, and a mechanism capable of carrying high peak combustion loads without imposing severe loadings on the framing and main bearings. In 1922, the radial scavenge ports were superseded by tangential ports which imparted a swirling motion to the air, but it was soon discovered that the swirling air tended to blow the oil spray across the horizontally arranged fuel jets causing them to choke with soot. Accordingly, the orientation of the jets was changed from the horizontal to the vertical plane so that the two fuel valves each sprayed a vertical sheet of fuel spray towards the centre of the combustion space. This provided intimate mingling of air and fuel since the swirling air had to pass through the sheets of fuel, and at the same time overcame the choking problem.

Experiments were carried out to determine the optimum amount of swirl, and these showed that the best results were obtained when the air passed only once through the fuel spray at each injection. These changes resulted in a reduction of fuel consumption from 0·44 to 0·41lb./b.h.p./hr.

In 1926, the original flat-topped pistons were superseded by dished pistons. This change provided an even more favourable combustion chamber and further detail development eventually resulted in a reduction of fuel consumption to 0·36lb./b.h.p./hr.

Cylinder-liner wear has always been an important maintenance problem of oil engines, and here again the Doxford arrangement achieved a substantially smaller rate of wear from the start, compared with contemporary designs, due to the practice of warming the cooling water before attempting to start the engine.

In 1924, a further improvement of cylinder wear was obtained through the use of centrifugal purifiers for removing all water and mechanical impurities, as well as a substantial proportion of the ash content, of the fuel oil.

Cylinder-liner and piston-ring materials were naturally subjects for continuous research, both in the laboratory and under service conditions at sea, while the introduction of floating pistons was a mechanical feature which had an appreciable influence in reducing wear.

These investigations culminated in the introduction of cylinder liners made from vanadium-titanium iron, and service experience now indicates that, with this material, liner wear has been reduced to the point where the life of a set of liners is estimated at 11 years. During this period it is expected that the wear will amount to 6 mm. which can be accommodated by fitting new cast-iron rubbing rings to the steel pistons as required, and the use of the oversize piston rings.

Acknowledgments.

The author wishes to express his gratitude to Messrs. Vickers-Armstrongs Ltd. and Mr. E. Davies, M.I.Mech.E., for information on the early development of direct fuel injection; to The English Electric Company, Mr. G. H. Paulin, M.I.Mech.E., and Mr. R. Price Kerr, A.M.I.Mech.E., for notes on the development of the Fullagar engine; and to Messrs. Wm. Doxford & Sons and Mr. W. H. Purdie, M.I.Mech.E., for assistance in preparing the text and illustrations relating to the Doxford opposed-piston engine.

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25 (1874) : Gottheil; Gilles Free-Piston Engine.
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1,997 (1878) : Hanoversche Machinenbau - Actien - Gesellschaft; Wittig Three-Crank Opposed-Piston Engine.
1,500 (1879) : Linford; Opposed-Piston Engine with Rocking Levers and Links.
3,527 (1881) : T. H. Lucas; Opposed-Piston Engine with Two Crankshafts Connected by Gears.
2,712 (1885) : Atkinson; Differential Gas Engine.
9,496 (1890) : Robson; Three-Crank Opposed-Piston Engine.
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24,994 (1896) : Oechelhaeuser; Three-Crank Opposed-Piston Engine.
29,074 (1897) : Brillié; Three-Crank Opposed-Piston Engine.
2,847 (1899) : Nunn and White; Opposed-Piston Engine with Two Crankshafts Connected by Spur Gears.
14,259 (1901) : R. Lucas; Opposed-Piston Engine with Two Crankshafts Connected bv Bevel Gears and a Layshaft.
25,663 (1901) : Junkers; Opposed-Piston Three-Crank Gas Engine.
24,411 (1905) : Brandstetter; Direct Fuel Injection.
6,102 (1909) : Fullagar; Opposed-Piston Engine with Two-throw Crank and Oblique Rods.
27,579 (1910) : Vickers-Armstrongs; Direct Fuel Injection.
26,227 (1911) : Vickers-Armstrongs; Direct Fuel Injection.
102,281 (1916) : Vickers-Armstrongs; Direct Fuel Injection.
165,861 (1920) : Vickers-Armstrongs; Duplex Opposed-Piston Engine.
230,914 (1923) : Groves; Double-acting O.P. Engine.
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JUNIOR LECTURES.

PADDINGTON TECHNICAL INSTITUTE.

The Council's decision to resume the pre-war series of junior lectures delivered under the auspices of the Institute to engineering students at universities and technical colleges in London and other ports throughout the country has been implemented by the arrangement of a full programme of lectures to be delivered in London and provincial centres during the current session.

The first of the lectures in the London area was delivered at Paddington Technical Institute on Wednesday, 16th October, 1946, at 7 p.m., by Mr. A. G. Tyler (Member), on the subject of "Quality Control". The Principal of the College, Dr. S. C. Robinson, occupied the Chair.

The meeting was well attended, and the author's exposition of the intriguing subject of quality control proved highly interesting and instructive. The interest of the audience was evidenced by the fact that, although Mr. Tyler answered many questions following the lecture, he was informally occupied in the same manner for a considerable time after the closure of the meeting.

On the proposal of the chairman, who called attention to the Institute's offer of a prize for the best report of the lecture submitted by a student member of the audience, a very hearty vote of thanks was accorded to the lecturer.

UNIVERSITY COLLEGE, SOUTHAMPTON.

An audience of students of the College and visitors assembled at University College, Southampton, on Wednesday, 23rd October, 1946, at 7 p.m., to hear the first of the post-war lectures to be delivered under the auspices of the Institute at provincial centres. Mr. J. P. M. Pannel, M.B.E., A.M.Inst.C.E., A.M.I.Mech.E., Engineer to the Southampton Harbour Board, was the lecturer, his subject being "Welding".

The Principal of the College, Sir Robert Stamford Wood, occupied the Chair and, in welcoming the lecturer, expressed his appreciation of the extension of these lectures to provincial colleges and the hope that they might be privileged to co-operate with the Institute on similar occasions in the future.

Mr. Pannell commenced his lecture with a short history of arc welding, and then proceeded to deal with various aspects of the subject, including the modern process of arc welding, electrodes, sources of current, the team work necessary to secure effective welding, the deposition of metal by the arc, design for welding, technique and procedure, inspection and testing, and, finally, the welding of special steels. The lecturer illustrated his various points by means of lantern slides, and the numerous questions he was called upon to answer at the conclusion of the lecture were indicative of the interest aroused.

On the proposal of Mr. J. H. Sword (Member), Head of the Department of Marine Engineering of the College, a vote of thanks to Mr. Pannell for his excellent lecture was carried by acclamation.

A vote of thanks to the chairman, moved by Eng. Com. W. A. Graham, O.B.E., R.N.R. (Vice-President, Southampton), who was representing the Council at the meeting, was also carried with warm applause.

VISIT.

Messrs. J. & E. Hall, Ltd, Dartford.

On Saturday afternoon, 19th October, a party of 11 members were privileged to pay a visit to the Works of Messrs. J. & E. Hall, Ltd., Dartford.

The visitors were welcomed by Mr. J. D. Farmer and Mr. E. G. Russell-Roberts, both of whom personally conducted the tour of the Works and greatly added to the value of the visit by their informative comments on the machinery and processes which were inspected.

The initial visit was to the joiners' shop where various marine and land types of refrigerator cabinets were in process of manufacture. This was followed by an inspection of the medium assembly shop where lifts and lift machinery were being assembled. The next section was the thermostatic control assembly for the various types of refrigerators. This department proved of great interest to many of the visitors, who displayed a quite intimate knowledge of the various methods of construction.

A special feature of the small castings foundry, which was next visited, was that all the small work under about 5 cwts. is machine moulded. The Company's own method of casting high-pressure castings was explained, this being to feed the metal at a very high velocity. An examination of various castings showed no sign of porosity or other blemishes, even in small, intricate manifold castings.

The light machine shop with its batteries of Wards and Herberts used for the manufacture of the various refrigerator compressor parts was next inspected. The party was then taken to the light compressor assembly shop, where one small compressor was laid out so that each part of it could be examined. A noticeable feature of this compressor was the cast-iron crankshaft of a special austenitic iron developed by the Company for the purpose.

After an inspection of the large casting foundry, where large compressor components were in various stages of being moulded, cast and fettled, a visit was paid to the large compressor assembly shop, where various assemblies and sub-assemblies were examined. The final item of the tour was an inspection of the large machine shop where various parts such as those just described were being machined.

On the invitation of the directors the party then had tea in the directors' canteen. At the conclusion of the visit, the visitors' gratitude to Mr. Farmer and Mr. Russell-Roberts and to the directors of the Company was warmly expressed by Mr. F. A. Everard (Graduate).

ADDITIONS TO THE LIBRARY.

Presented by the Publishers.

B.S. 916 : 1946.—Black Bolts and Nuts—Hexagon and Square B.S.W. and B.S.F. 11pp., illus., price 2s. net, post free.—British Standards Institution.

Ministry of Fuel and Power: "Fuel and the Future" Conference, September, 1946. Copies of Papers.

Transactions of the Institution of Engineers and Shipbuilders in Scotland. Bound Volume 89. Session 1945-46.

Investigation of the German Fuel and Power Industries. Fuel Efficiency Bulletin No. 47, October, 1946. Prepared by the Fuel Efficiency Committee of the Ministry of Fuel and Power. 12pp. This Bulletin can be obtained free on application to the Ministry of Fuel and Power, Queen Anne's Chambers, Dean Farrar Street, Westminster, or from the Ministry's Regional Offices.

Fire Fighting on Ships. By Edward W. Reanney, A.M.I.Fire E., Ex. Inspector Liverpool Fire Brigade. Brown, Son & Ferguson Limited, Glasgow. 1946. 112 pp., illus., 7s. 6d. net.

In compiling this book the author's aim has been to bring to the fore the absolute necessity for complete understanding and co-operation between officers and men of the Nautical and Fire Services. The only nautical officers who can possibly be well versed in fire experience will be those of the Marine Salvage Association. To the sea-going officer a fire is an occurrence that is to him unusual, and in that direction he may easily encounter a situation of which he has never had any previous experience.

Since the majority of fires occur in ports the port fire officer gets a very varied experience, but he does not go to sea.

In the course of 25 years the author has attended hundreds of fires on board ships, many of which have been of a most unusual type. In this book he does not lay down any definite plans as to what action should be taken in the case of fire. Not having the experience of a sea-going officer he can only hope that the described experiences can be applied in the circumstances that arise on each occasion.

The explanations, drawings, etc. in this book are based on the personal view and experience of the author, and many of the points have been the result of putting fires out "twice", but with the added advantage of also seeing the remedy applied. It is only by a varied experience that the technical knowledge required to cover these circumstances can be applied, and mainly by comparative experience; it will still in spite of any extent of experience be a case of applied reasoning.

The subject has been treated in a simple non-technical manner devoid of formulæ and with no textual rules of extinguishment, the whole treatment being concerned with the effects of both fire and the action of the water and other substances applied to control it.

The United States and Britain. (Second Printing). By Crane Brinton, Professor of History, Harvard University. Cambridge Massachusetts Harvard University Press. London: Geoffrey Cumberlege, Oxford University Press. 1945. 298 pp., 9s. 6d.

Mr. Sumner Welles in his introduction states clearly the *raison d'être* for this book:—

> "A lasting understanding between the American and British peoples is vitally needed. It can be achieved notwithstanding the obstacles which may from time to time arise".

Although written mainly to explain Britain to the Americans, real understanding between the two countries would be further helped by a book of equally high standard written to explain the American people to the British public.

The book makes clear to the American public our historical background as it affects our form of government, religions, and educational systems, why we have what the author terms a "Class Society", the effect of war economy, and finally the author gives an extremely reasoned explanation of our economic problems at the present time.

The book does present a true picture of Great Britain and its people, and what criticisms there are, are not carping but helpful.

The book is strongly recommended for use in all adult education groups and the higher schools, the appendices being particularly valuable.

After reading it one must feel with Kipling "How little they know of England who only England know".

Examples in Applied Mathematics. By F. W. Kellaway, B.Sc., Dip.Ed. Blackie & Son Limited. London, 1946. 110pp., 4s. net.

This collection, containing just over 400 examples in statics, dynamics and hydrostatics, divided into 20 convenient sections, is designed to provide practice and a testing-ground for students preparing for such examinations as the qualifying examination of the Mechanical Sciences Tripos (Cambridge), the Intermediate B.Sc. Engineering (London), and the Intermediate Arts and Science (London), and for those doing similar work.

Questions requiring almost entirely "bookwork" or its immediate applications (*e.g.* those necessitating nothing but substitution of numbers in a formula) have been excluded. A good variety of problems in each section, without undue repetition, has been an objective. Many of the questions are original; others have been selected from various examination papers.

Molesworth's Pocket Book of Engineering Formulæ. (33rd edition). Edited by A. P. Thurston, M.B.E., D.Sc.(Engineering)Lond., M.I.Mech.E., F.R.Ae.S., M.I.A.E. E. & F. N. Spon, Ltd, London. 1945. 939pp., illus., 12s. 6d.

Although this pocket-book was first published eighty-two years ago and has now reached its thirty-third edition, it cannot be said to have outlived its usefulness nor, in spite of frequent revision, lost those characteristics which, from the guidance it has always given, have earned for it the familiar epithet, the "Engineer's Bible". At the same time, it must be admitted that the great extension of the field of engineering since it was first issued, and subsequently revised, makes some additions desirable. Unfortunately, present-day circumstances, such as restriction of paper, shortage of labour and so forth, have temporarily arrested growth.

There are, however, in this edition some new notes on such things as the measurement of smoke density, the size of air-borne particles and of silt, sand, and clay particles, the relation between suction lift and vacuum, the safe load on bolts, the safe load on slings, the air consumption of pneumatic tools, hardness of minerals, and other subjects, mostly presented in simplified form.

The section relating to the hardness of metals has been greatly expanded and a table of comparative hardness numbers obtained by the most commonly accepted testing methods has been added. The table of trigonometrical ratios headed "Natural Sines, etc.", has also been extended, each degree of arc having now 20 subdivisions.

Some paragraphs, which correspondence with users of the book has indicated as possessing a degree of ambiguity, have been re-cast, while some typographical errors, which have crept in through repeated re-settings, have been corrected.

B.R. 1333. The Distilling Plant—Theory and Operation. Admiralty (P. Branch) P.17449/45. 1945. 57pp., 26 figs.

It is no exaggeration to say that the distilling plant is the most important auxiliary in the modern warship, for upon its capabilities of turning out ample quantities of water of a high standard of purity depends not only the ability of the ship to continue steaming, but also the life of the boilers and engines and the cleanliness, health and contentment of the ship's company. The efficient operation and maintenance of this plant is rendered particularly important in war-time by the greater demands for water due to increased complements, reduced opportunities for making good steam and water leaks, longer hours of steaming, higher criusing speeds and lack of facilities for receiving shore water.

Distilling plants in the past have been run largely without any clear idea of exactly what the plant is designed to do, or how it does it—apart from an elementary idea of the broadest general principles. It is with the object of making good this gap in knowledge that these notes have been written, so that by understanding exactly how their plant works and what is the precise function of each part of it, ship's officers and senior ratings will be able to obtain the very best service from it.

In preparing these notes every effort has been made to present each argument in its simplest form so that it shall be capable of being understood by those with a minimum of scientific training—though this requirement has not been allowed to stand in the way of those problems whose solution it is not possible to explain in simple language.

Tables for Measurement of Oil. Measurement and Sampling Sub-Committee of the Institute of Petroleum. London, July, 1945. 320pp., price 25s., or $6.00.

This book has been prepared to meet the demands of the petroleum industry for authoritative tables for use in computing oil quantities in territories which employ the British (Imperial) system of weights and measures. The need for a publication of this nature has long been apparent. Although countries using the United States system of weights and measures have the official Bureau of Standards Circular C 410 as a standard, no such official guidance has been available in territories adhering to the British system.

The work can, therefore, be regarded as the official British counterpart of the American publication "National Standard Petroleum Oil Tables—Circular C 410", but it is more extended in scope. In this new book the main tables contained in Circular C 410 have been recalculated to allow entry to be made with specific gravity instead of A.P.I. gravity, and they have been supplemented with additional tables. These additional tables, giving weights per unit volume and volumes per unit weight, have been computed using, wherever possible, basic data which is legally recognized, or which recent metrological research has shown to be most accurate. For these reasons the tables will also find wide application in the American oil industry.

The Committee responsible for the preparation of the book has paid particular attention to ease of reference. The style of type and the format of the tables were also given careful consideration. Each table is preceded by its own introductory notes showing, among other things, why the table is necessary and giving examples of correct use.

Every one of the 16 tables included in this authoritative publication will find a regular use in some branch of the petroleum industry. Its appearance will provide a long-needed standard for the correct computation of bulk oil quantities.

Water Transport: Origins and Early Evolution. By James Hornell, F.L.S., F.R.A.I. Cambridge University Press. 1946. 307pp., 87 photographs, 69 figures in text, 30s. net.

All who are interested in the beginnings and development of water craft will welcome this new book by James Hornell, for he has described in detail the many devices upon which men launch themselves on river, lake and sea. He has explained their construction and use, their origin and how experience affected their design. Mr. Hornell has also included a great number of excellent photographs and drawings some of which are his own work.

Dividing his many subjects into three groups he has first considered floats and rafts; next skin boats and finally bark canoes, dugouts and plank-built craft. As well as describing each individual type, he has much to add from their history and from the influences of religious and superstitious practices. Such a book could not have been written without first-hand knowledge, and it is immediately apparent that Mr. Hornell has this requirement. It is our good fortune that his interest in boats and his work should have coincided, for he has held a number of official appointments, where it was his duty to study and to advise native races, in many parts of the world, on their fishing and boating problems. Yet, as the author wisely points out in his introduction, this is not a subject that can be properly understood by any armchair study of travellers' tales with any degree of accuracy or probability. The only way is to see the craft going about their normal duties in both fair weather and foul, to watch the crews trying to land a canoe through the thunder and crash of a boiling surf, or drowsing happily in fine weather. Most of us, unfortunately, will not be able to take Mr. Hornell's advice, but even so, his book makes a very good second-best to reality.

The Engineers' Sketch Book of Mechanical Movements. (Seventh edition, new impression). By Thomas Walter Barber, M.Inst.C.E. E. & F. N. Spon, Ltd. London, 1946. 355pp. with nearly 3,000 illus., 17s. 6d.

This "Engineers' Sketch Book" is really an illustrated dictionary of mechanical devices and as such would undoubtedly be very useful to designer and student alike. The sketches are clear and although sometimes lacking in detail would seem to point the way to the man seeking some way out of a mechanical perplexity.

Anyone thinking he has a novel idea, worthy of a patent, would also do well to study this book to see how far his idea has already been covered.

Presented by The Admiralty Ship Welding Committee.

Report on Hogging and Sagging Tests on All-welded Tanker M.v. "Neverita". Report No. R.1. By Authority of the Lords Commissioners of the Admiralty. Published by H.M.S.O. London, 1946. 160pp., 150 figs., 7s. 6d. net.

The present report describes a full-scale hogging and sagging experiment in still water on a welded 12,000-ton tanker, the methods used for determining the strains and deformations, and the results obtained. This experiment constitutes one of a series planned by the Admiralty Ship Welding Committee, with the ultimate object of comparing the structural behaviour of similar riveted and welded vessels.

As a complement to the work described in this report the Committee proposes to carry out a similar experiment on a tanker of identical form and similar structural arrangement, but in which a large proportion of the structure is riveted.

The main purpose of the experiment described in this report was to study the stresses set up on a cross-section of the ship, near amidships, by known changes in longitudinal bending movement, and to observe the deflections of the ship's girder under these changes.

In comparison with previous work of the kind, the Committee was fortunate in this case in having the advantage of recent important developments in instrumentation and technique, which made possible a much more complete study than had hitherto been practicable. Many of the instruments and much of the technique was specially developed for this work. These developments are fully described in the report in the hope that advantage may be taken of them by later workers, not only in pursuit of knowledge on ships' structures, but possibly also in other branches of structural engineering.

Presented by the Authors.

Aerodynamic Experiments with Models of Cooling Water Inlets for Marine Condensers. By Dott. Ing. Bernardino Lattanzi and Dott. Ing. Erno Bellante. Aeronautical Publishing Office, Rome, 35pp., illus., no price indicated.

This publication describes and illustrates a series of experiments carried out in the aerodynamic wind-tunnel of Guidonia on behalf of the Committee of Ship Design of the Royal Italian Navy, in order to determine the capacity and flow resistance of the dynamic type cooling-water inlets for ships' condensers designed by Constructor General Francesco Modugno, as compared with the Schmidt-type inlets already in use in the ships of the Italian Navy.

The results of the tests proved that the Modugno design of inlet is definitely superior both as regards construction and performance. It comprises a duct of rectilinear section with guide vanes at the inlet to ensure a uniform velocity of flow through the condenser.

The text is in Italian.

Purchased.

Boiler Room Questions and Answers. By Alex Higgins. McGraw-Hill Book Company, Inc. New York and London. 1945. 134pp., profusely illus., 15s.

It has been the experience of the author in many years of teaching and power plant construction and operation that a great number of good practical engineers have difficulty in passing written examinations because of their inability to express themselves in writing. This book has been compiled to help such men to overcome this handicap and to give them, as well as others who may happen to be more proficient in this respect, a comprehensive review of typical examination questions on boiler-room operation, written in clear and concise language that can be readily understood by all practical power-plant operators.

Though the primary purpose of the book is to assist men who are studying for licenses or certificates as operating engineers, it also provides an excellent reference and valuable aid to the plant operator in the solution of the problems that constantly confront him in his daily routine.

The following are the twenty-six chapter headings in their order of presentation—Boiler Regulations and Methods of Study; Boilers: Safety, Definitions, Fire-tube Types; Water-tube Boilers-Figuring Surface; Construction Materials and Details—Heat-treatments and Processes; The Mechanics of Materials and Some Details of Boiler Construction; Stays, Stay Bolts; Boiler Calculations; Steam Gauges and Water Columns; Safety Valves, Water-level Alarms, Fusible Plugs; Boiler-feed and Blow-off Accessories, Valves; Boiler Construction, Cleaning and Inspection; Boiler Foundations and Erection; Some Typical Boiler Repairs; Some Important Fuel Facts; Flue-gas Analysis; Method and Meaning; Fuel and Gas (Concluded)—Facts about Draft; Draft and Its Control; Hand Firing and Stoker Firing; Facts about Pulverized Fuel, Gas, Oil and Combustion; Boiler Feed-water Heating and Treatment (Part I); Boiler Feed-water Heating and Treatment (Part II); Heat Facts, Laws and Problems; How to Use Steam Tables; Injectors and Pumps; Pumping Problems; Pipe and Piping Accessories; Piping Layout and Calculations.

Internal-combustion Engines—Theory and Design. (Second edition. Second impression). By V. L. Maleev, M.E., Dr. A. M. McGraw-Hill Book Company, Inc. New York and London. 1945. 636pp., profusely illus., 25s.

During the twelve years that have elapsed since the first edition of this book was published, the progress in the field of internal-combustion engines has continued, possibly even with an accelerated tempo. The design and construction of existing engines have been improved and changed; new and better designs have appeared on the market, with a very conspicuous trend towards higher speeds and greater power output. Deeper and more correct understanding has been attained in respect to thermo and hydro-dynamical processes and also in respect to the strength and wear of various machine parts.

This is justification for a new, entirely revised edition of the book. The author has tried to improve the book for class use by taking into account not only the suggestions which he has received from instructors who have used his book in their classes but also his own teaching experience. As might be expected, the suggestions were of a greatly differing nature. Some wanted more material in respect to theory; others in respect to recent research; and several asked for strengthening the chapters devoted to design.

At first the author was afraid that complying with all these suggestions would make the book too bulky as a text for an undergraduate course. However, since the book, even in the first edition, contained slightly more material than could be covered satisfactorily in a one-semester course, the author decided to include all material which seemed to be of interest from various points of view but to present it in such a way that certain chapters could be omitted without harm to the fundamental exposition. This gives a valuable flexibility to the book as a class text: it may be used in undergraduate courses, whether short or long, by covering only those chapters which the individual instructor considers most essential; the rest of the chapters may be used in a second, advanced course. The book may also be used as a text in a course consisting of classes in theory and in a design laboratory. Finally, the book has enough material for two consecutive courses, the first of a theoretical nature, followed by a second course dealing with the design of internal-combustion engines, the latter course to be in conjunction with corresponding laboratory work.

In spite of the increase of the amount of material included in this revised book, the author hopes that he has succeeded in his attempt to follow the general tendency toward fundamentals rather than the tendency towards specialization in engineering education. The theoretical discussion has been strengthened, and the chapters dealing with the design of parts are presented as a basis for similar design and not just filled with practical and empirical data. The order of presentation was rearranged with the purpose of further improving the teachability of the text. The problems have been revised and increased in number from 225 to 543.

Handbook for Welded Structural Steelwork. Fourth edition. 1946. Published by The Institute of Welding, 2, Buckingham Palace Gardens, Buckingham Palace Road, London, S.W.1. 234pp., profusely illus., 7s. 6d. post free.

Final Summary of the Sub-Committee for Shipbuilding in Germany. British Intelligence Objectives Sub-Committee. (F.I.A.T. Final Report No. 704). H.M.S.O. 1946. 16pp. 1s. 6d. net.

Smoke and its Measurement. The Correlation of Optical Density with the Nature and Quantity of Smoke from a Hand-fired Lancashire Boiler. Department of Scientific and Industrial Research. Fuel Research. Technical Paper No. 53. 1946. 20pp., 14 figs. H.M.S.O. 6d. net.

Designs of Hollow Turbine Blades for Jet Engines. William Prym, Stolberg and Zweifall. Combined Intelligence Objectives Sub-Committee. (Item No. 5. File No. VI-28 & 29 and VIII-13). H.M.S.O. 1944. 37pp., 18 figs. 3s. 6d. net.

Report on Velox Boilers. British Intelligence Objectives Sub-Committee. (F.I.A.T. Final Report No. 734). H.M.S.O. 1946. 3pp., 6d. net.

Brassey's Naval Annual, 1946. Edited by Rear-Admiral H. G. Thursfield. Published by William Clowes & Sons, Limited. London. 282pp., profusely illus., 30s.

Instructions as to the Survey of Life Saving Appliances. Issued by the Board of Trade. Published by H.M.S.O. London, 1936. Reprinted 1946. 202pp., 3s. net.

Survey of Equipment for Shipbuilding—German Shipyards. British Intelligence Objectives Sub-Committee. (F.I.A.T. Final Report No. 206). H.M.S.O. 1945. 8pp., 1s. net.

Deutsche Erdol A.G. Hamburg-Germany. Crude Oil and Products. British Intelligence Objectives Sub-Committee. B.I.O.S.—Final Report No. 638. Item No. 30. H.M.S.O. 1945. 13pp., 1s. 6d. net.

Brown's Nautical Almanac (Incorporating "Pearson's Nautical Almanac"): Daily Tide Tables for 1947. Edited by Captain Chas. H. Brown, F.R.S.G.S., assisted by C. W. T. Layton, A.I.N.A. Printed and published in Great Britain by Brown, Son & Ferguson, Ltd., The Nautical Press, 52-58, Darnley Street, Glasgow, S.1. Price 5s.

MEMBERSHIP ELECTIONS.

Date of Election, 5th November, 1946.

Members.

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Charles Hay Bennett.
Norman Purvis Blackburn.
John Adams Bolton.
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Donald McGregor Clark, Lieut.(E.), R.N.R.
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Thomas Dawson.
Raymond Edgar.
Cornelis Hendrikus Franken.
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Carlos Godino.
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Frederick Bottin Gray.
Edward Lawrence Green.
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Albert Edward Holdforth, Lieut.(E.), R.N.R.
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Geoffrey Richard Jones.

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Graduates.

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James Nesbit Fatkin.
Aubrey James Godward.
Denis Knowles.
Donald Ian Stuart, A/Lieut.(E.), R.N.

Students.

Neil Kirkwood, A/Lieut.(E.), R.N.
Harry Graham Julian, A/Lieut.(E.), R.N.

Transfer from Associate Member to Member.

Wilfred Roy Harvey.
John Falconer Mitchell, B.Sc.

Transfer from Associate to Member.

Henry Arthur Brooks.
Arthur Craig.
Jacobus Ehrenburg, Lt.-Com.(E.), R.Neth. N.
Richard Stuart McRae Harris.
James Holt.
Kenneth Robert Longes.
George Victor Lawson, T/Lt.(E.), R.N.R.
Jack Lewis Vandyck Temple.

Transfer from Associate to Associate Member.

John Pollock Crawford.
Thomas George Pickering, Lieut.(E.), R.N.

Transfer from Graduate to Member.

Frederick Alfred John Beatty Everard.

Transfer from Graduate to Associate.

John Gray Mathew-Jones, Major, R.E.M.E.
Charles Alan Rees.

Transfer from Student to Graduate.

Leif Tranberg, Sub. Lt.(E.), R.Nor.N.

PERSONAL.

A. H. ABRAHAM (Member), on his demobilization from the Royal Navy with the rank of Lt.(E.), R.N.R., has been re-appointed a surveyor to The Eagle Star Insurance Co., Ltd. and is stationed in the South Wales district.

J. S. BELL (Member) has been demobilized from the Royal Navy and has returned to duty with his former employers, The Salvage Association (London).

J. C. BOOTHMAN (Associate) has been demobilized from the Royal Navy with the rank of Lt.(E.), R.N.R. and has been appointed to the chief engineer's department of Imperial Chemical Industries, Ltd., General Chemicals Division.

E. F. BUTLER (Member) has been appointed a surveyor to Lloyd's Register of Shipping.

JAMES H. CAMERON (Member) has been elected a town councillor for the Fifth Ward of the Royal and Ancient Burgh of Dumbarton.

K. P. CAMPION (Associate) has left the service of the Anglo-Saxon Petroleum Co., Ltd. and has joined the South American Saint Line, Ltd.

J. H. CLARKE (Associate) has been appointed an assistant surveyor to J. G. Harrison, F.C.M.S., marine surveyor and consulting engineer, Newcastle-on-Tyne.

R. H. COCKBURN (Member) has been appointed an engineering assistant with the Ministry of Works.

H. J. COLES (Graduate) has been released from the Royal Navy with the rank of Lt.(E.), and has been appointed mechanical engineer to Mitchell Engineering, Ltd., London.

D. A. R. CROWLEY (Associate) has been released from the R.N.R. and has been appointed an engineer surveyor for the Exeter district by the Municipal Mutual Insurance, Ltd.

H. T. CROWTHER (Member) has been appointed an engineering assistant with the Ministry of Works.

E. H. DUNCAN (Associate) has been appointed a junior fuel engineer with the Ministry of Fuel and Power.

LT.(E.) J. EHRENBURG, R.Neth.N. (Member) has been promoted to the rank of Lt.-Com.(E.) and is at present stationed at Sydney.

W. J. EVANS (Member) has been appointed chief engineer of the Seamen's Hospital Society.

W. J. FRIER (Member), branch manager of the marine sales department of The Vacuum Oil Co., Ltd., Liverpool, is being transferred as branch sales manager to the Company's industrial department at Newcastle-on-Tyne.

H. A. GARNETT (Member), senior engineer surveyor on the London outdoor staff of Lloyd's Register of Shipping, has been appointed the Society's principal surveyor for Australia and New Zealand.

W. H. GREGORY (Associate Member) has been awarded the D.S.C. for services rendered during the Japanese campaign. Mr. Gregory was recently demobilized from the Royal Navy.

L. HAYES (Associate) has been released from the Royal Naval Reserve and has joined The British Aluminium Co., Ltd. as assistant production superintendent at their Warrington Works.

W. F. HOLMAN (Member) has been demobilized from the Royal Navy and has been appointed works engineer to Messrs. Howards & Sons, Ltd., Ilford.

W. D. JOHNSTON (Associate) has been appointed an engineer surveyor to the Vulcan Boiler & General Insurance Co., Ltd.

E. A. LEGG (Associate) has been demobilized from the Royal Navy with the rank of Lt.-Com.(E.), R.N.R., and has rejoined the Cornhill Insurance Co., Ltd. as deputy chief engineer, boiler department.

K. R. LONGES (Member), recently demobilized from the Royal Navy, has joined the technical staff of Bailey Meters & Controls, Ltd.

R. A. MCCOWATT (Associate) has been appointed an engineering assistant with the Ministry of Works.

W. MCLAUGHLIN (Member), who was interned at Stanley Camp, Hong Kong, during the war, has returned to duty with the Chinese Maritime Customs and is now stationed at Shanghai.

T. A. V. MEIKLE (Associate), released from the Merchant Navy, has joined the staff of The British Thomson-Houston Co., Ltd., Rugby, as an engineering draughtsman.

J. H. MILLAR (Member) has been elected a Member of the Institute of Fuel.

T. A. MOLYNEUX (Member) has been demobilized from the Royal Navy and has taken up an appointment as chief mechanical engineer to The Trinidad & Tobago Electricity Commission.

G. D. POUNDER (Member), after nine years on the technical staff of the Engineer-in-Chief's Department, Admiralty, has joined the staff of The Iraq Petroleum Co., Ltd., London. Mr. Pounder was recently elected an Associate Member of the Institute of Petroleum.

D. D. ROBB (Member) has been released from the Royal Navy with the rank of Lt.-Com.(E.). Commander Robb was awarded the D.S.C. for services rendered at Dunkirk.

T. ROWAN (Associate) has joined the staff of The Gas Light & Coke Co., Fulham.

H. SEYMOUR (Associate), recently elected a Member of the Institute of Fuel, has been appointed superintendent engineer of The Express Dairy Co., London.

JOHN A. SMITH (Graduate), after spending six months in the gearing research section of Messrs. Vickers-Armstrongs, Ltd., Barrow, following his release from the Royal Navy, has been appointed an assistant engineer superintendent with Elder Dempster Lines.

J. M. SOMERFORD (Associate) has been appointed an engineer surveyor for Ajax Engineering Policies by Lloyd's.

JOHN STAINCLIFFE (Member) has been appointed a surveyor to Ajax Insurance Co., Ltd.

P. H. L. THOMAS (Member), released from the Royal Navy, has returned to the Ministry of Supply as assistant to the Principal Director of Technical Development (Defence).

LT.-COM.(E.) H. G. THOMPSON, R.N.R. (Member) has joined the staff of The English Electric Co., Ltd.

J. WHITE, D.S.C. (Member) has been released from the Royal Navy and has been appointed marine representative in Liverpool of The Texas Oil Co.

J. J. WILSON (Associate Member), surveyor to Lloyd's Register of Shipping, is now stationed at Belfast.

LT.-COM.(E.) T. R. WORRALL, R.N.R. (Member) has been released from the Royal Navy and has established himself in business as one of the principals in a firm importing, exporting, general constructing and logging at Vancouver, Canada.

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F. H. Warren	1	0	0
W. D. Ewart	3	0	0
Engineer Officers, S.S. "Barala" (per H. H. Winch)	4	0	0
Major W. Gregson, M.Sc.	10	10	0
G. Cavan	1	1	0
C. G. Harris	2	2	0
G. L. Rischmiller	2	2	0
J. A. Ferguson	2	10	0
J. C. Herriot	5	5	0
F. Gordon	2	7	2
C. F. Wrigley	1	0	0
A. Oates	1	0	0
J. J. Preston	3	0	0
H. Newton		10	0
F. W. Roper	2	2	0
H. Musker	1	1	0
H. P. Bowen-Evans	2	2	0
A. Moore	5	0	0
A. Paul	5	5	0
I. L. Wren	2	2	0
W. A. Miller	2	0	0
R. M. Logan	2	4	11
T. F. Johnson		10	0
V. W. Back	10	0	0
L. Roy	5	0	0
C. E. Roffey	10	10	0
Babcock & Wilcox, Ltd.	250	0	0
E. B. Dodd	2	2	0
Eng. Vice-Admiral Sir J. Kingcome, K.C.B.	10	10	0
E. N. Cady	1	0	0

Marine Engineers' National War Memorial Building Fund.

	£	s.	d.
K. H. Marsh	5	0	0
A. N. Reid	3	3	0
P. Watkinson	2	2	0
Dover Navigation Co. Ltd.	25	0	0
J. MacCallum	1	0	0
R. C. Probert	2	2	0
Richard Dunston Ltd.	25	0	0
J. T. Oliver	2	2	0
John Swire & Sons, Ltd.	50	0	0
Harvey, Trinder & Van Ommeren Ltd.	25	0	0
Elders & Fyffes Ltd.	26	5	0
Anglo-Danubian Transport Co. Ltd	5	5	0
Caledon Shipbuilding & Engineering Co. Ltd.	105	0	0
Royal Mail Lines, Ltd.	250	0	0
Houlder Bros. & Co. Ltd.	100	0	0
Wm. Gray & Co. Ltd.	100	0	0
Edward Nicholson Ltd.	2	2	0
J. Crighton, Jnr.	10	10	0
E. D. Parsons		10	0
London Graving Dock Co. Ltd.	52	10	0
Thames Welding Co. Ltd.	15	15	0
Ayr Engineering & Construction Co.	10	10	0
Universal Welding & Construction Co.	10	10	0
W. A. Massey & Sons, Ltd.	1	1	0
Barclay, Curle & Co. Ltd	800	0	0
Jas. Fisher & Sons, Ltd.	26	5	0
Union Castle Mail Steamship Co. Ltd.	262	10	0
Sir Leighton Seager, C.B.E., D.L., J.P.	10	10	0
Furness Withy & Co. Ltd.	250	0	0
Cook, Wilton & Gemmell Ltd.	2	2	0
London Welding Co. Ltd.	5	5	0
C. W. Herbert		10	6
J. H. Davidson, O.B.E.	5	0	0
S. Lockington & Co. Ltd.	2	2	0
J. C. Lowrie	21	0	0
J. T. Parsons	3	3	0
John I. Thornycroft & Co. Ltd.	100	0	0
H. G. Ferrier	5	5	0
G. More	2	0	0
Bolton Steam Shipping Co. Ltd.	2	2	0
Denholm Line Steamers, Ltd.	25	0	0
Shaw, Savill & Albion Co. Ltd.	100	0	0
Aberdeen & Commonwealth Line	100	0	0
Ocean Steam Ship Co. Ltd.	2000	0	0
China Mutual Steam Navigation Co. Ltd.	1000	0	0
Glen Line Ltd.	1000	0	0
R. Jackson	2	2	0
Hain Steamship Co. Ltd.	500	0	0
British India Steam Navigation Co.	1000	0	0
Scottish Co-operative Wholesale Society	2	2	0
Peninsular & Oriental Steam Navigation Co.	1000	0	0
H. H. Norman	2	2	0
Singapore Straits Steamship Co. Ltd.	250	0	0
James Nourse, Ltd.	250	0	0
Orient Steam Navigation Co. Ltd.	1000	0	0
Moss, Hutchison Line, Ltd.	250	0	0
Gow, Harrison & Co.	25	0	0
Ho Hong Steam Ship Co. Ltd.	100	0	0
Capper Alexander & Co. Ltd.	25	0	0
Strick Line Ltd.	250	0	0
Union Steam Ship Co. of New Zealand, Ltd.	210	0	0
General Steam Navigation Co. Ltd.	250	0	0
N. Turner	1	0	0
The Rowhedge Ironworks Co. Ltd.	5	5	0
A. Fletcher	5	5	0
Gray, Dawes & Co. Ltd.	100	0	0
Hudson Steamship Co. Ltd.	5	5	0
Engr. Capt. S. Zinoviev, U.S.S.R.N.	1	0	0
Lambert Bros. Ltd.	100	0	0
Plenty & Son, Ltd.	10	10	0
Hull Gates Shipping Co. Ltd.	2	2	0
Northern Co-operative Society Ltd.	2	2	0
Blue Star Line, Ltd.	200	0	0
H. W. Taylor	3	3	0
J. O. Shirley Elgood	2	0	0
W. W. Adamson	1	1	0
Mrs. J. A. Harvey	2	2	0
G. T. Gray	2	2	0
R. & H. Green & Silley Weir, Ltd	500	0	0
Silley, Cox & Co. Ltd.	250	0	0

	£	s.	d.
London Scaling Co. Ltd.	250	0.	0
Broken Hill Proprietary Co. Ltd.	100	0	0
Arthur Guinness, Son & Co. Ltd.	25	0	0
Anglo-American Oil Co. Ltd	525	0	0
Watergate Steam Shipping Co. Ltd.	10	10	0
Wm. Denny & Bros. Ltd.	200	0	0
Athel Line Ltd.	105	0	0
Wm. Cory & Son, Ltd.	262	10	0
Joseph Constantine Steam Ship Line, Ltd.	300	0	0
Smith's Dock Co. Ltd.	500	0	0
Clan Line Steamers Ltd.	1000	0	0
Eagle Oil & Shipping Co. Ltd.	250	0	0
J. E. Steel	1	1	0
A. Wilson	1	0	0
W. E. W. Delo	1	0	0
M. Wardropper	1	0	0
John Crighton	15	15	0
Pacific Steam Navigation Co.	100	0	0
J. Wharton (Shipping) Ltd.	5	0	0
Moller Line (U.K.), Ltd.	10	10	0
W. T. Pinnock	2	2	0
B. Stephenson	10	10	0
A. Martin	5	0	0
A. Wilson	2	2	0
British Phosphate Commissioners	1	1	0
Federal Steam Navigation Co. Ltd.	1000	0	0
G. R. McKay	1	0	0
New Zealand Shipping Co. Ltd.	1000	0	0
Aberdeen Coal & Shipping Co. Ltd.	10	10	0
Australasian United Steam Navigation Co. Ltd.	150	0	0
Eastern & Australian Steamship Co. Ltd.	150	0	0
Richardsons, Westgarth & Co. Ltd. North Eastern Marine Engineering Co. Ltd. George Clark Ltd.	525	0	0
J. A. Nevill	5	5	0
Bulk Oil Steamship Co. Ltd.	100	0	0
John Readhead & Sons, Ltd.	210	0	0
H. A. Parker	10	10	0
L. Teasdale	1	1	0
Maclay & McIntyre, Ltd.	100	0	0
Manchester Dry Docks Co. Ltd.	105	0	0
Anglo-Saxon Petroleum Co. Ltd.	525	0	0
C. H. Jones	1	0	0
C. M. Procter	5	5	0
N. L. Wright	4	4	0
W. Graham		10	0
Trinidad Leaseholds Ltd.	10	10	0
C. T. Birdwood	1	1	0
W. Mellor	10	0	0
Wailes Dove Bitumastic Ltd.	105	0	0
Bibby Bros. & Co.	300	0	0
P. Henderson & Co.	300	0	0
London & North Eastern, London, Midland & Scottish, Great Western, and Southern Railways	105	0	0
F. T. Brown	5	5	0
N. Williams		8	5
Indo-China Steam Navigation Co. Ltd.	50	0	0
Wallsend Slipway & Engineering Co. Ltd.	500	0	0
Middle Docks & Engineering Co. Ltd.	105	0	0
Swan, Hunter & Wigham Richardson Ltd.	1000	0	0
J. C. O'Shea	5	5	0
Eng'r Lt. Com'r. G. A. O'Neill, R.N. (ret).	3	3	0
Anonymous	3	3	0
J. H. Mackinlay	2	0	0
L. J. Lewer		6	0
F. T. Everard & Sons Ltd.	105	0	0
J. W. Taylor	3	0	0
W. G. Davies	5	0	0
Lieut.(E.) J. Bisset, R.N.R.	1	0	0
The Bank Line Ltd.	1,000	0	0
United Baltic Corporation Ltd.	250	0	0
MacAndrews & Co. Ltd.	250	0	0
J. Logie	3	0	0
G. Seales		18	0
J. Jeffries & Sons Ltd.	26	5	0
A. M. Bennett	2	2	0
Lloyd's Register of Shipping	1,000	0	0
A. P. McCormick	5	5	0
L. Miller	2	2	0
A. M. Keith	1	0	0
R. C. Lacey	10	0	0

Marine Engineers' National War Memorial Building Fund.

	£	s.	d.
A. Bird		10	6
T. Walker	3	0	0
H. G. Thompson	5	0	0
T. Cockburn		15	0
Captain G. T. Firth, M.B.E.	1	0	0
P. R. Owens	3	3	0
T. Morton	5	0	0
J. Austin	10	10	0
Cammell Laird & Co. Ltd.	500	0	0
Elder Dempster Lines, Ltd.	500	0	0
British Tanker Co. Ltd.	525	0	0
Eng. Com'r. W. R. Steele, R.D., R.N.R.	5	5	0
W. Dick	2	2	0
T. & J. Brocklebank	100	0	0
Corporation of Lloyd's	100	0	0
Grayson, Rollo & Clover Docks, Ltd.	105	0	0
Eng. Captain J. E. Moloney, C.I.E., R.I.N.(ret.)	3	3	0
J. B. Harvey	5	5	0
Vickers-Armstrongs, Ltd.	1,000	0	0
Hugh Barr	5	0	0
J. J. Teasdale	2	2	0
Harland & Wolff, Ltd.	1,000	0	0
Cunard White Star	1,000	0	0
Port Line, Ltd.	500	0	0
Ellerman Lines, Ltd.	1,000	0	0
E. Souchotte	2	10	0
R. W. Groom	10	10	0
A. J. Wharton	2	2	0
R. S. Cowan	10	0	0
G. Filshie	5	0	0
John Brown & Co. Ltd.	1,000	0	0
C. Zulver	5	5	0
G. Blakely	2	0	0
Ellerman's Wilson Line	250	0	0
Tilbury Contracting & Dredging Co. Ltd.	10	10	0
W. G. Ireland		10	0
D. S. Kennedy	2	0	0
Tyne Dock Engineering Co. Ltd.	25	0	0
W. B. Angel	1	1	0
Humber Graving Dock and Engineering Co. Ltd.	100	0	0
Quasi-Arc Co. Ltd.	10	10	0
Smith & McLean, Ltd.	10	0	0
Hindustan Steam Shipping Co. Ltd.	26	5	0
R. H. Wilson	5	5	0
Taylor & Hubbard, Ltd.	2	2	0
H. G. Hall	2	2	0
Ferguson & Timpson, Ltd.	52	10	0
Raeburn & Verel, Ltd.	25	0	0
Lancaster and Tonge, Ltd.	10	10	0
J. Bowman	1	1	0
Cruikshank & Co. Ltd.	5	0	0
Red Hand Compositions Company	10	0	0
Clarke, Chapman & Co. Ltd.	150	0	0
Limmer and Trinidad Lake Asphalt Co. Ltd.	2	2	0
Standard Piston Ring and Engineering Co. Ltd.	5	0	0
Niven, Nelson & Matthews, Ltd.	10	10	0
Bell's Asbestos & Engineering, Ltd.	10	10	0
Wm. Doxford & Sons, Ltd.	750	0	0
Wood and Clark, Ltd.	1	1	0
Cementation Co. Ltd.	25	0	0
W. Broady & Son, Ltd.	10	10	0
British Paints, Ltd.	5	5	0
Donkin & Co. Ltd.	5	5	0
Hoyt Metal Co. of Great Britain, Ltd.	10	10	0
British Transformer Oil & Lubricants, Ltd.	2	2	0
Heenan & Froude, Ltd.	10	10	0
Sub.-Lieut.(E.) S. W. Pappius, P.N.	2	0	0
G. W. Kitching	10	10	0
F. Jennings	1	1	0
Ansell, Jones & Co. Ltd.	5	5	0
Buck & Hickman, Ltd.	5	5	0

	£	s.	d.
Hawthorn, Leslie & Co. Ltd.	1000	0	0
Charles Churchill & Co. Ltd.	100	0	0
J. & E. Hall, Ltd.	250	0	0
Baron Rolf Beck	2	2	0
B. R. Vickers & Sons, Ltd.	5	5	0
Fielding & Platt, Ltd.	10	10	0
A. Murray Wilson & Co. Ltd.	5	0	0
R. L. Holland	10	10	0
Key Engineering Co. Ltd.	2	2	0
Manganese Bronze & Brass Co. Ltd.	52	10	0
Modern Wheel Drive, Ltd.	10	10	0
W. H. Arnott, Young & Co. Ltd.	2	2	0
Macrome, Ltd.	5	5	0
Germ Lubricants, Ltd.	3	3	0
Hepworth & Grandage, Ltd.	10	10	0
B. A. Wilkinson	1	0	0
Rylands Brothers, Ltd.	10	0	0
G. A. Harvey & Co. Ltd.	250	0	0
Drysdale & Co. Ltd.	250	0	0
J. W. Markes	1	1	0
Beldam Packing & Rubber Co. Ltd.	105	0	0
James Pollock, Sons & Co. Ltd.	21	0	0
Wilson Brothers Pipe Fittings, Ltd.	3	0	0
Malone Instrument Co. Ltd.	5	5	0
B. P. Arrowsmith	5	5	0
S. G. Brown, Ltd.	10	10	0
Carborundum Co. Ltd.	25	0	0
A. Paszyc	1	1	0
Pyrene Co. Ltd.	26	5	0
E. J. Loader	5	0	0
H. B. H. Maundrell	10	0	0
A. D. Burgess	1	1	0
J. C. Bennett	1	1	0
R. Wanless	2	0	0
F. C. Ashby	1	1	0
C. E. Bjorck		10	6
G. H. Allen	2	18	0
R. H. Lowes	1	1	0
E. R. Chamberlain	3	3	0
F. O. Beckett	2	0	0
A. G. Dobbs	3	3	0
J. Kode	1	1	0
S. Atkinson	1	1	0
W. Veysey Lang	2	2	0
Eng. Rear Admiral F. V. King, (ret.)	5	5	0
Axia Fans, Ltd.	100	0	0
E. L. Green	2	0	0
F. G. Ritchie	10	10	0
Renton & Fisher	5	5	0
Yorkshire Copper Works, Ltd.	100	0	0
H. Saunderson Jones	2	2	0
W. P. Hunter	2	2	0
British Arc Welding Co. Ltd.	50	0	0
C. F. Jones	2	2	0
C. L. Stokoe	5	5	0
G. Soutar	1	1	0
R. C. Davis	5	0	0
A. R. Riddell	1	1	0
Foster Wheeler, Ltd.	105	0	0
Renold & Coventry Chain Co. Ltd.	10	0	0
C. E. Daniels	1	1	0
R. H. Rowe	2	0	0
J. E. Palmer	2	2	0
Texas Oil Company, Ltd.	10	10	0
J. L. Coates		10	0
W. B. Dick & Co. Ltd.	52	10	0
A. H. Wilson	3	3	0
Richard Crittall & Co. Ltd.	5	5	0
R. C. Beavis	1	1	0