A SYMPOSIUM OF PAPERS

on

RECENT DEVELOPMENTS IN MARINE DIESELS

TURBOCHARGING OF BURMEISTER AND WAIN OPPOSED PISTON AND POPPET VALVE ENGINES

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The paper describes some of the special conditions in connexion with the turbocharging of the opposed piston and poppet valve engines of the author's company, particularly the turbocharging system for full turbocharge.

Some design features of the engines are shown and reference is made to experience from plants in service.

For recent developments in marine Diesel engines it has been of vital importance that engine types which to a large extent met the demands on modern Diesel plants were already at hand.

For the author's company and their licensees it was a matter of single-acting, two-stroke engines with uniflow scavenging built either as poppet valve engines or as opposed piston engines with eccentrics.

In Great Britain it is of these two engine types that the opposed piston engine with eccentrics has been built most extensively. The latest development of this engine type is the introduction of their turbocharging system which since 1952 has been applied with excellent results to their poppet valve engine types; in January 1956 sixty-three of these plants utilizing in all 526,640 b.h.p. were in service.

The two first fully turbocharged opposed piston engines were built by his company for the Norwegian cargo ship *Balzac,* owned by Messrs. Fred Olsen and Company and put into service in June 1955, and by Harland and Wolff, Ltd., for the British cargo liner *Demodocus,* owned by Messrs. Alfred Holt and Company and put into service in August 1955.

Since then two more ships with engines built by Akers and Harland and Wolff, Ltd., respectively, have been put into service and, further, three engines have been built and tested by Akers.

In January 1956, forty-three engines involving 261,650 b.h.p. were on order.

The opposed piston engine types are built as crosshead engines and yield respectively the following output with or without turbocharge: —

			B.H.P. per cylinder	
Diameter	Stroke	R.P.M.	Non-turbocharged	Turbocharged
500	1,100 + 400	170	580	780
620	1,400 + 470	130	850	1,150
750	1,500 + 500	120	1,230	1,650
750	1,700 + 600	110	1,300	1,730

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The demand for increased output without the use of double acting two-stroke engines, which in his company's versions were also opposed piston engines, resulted shortly before the war in the appearance of their single acting two-stroke crosshead engines with poppet valves, and a few years after the war of their single acting two-stroke opposed piston engines.

The latter engines were designed in close conformity with the two first mentioned, and were based on experience gained with these engines. To those who prefer opposed piston engines, their opposed piston engine with eccentrics offers the advantage of a relatively simple crankshaft which, owing to its rigidity, may be used without difficulty and without vibration damper for any number up to and including ten cylinders and which may be bedded into the bedplate in the normal way, as for poppet valve engine crankshafts.

Fig. 1 shows a crankshaft with eccentrics.

As regards piston overhaul, which nowadays is the most important maintenance work to be carried out on board, the opposed piston engine has the advantage of its long length of stroke and consequently a small number of cylinders at a given output, while the overhaul of the remaining moving parts will be relatively more extensive than for the poppet valve engines on account of the great number of crank bearings, eccentrics, and crosshead bearings.

With the large stroke-diameter ratio used in at any rate three of the above-mentioned engines, the opposed piston engines with eccentrics have at a given output the same short overall length as the poppet valve engines with the same output and r.p.m. The weight will be greater, however, and the manufacturing costs will generally speaking be somewhat higher, too; this applies also to the individual parts.

For the non-turbocharged versions the mechanical efficiency and therefore the fuel consumption per b.h.p.-hr. are equal for opposed piston engines and poppet valve engines. In the opposed piston engines the scavenge pressure is lower, however, owing to the large scavenge ports and their quick opening, and accordingly the blower work is lower than in the poppet valve engine, whereas, owing to the eccentrics, the friction losses in bearings will be larger than in the poppet valve

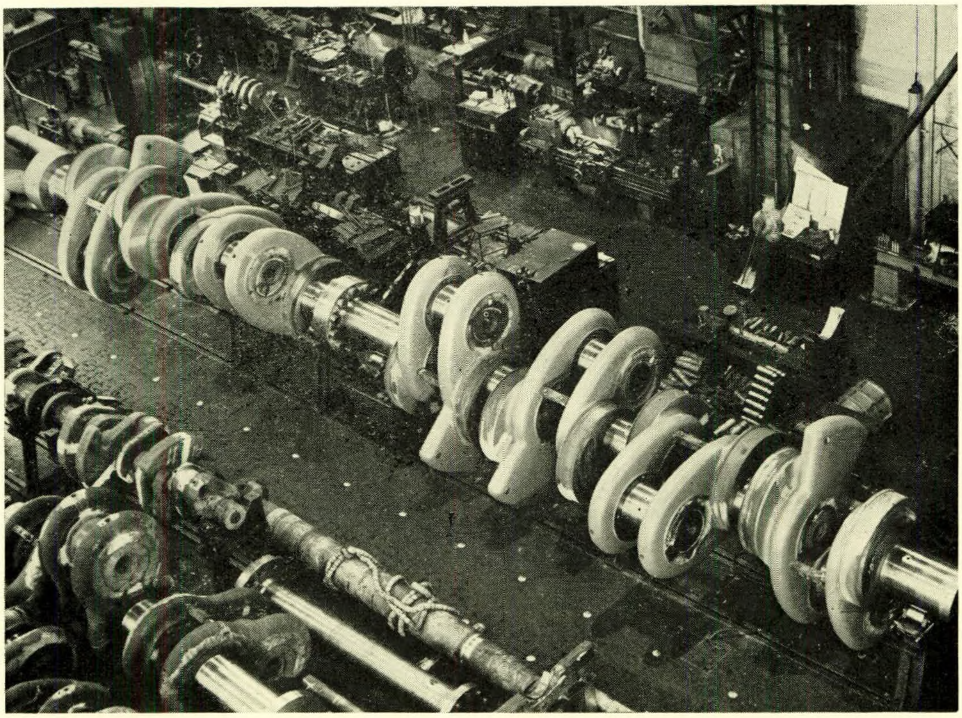

FIG. 1—*Crankshaft with eccentrics*

engine. As mentioned below, this is of a certain importance when the engines are turbocharged.

The opposed piston engines may, like the company's poppet valve engines, be arranged for semi-turbocharging immediately, as was the case in the m.s. *Lufira,* owned by Compagnie Maritime Belge, and put into service in April 1955; this vessel is propelled by a double acting opposed piston engine with a cylinder diameter of 590 mm. and stroke length of 1,250 + 450 mm., and it was built by Cockerill.

In this semi-turbocharging system where the normal chain driven scavenge blowers are retained, the equal pressure principle is applied, the turbines of the two turbocharger units being connected with the exhaust manifolds for the top and bottom cylinders. The blowers of the turbochargers supply the air through air coolers to the chain driven scavenge blowers, which deliver it to the scavenge air receiver of the engine in the normal way.

By this system an increase in output of about 35 per cent compared with a non-turbocharged engine could be obtained, i.e., the same as for full turbocharging, but the economy will be inferior and the fuel consumption higher owing to the energy used in the chain driven blowers to increase the air pressure from the pressure provided by the turbochargers, up to the scavenge pressure required. The result will, therefore, largely depend on the overall efficiency of the turbocharger units; the higher the efficiency, the more the chain driven scavenge blowers are relieved of work, the better becomes the mechanical efficiency of the engine, and therefore the economy. With a turbocharger efficiency of about 55 per cent and an increased engine output of about 35 per cent, an increase in fuel consumption of about 2 per cent could be expected, as compared with a non-turbocharged engine.

Even with the increased fuel consumption, however, this arrangement is of some importance, because it is in this way possible, at reasonable cost, to increase the output of existing plants, as was the intention when Compagnie Maritime Belge installed a semi-turbocharging system in m.s. *Lufira.*

The introduction of the turbocharging system for full turbocharge of the opposed piston engines with eccentrics has been possible just because the eccentrics give the short cylinder distance which is necessary in order to keep volumes and lengths of exhaust pipes within such limits that the greatest possible amount of energy with a high degree of efficiency is transmitted to the turbines, making it possible to operate economically with relatively large air quantities and pressures; and thus by suitable timing obtain a low heat load on the engine and a low fuel consumption as in the poppet valve engines.

This result was obtained after relatively small alterations of the non-turbocharged engine and the progress may be considered, therefore, a normal and natural development of the company's opposed piston engine. The more important parts that must be altered for turbocharging are the cylinder liners, the exhaust belts, and the scavenge air receiver; to this comes the increase in fuel pump capacity and the alteration of piping and platforms.

Fig. 2 shows a cross-section in a turbocharged opposed piston engine, and Fig. 3 shows a five-cylinder turbocharged opposed piston engine with cylinder diameter of 500 mm. and stroke of 1,100 + 400 mm.

As for the cylinder liners, it should be mentioned that so long as it is a question of the present moderate turbocharging, the type of liner now used will probably suffice. However, on his side of the North Sea, there have been some cases, owing to foundry difficulties, where these cylinder liners have cracked from the outside on account of casting defects, and on this side of the North Sea there have been some cases where cylinder liners have for other reasons cracked from the inside. In order to counteract such difficulties in connexion with an increase in the maximum pressure by an eventual higher turbocharging, a tripartite liner has been designed, and some have been in service already for some time, so far with good results.

As shown in Fig. 4, this cylinder liner is made in accordance with the liners in poppet valve engines—which for a number of years have proved fully satisfactory—in such a way that there are no gas joints in the cooling water space which may give rise to leakages to the cylinder.

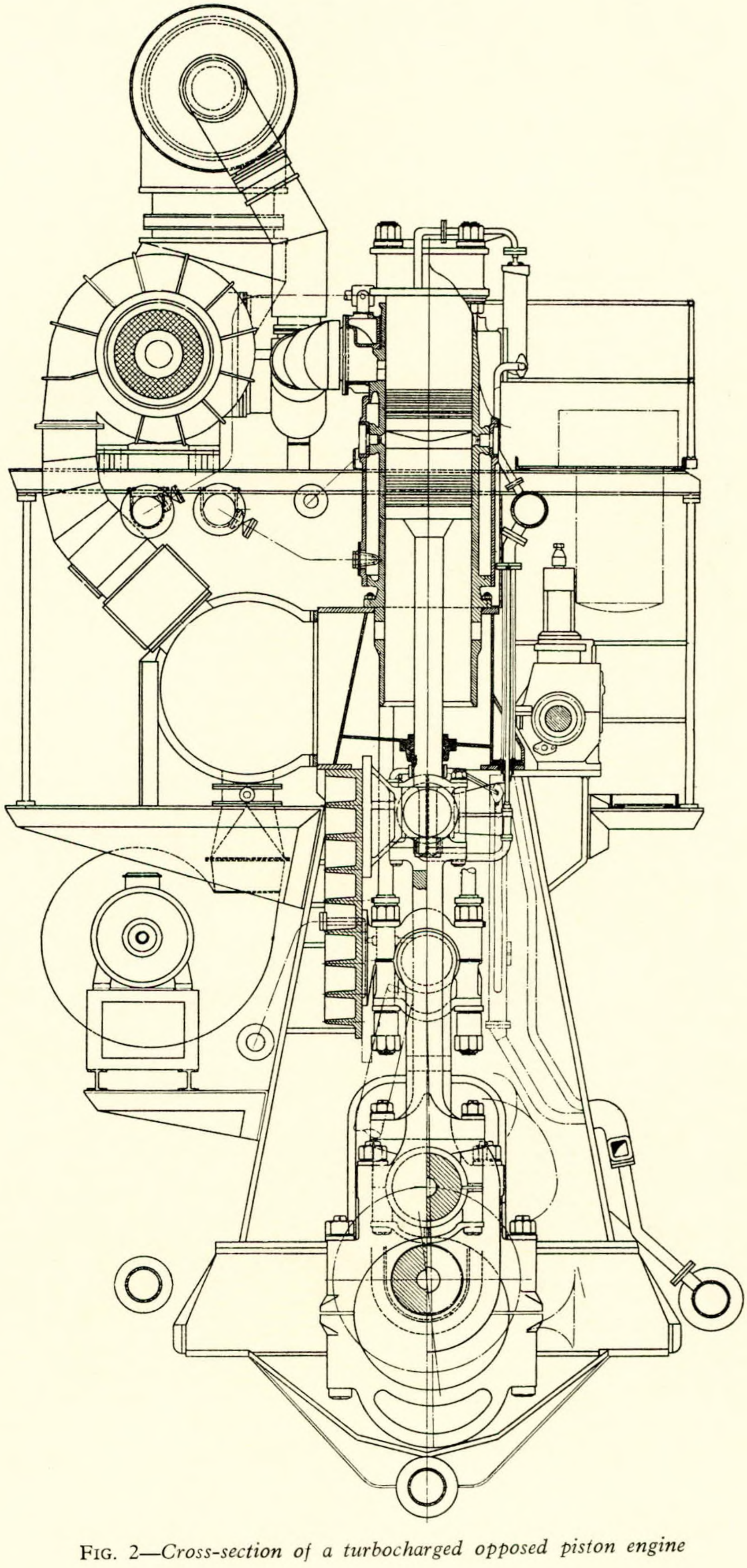

FIG. 2—*Cross-section of a turbocharged opposed piston engine*

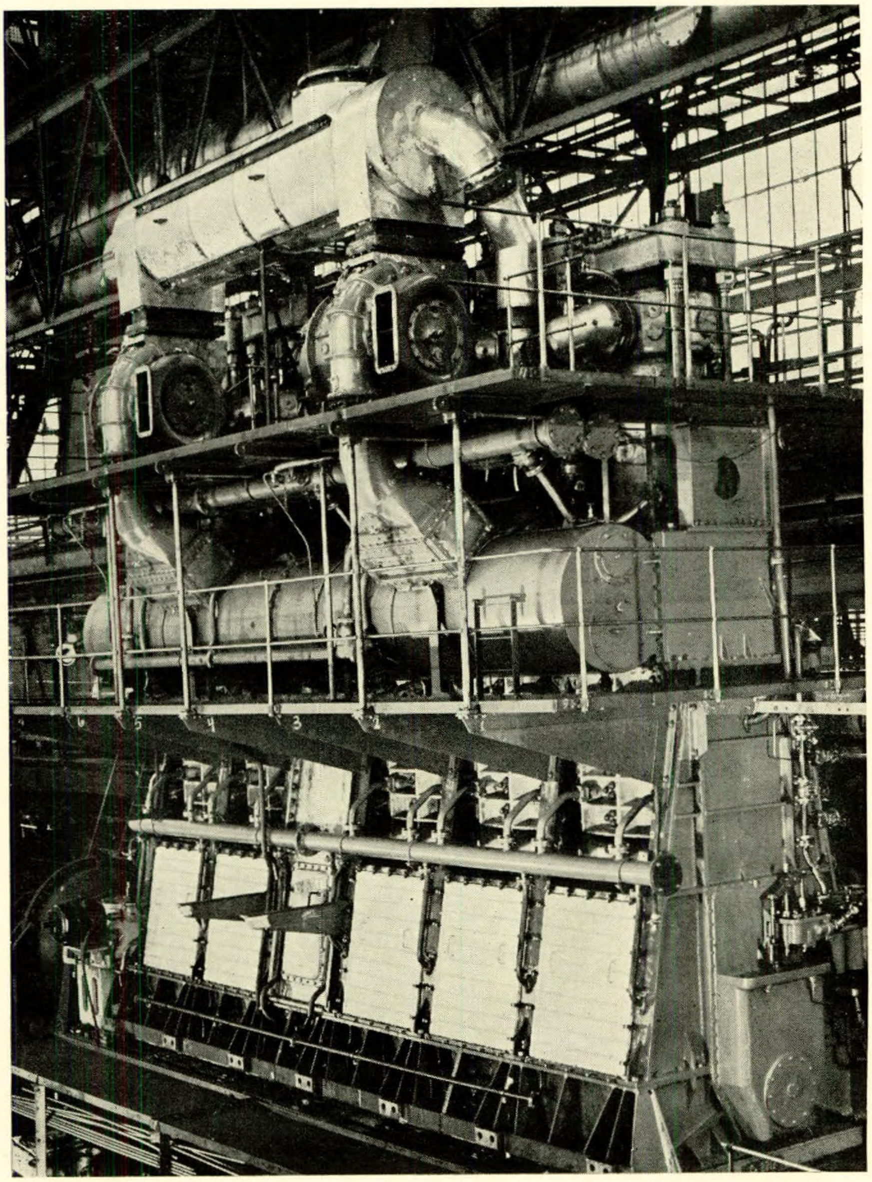

FIG. 3—*Five-cylinder turbocharged opposed piston engine: cylinder diameter 500 mm. and stroke 1,100 + 400 mm.*

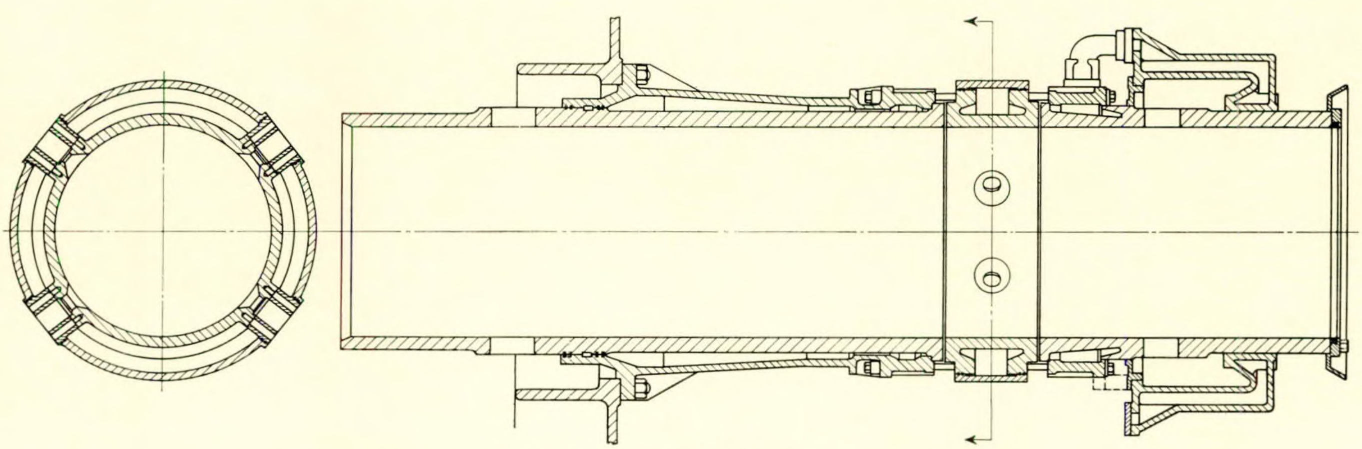

FIG. 4—*Cylinder liner*

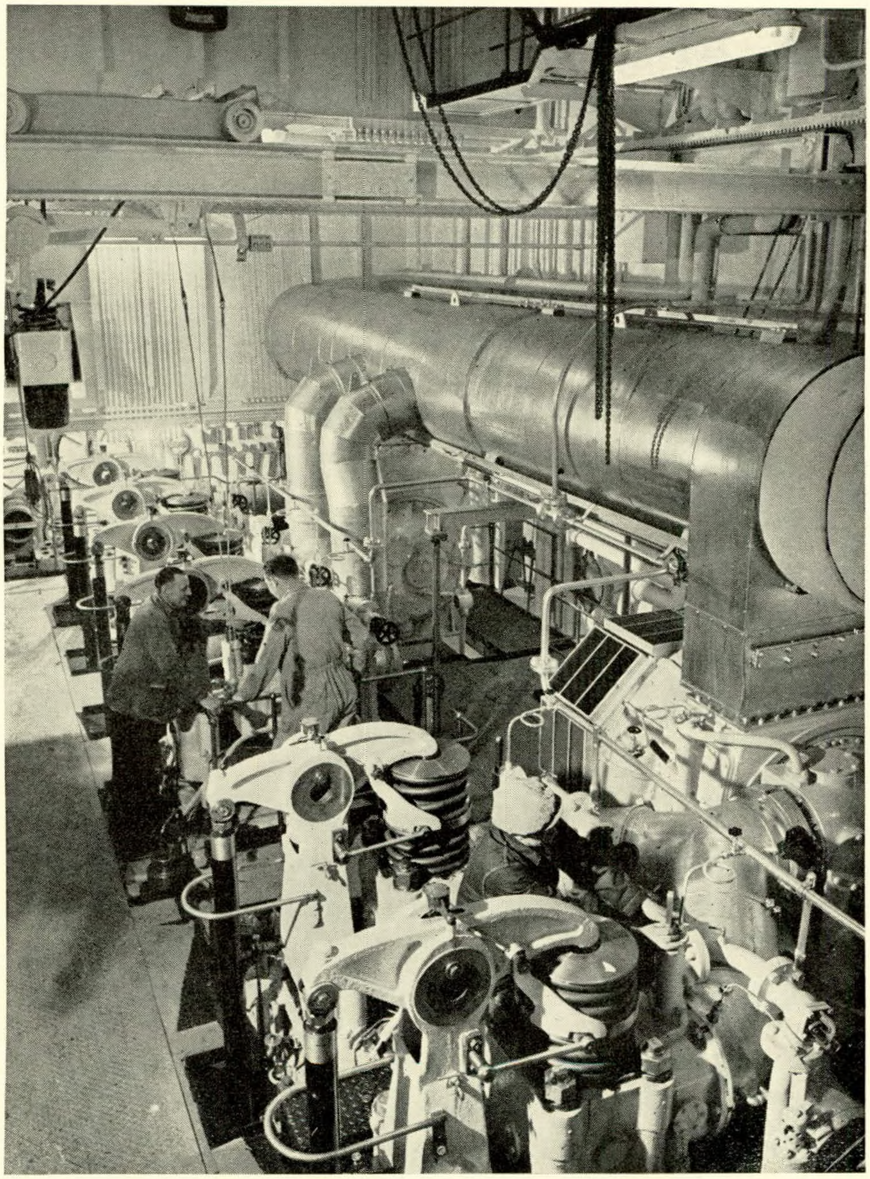

FIG. 5—*Arrangement of turbochargers on the seven-cylinder poppet valve engine, 740 × 1,600 mm., in m.s.* Sargodha

For the opposed piston engine it is more difficult to obtain satisfactory conditions for full turbocharge than for the poppet valve engine. The undesirable effect of the larger volumes and lengths of exhaust belts and pipes is counteracted, however, by the advantages resulting from the quicker opening of the exhaust ports. The timing of scavenging as well as exhaust ports, together with the requirements for ahead and astern running of the engine, does not afford the same uncomplicated liberty in choice of timing that exists for the poppet valve engine where the timing is reversible; among other things this means that for some cylinder numbers a higher air pressure is required from the turbochargers for opposed piston engines than for poppet valve engines, in order to retain an adequate amount of air in the cylinders for combustion.

Further, in these circumstances and contrary to the case for the poppet valve engine, it is necessary to use auxiliary air during manœuvring and dead slow running. For this reason a special arrangement had been introduced, comprising an electrically driven auxiliary blower supplying a pressure of about 0·3 m. W.C. during manœuvring and dead slow

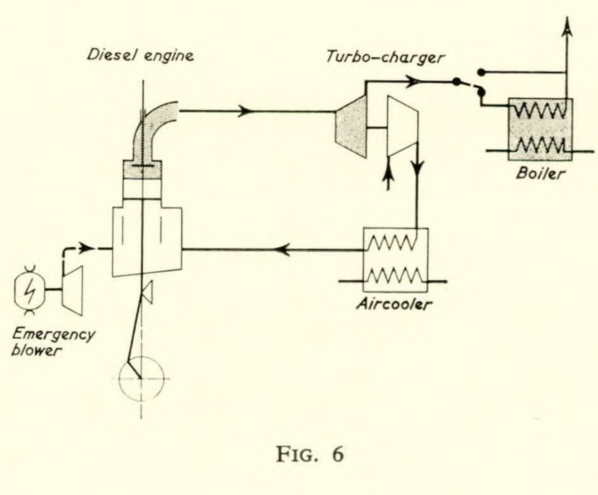

FIG. 6

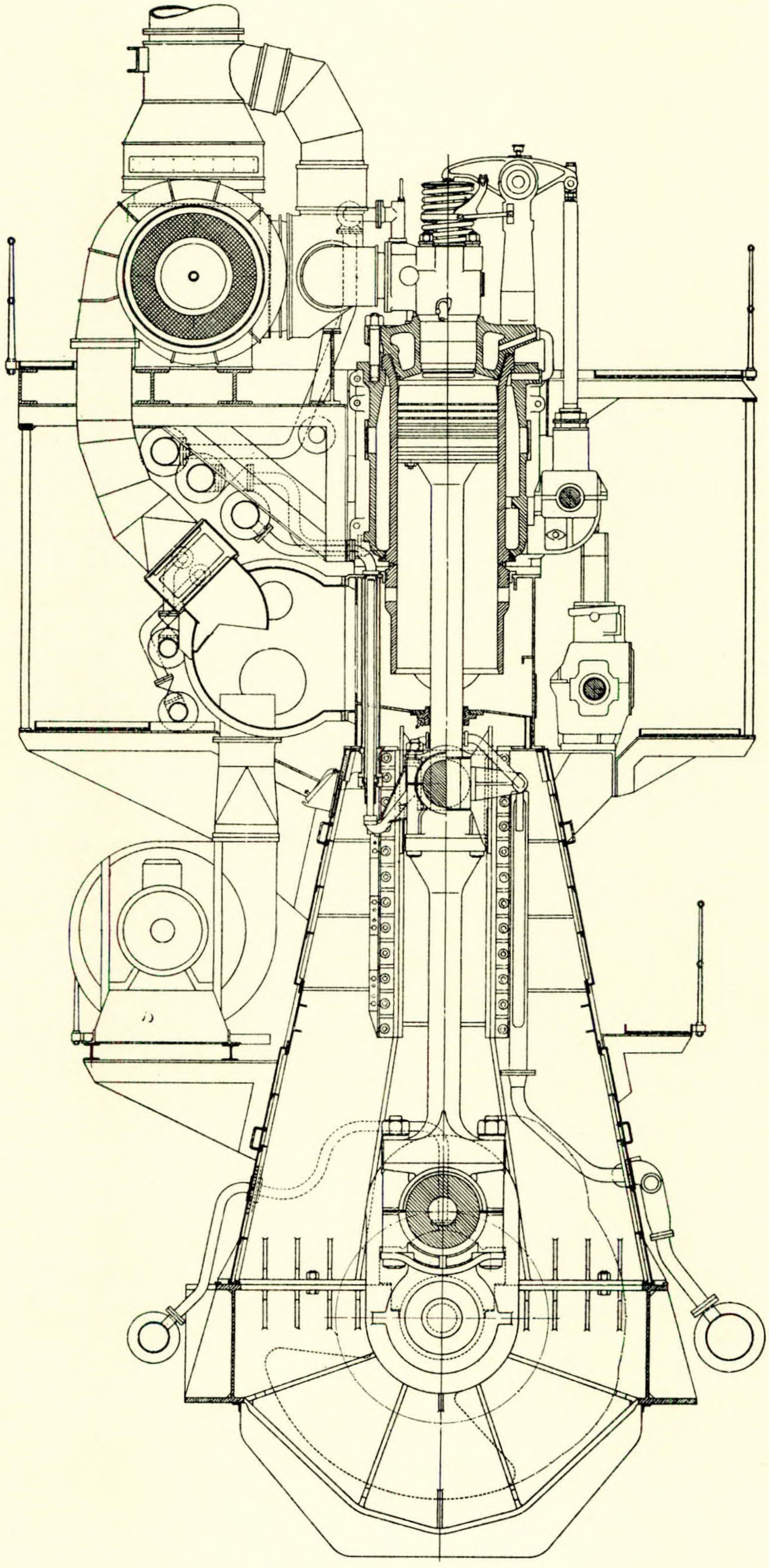

FIG. 7—*Cross-section of a turbocharged poppet valve engine*

running, which uses less than 1 per cent of the normal engine output. The equipment is made so that the only attention required is in starting and stopping the electrically driven auxiliary blower—and this may be done at any time—while the system is self-regulating and thus adapts itself to prevailing conditions, i.e. whether the auxiliary blower is running alone or together with the turbochargers. This complication is thus insignificant and negligible in its influence on the economy of the plant. The arrangement may be adapted in such a way that the auxiliary blowers, if desired, can be used as emergency blowers in case of the breakdown of one or more turbochargers.

In the two plants hitherto built by Harland and Wolff, Ltd., the turbochargers are provided with electric motors which drive them during manœuvring and running at low revolutions. These electric motors and their lubricating oil pumps are automatically engaged and disengaged at a given number of revolutions on the turbochargers by means of a special relay system.

So far turbochargers for their opposed piston engines have been made by D. Napier and Son, Ltd., of Great Britain, Société Rateau of France, and Brown, Boveri and Co., Ltd., of Switzerland; turbochargers for the poppet valve engines are also made by these companies and by Helsinger Skibsvaerft og Maskinbyggeri and the author's company.

Fig. 5 shows the arrangement of the turbochargers of their own make on the seven-cylinder poppet valve engine, 740 × 1,600 mm., in m.s. *Sargodha,* owned by the East Asiatic Company, Copenhagen.

One, two or three cylinders are connected to a common turbine inlet, but whereas in the poppet valve engine two turbochargers are used for as many as eight cylinders, it is necessary for three turbochargers to be provided in an opposed

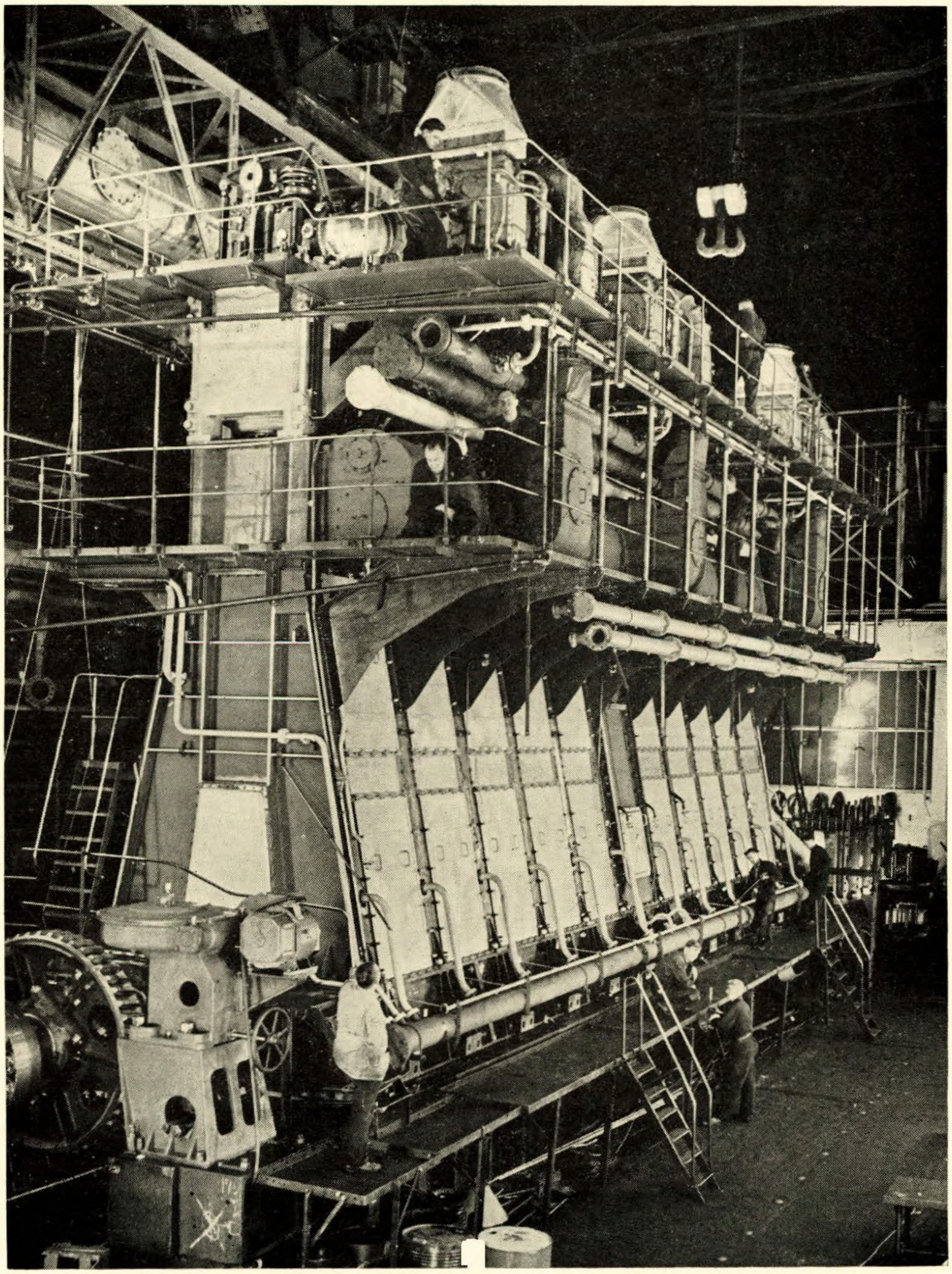

FIG. 8—*Ten-cylinder turbocharged poppet valve engine: cylinder diameter 740 mm., stroke 1,600 mm. and continuous output 12,500 b.h.p. at 115 r.p.m.*

piston engine with seven cylinders owing to the firing order and the relatively large cylinder distance, though the eight-cylinder engine may be arranged with only two chargers.

The poppet valve engine as well as the opposed piston engine have particular advantages in regard to energy consumption for the charging blowers as they require a smaller amount of air to expel the combustion products than engines with other scavenging systems. With his company's turbocharging system applied to these engine types full turbocharge is therefore obtained with increased output through the increase of charging air quantity and pressure, and at the same time a reduction of fuel oil consumption without increasing the thermal load and the maintenance cost.

The air drawn from the engine room or from outside is compressed in the turboblower and delivered to the air intercooler where it is cooled down to about 10 deg. C. (18 deg. F.) above sea water temperature; from the cooler the air passes to the scavenging space of the engine (Fig. 6). The exhaust gas is delivered through the exhaust valves or the exhaust ports to the turbine, the impellers of which are fitted on the same shaft as the blower wheel.

From the turbochargers the exhaust gas is expelled either through a silencer or through an exhaust boiler.

Fig. 7 shows a cross-section in a turbocharged poppet valve engine and Fig. 8 a ten-cylinder turbocharged poppet valve engine with a cylinder diameter of 740 mm., stroke 1,600 mm., and continuous output of 12,500 b.h.p. at 115 r.p.m.

For turbocharged engines the exhaust temperature measured after the turbine will be about the same as the exhaust temperature measured at the outlet on the manifold of an engine without turbocharge. At a given engine output, therefore, about the same amount of heat will be available for steam production in an exhaust gas boiler from a turbocharged and from a non-turbocharged engine.

The turbochargers are supplied by the charger manufacturers to engine builders' specifications so that the charger in each individual case specially suits the engine and meets the demand for air quantity and pressure corresponding to the ratings of their engines.

At an increase of the indicated mean pressure from 6·5 kg. per sq. cm. (93lb. per sq. in.) for the non-turbocharged engine to 8·0 kg. per sq. cm. (114lb. per sq. in.) for the turbocharged engine, the thermal load will not be higher than for the non-turbocharged engine; this has been checked partly by measuring wall temperatures, partly by measuring the heat flow to the cooling water and cooling oil.

Fig. 9 shows the fuel oil consumption at varying loads corresponding to the propeller law for a poppet valve engine 740 × 1,600 mm. The improved consumption of about 3 per cent compared with the consumption of the non-turbocharged engine is due to an increased mechanical efficiency owing to the elimination of the direct driven blowers.

For the turbocharged opposed piston engines a slightly higher consumption should generally be assumed, under otherwise equal conditions, owing to the influence of the mechanical efficiency previously mentioned.

At an increase of the indicated mean pressure from 6·5 to 8·0 kg. per sq. cm., the output of the turbocharged engine is increased by about 35 per cent, corresponding to a reduction in weight of about 25 per cent, in length of about 20 per cent, and in lubricating oil consumption of about 25 per cent for a given power.

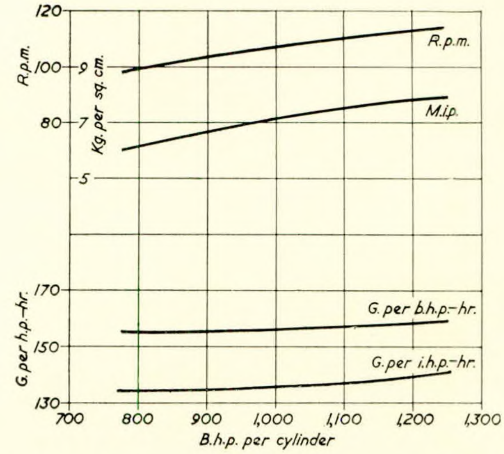

FIG. 9—*Fuel oil consumption at varying loads*

As the heat flow through the cylinder walls is the same for turbocharged and non-turbocharged engines, the amount of cooling water and lubricating oil, also coolers, piping, etc., for a given number of cylinders, will be the same in both cases.

Starting air receivers and compressors are dependent only on the number of cylinders, and the power consumption for pumps and compressors will be the same, therefore, in both cases.

The total weight of the necessary auxiliary machinery per b.h.p. is thus considerably lower for turbocharged plants than for plants with non-turbocharged engines.

The results available from the seventy Burmeister and Wain turbocharged plants now in service confirm that the turbocharged and the non-turbocharged engines show equally good performance figures, and that the turbocharging has not given rise to new problems in regard to the engines themselves.

As for the turbochargers and air coolers, experience has shown that it has been expedient to introduce some modifications to lubrication and silencing. Air filters are now generally fitted before the turbochargers to minimize fouling of the air coolers and the latter have been made easier to clean.

There can hardly be any doubt that the part turbocharging is playing only slightly more than three years after the first plant in the tanker *Dorthe Maersk* was put into service, and the interest shown all over the world in turbocharging—either full turbocharge or semi-turbocharge—for an ever increasing number of engine types, confirm that this progress is the greatest in the past twenty-five years, and there is no doubt that it will form the basis of future progress which will further strengthen the position of Diesel plants in competition with other power sources.