Geared Steam Turbine Installations for Tramp Steamers.

by

S. S. COOK, F.R.S., (Member).

Reprinted by permission from the Transactions of The Institute of Marine Engineers

December, 1934.

The
INSTITUTE of MARINE ENGINEERS
Founded 1889. Incorporated by Royal Charter, 1933.

Patron: HIS MAJESTY THE KING.

SESSION 1934.

Vol. XLVI. Part 11.

President: JOHN H. SILLEY, ESQ., O.B.E.

Geared Steam Turbine Installations for Tramp Steamers.

READ

By S. S. COOK, F.R.S., (Member).

On Tuesday, November 13th, 1934, at 6 p.m.

CHAIRMAN: Mr. J. HAMILTON GIBSON, O.B.E., M.Eng. (Chairman of Council).

Synopsis.

UNIFORM rotary motion being required for a ship's propeller, an engine of the purely rotary type like the steam turbine is the most appropriate for driving it. Absence of propeller racing makes the turbine-driven ship steadier in a heavy sea. Other practical advantages attaching to uniform rotary drive are mentioned. The geared steam turbine entered the field of cargo boat propulsion with the re-engining of the s.s. "Vespasian" with engines of this type in 1910 and a large number of vessels have been so equipped since that time, not only for cargo boats but for vessels of all classes. An installation of geared turbines recently specially designed for cargo boats, making a compact unit with its auxiliaries and simplifying erection and overhaul, is described, and results are given of steam consumption tests carried out with such a set erected at Turbinia Works.

The rotating screw propeller is the best instrument so far evolved for the propulsion of a large ship through the water, and the problem of ship propulsion is one of imparting rotary motion to a screw propeller in the most efficient and reliable manner, efficiency and reliability being both understood in their broadest significance. A uniform rotary motion being therefore required for the propeller, an engine of the purely rotary type like the steam turbine appears to be the most appropriate for driving it. Before the advent of the steam turbine, however, the reciprocating steam engine was for many years the only prime mover available, and thus it comes about that the present generation is thoroughly familiar both with the idea and with the technique of the conversion of a reciprocating motion into a rotary one. It is interesting to speculate what might have been our attitude towards this question if the steam turbine, or some other form of rotary engine, had been invented first.

Apart from such general considerations there are good economic and other reasons for holding it preferable to have a rotary drive for a rotary propeller. One most important consideration is the avoidance of propeller racing. It is a commonplace experience that under average voyage conditions absence of propeller racing is a valuable asset to a turbine driven ship inasmuch as it enables it to maintain its speed in a heavy sea. Considerable advantage in this respect has been claimed for those systems in which exhaust steam turbines have been added to reciprocating engines, from the pronounced steadying effect of the turbine observed in such installations, an advantage which must obviously belong in still greater degree to an all-turbine drive. Moreover propeller racing must inevitably be accompanied by actual loss of power, making it necessary to develop a larger shaft horse power to maintain the same speed.

Even under normal weather conditions, want of uniformity of rotational velocity of the propeller must have this effect to a greater or less degree. There is here a factor to the advantage of a turbine-driven ship, for which however in the usual methods of estimating performance the ship receives all the credit in the form of an increased coefficient. To obtain the relation between the shaft horse power of the ship when driven by turbines and the indicated horse power when driven by reciprocating engines, comparison should be made between two sister ships each fitted with one of these types of engine and run at the same speed under identical conditions, steaming, for example, side by side. Such an experiment was actually carried out with two steamers belonging to the Cairn Line in 1913, the s.s. "Cairngowan" with reciprocating engines and the s.s. "Cairnross" with geared turbines, and the results were given in a *paper by Mr. C. Waldie Cairns, under whose supervision the trials were conducted. This interesting experiment showed that the s.h.p. of the turbine driven ship was 87·7 per cent. of the i.h.p. of the reciprocating engine of the other ship.

The uniform velocity and uniform turning moment of a steam turbine also result in freedom from vibration and absence of noise, which although perhaps not so important in themselves for a tramp steamer as for a passenger carrying ship, must be conducive to general efficiency and reduce wear and tear. The absence of cyclic variations of temperature of the cylinder walls is a factor of the same degree of importance.

With the reciprocating engine in converting the reciprocating motion into a rotary one, one direction of rotation is as good as another, and this appears at first glance to give to that type of engine a superiority as regards reversal of the direction of rotation of the propeller shaft, a change of sequence of valve operation being all that is necessary for the purpose.

* See Transactions, N.E.C. Institution of Engineers and Shipbuilders, Volume *XXIX* 1912-1913 "A Comparative Trial between the Triple Expansion Engine and Geared Turbines in Cargo Steamers", by C. Waldie Cairns, M.Sc.

With a steam turbine the only practical solution of the reversing problem so far evolved is an additional turbine with blades of the opposite hand. In spite of this the turbine system consisting of an ahead turbine and an astern turbine, to either of which steam can be admitted at will, provides the best arrangement yet devised for manœuvring a ship. Full steam can be admitted to the astern turbine and operate on the blading of the whole turbine at all speeds—even when running in the ahead direction. In a reciprocating steam engine put astern, steam does not get through to the intermediate and low pressure cylinders until the engine has actually reversed, and even when reverse motion has commenced the quantity of steam admitted is only proportional to the speed. In view of this characteristic difference in operation, the maximum astern power which it is possible to develop when running full speed astern is no criterion of the stopping power. The stopping force developed by the reciprocating engine in the early stages of reversal is only equivalent to about one-third of the full ahead torque, whereas the turbine can immediately develop a force astern equivalent to more than the full ahead torque, in fact, about twice that torque if necessary. During this part of the act of stopping, the energy of the ship's motion, propeller shaft and machinery is being absorbed by the steam in the form of heat, the steam admitted to the astern turbine when the ship is running in the ahead direction acting as a powerful brake, and the heat energy so absorbed passes over into the condenser, which with its circulating water is provided for the absorption of heat to the extent of four or five times the power of the machinery.

In a reciprocating engine, the piston rings require lubrication, especially so when superheat is employed. With a turbine the losses due to mechanical friction are small and such friction is entirely external to the turbine. Within the turbine the fixed and moving parts are not in contact. This carries with it the important practical advantage that, no internal lubrication being required, it is possible to maintain the boiler feed water free from grease. There is also no appreciable consumption of lubricating oil, the same oil circulated and cooled sufficing over a long period of service.

Because of the absence of internal lubrication there is no difficulty with a turbine in operating on the highest degree of superheat the boilers can supply, and the materials will stand.

In general, however, it has been the superior efficiency of the turbine that has brought it into such extensive use, and as is well known its ability to utilise a high vacuum gave it considerable advantage in this respect over the reciprocating steam engine. At the present time with the assistance of mechanical gearing to reconcile the high speed suitable for the turbine with the low speed of revolution suitable for a ship's propeller it is applic-

able to practically all classes of mercantile propulsion. It made its entry into the field of cargo boat propulsion with the famous experiment carried out in 1910 in the steamer "Vespasian", the reciprocating engines of which were taken out and replaced by geared turbines. The "Vespasian's" gearing was single reduction with a ratio of 20 to 1 between the speeds of the turbine and the propeller shaft, a ratio which was found to be not quite high enough for cargo boats to reap the full benefit of turbine propulsion. The natural immediate development to double reduction was however interfered with by the war period and the depression in mercantile building which followed it. The use of double reduction and incidentally the application of turbine drives for cargo boats was further retarded by difficulties encountered in the years immediately following the war from the fracture of pinion teeth. Those who are familiar with the circumstances will remember that there was a kind of epidemic of tooth fractures lasting over a short period of time. Since such fractures occurred not after long years of service, but in nearly every case on the first voyage of the vessel, and since the difficulties disappeared on replacement, they were clearly not due to any inherent deficiency in the gearing. But as this experience occurred at the time that double reduction was first coming into use, a false impression was created as to the reliability of double reduction gearing. To prove, however, that there is nothing intrinsically amiss with double reduction gearing it is necessary only to refer to some of the numerous well-known instances in which it has been successfully adopted.

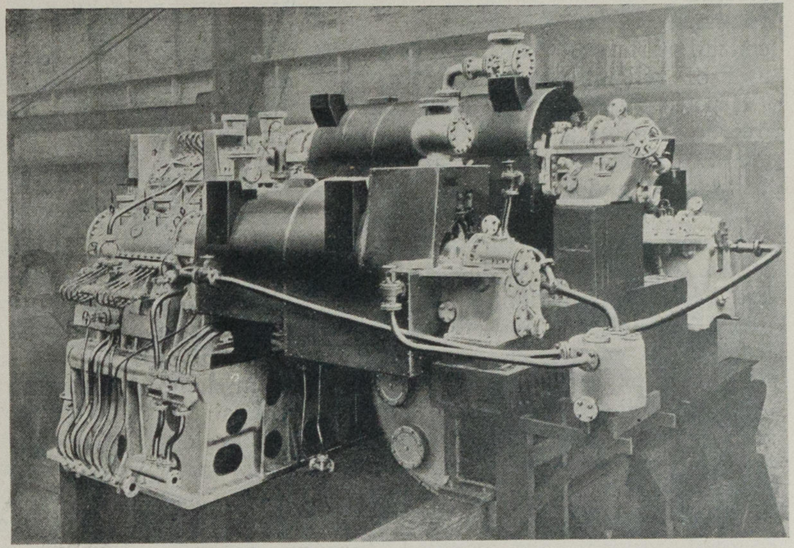

Fig. 2.—Three-turbine arrangement as fitted in cargo boats for the Canadian Pacific Steamships, Ltd.

The fact that in the experiments referred to above in the s.s. "Vespasian" mechanical gearing was first introduced and investigated particularly for cargo boat propulsion has been somewhat obscured by the rapid development which immediately took place in the use of gearing for other classes of marine propulsion.

The 1,090 h.p. geared turbines of the "Vespasian" realised a reduction in steam consumption in comparison with the triple expansion engines which they replaced of about 15 per cent. In the s.s. "Cairnross", a vessel of 1,600 s.h.p. built for Messrs. Cairns, Noble & Co., in 1912, with single reduction geared turbines, a similar improvement was obtained on the basis of a series of comparative trials with a sister ship having triple expansion engines, the s.s. "Cairngowan". This experiment has already been mentioned above in connection with the relation between s.h.p. and equivalent i.h.p.

The s.s. "Cairnross" was used for coal transport during the war and was sunk by enemy action. She was replaced in 1920 by another ship of the same name of somewhat larger power, in which double reduction geared turbines were fitted, and a considerable further improvement obtained. With 200° F. of superheat the steam consumption (turbines only) was 9lb. per s.h.p. hour, equivalent to less than 8lb. per i.h.p. Subsequently

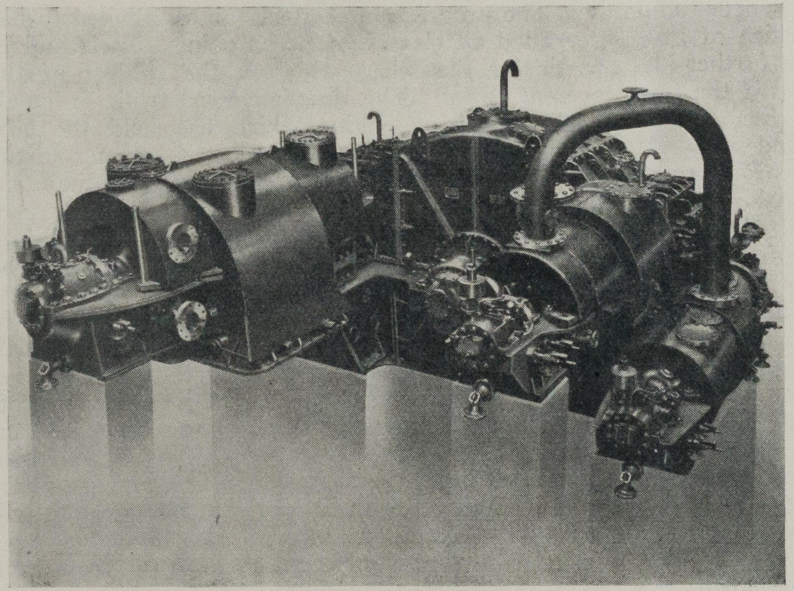

Fig. 1.—Turbines and D.R. gearing, with three turbines.

steamers for the same owners, also with double reduction turbines, have given similarly reduced consumptions. As an example of low upkeep cost and of reliability it was stated by Mr. Waldie Cairns in 1928 that the total cost of renewals and overhauls after a period of 5½ years' running of a geared turbine ship under his control and working constantly under North Atlantic conditions was under £30. The main machinery in these vessels consisted of three turbines through which the steam expanded in series, an arrangement which has been widely adopted in marine work on the ground of lightness and efficiency, the high pressure part of the expansion range being caried out in a small high pressure turbine which could be made of high revolutions and small diameter with gain of efficiency and a more rigid construction. The h.p. and i.p. turbines coupled tandem drove one primary gear and the l.p. turbine the other. In other cases of 3-turbine designs the h.p. and i.p. instead of being coupled tandem are coupled through separate pinions to the primary wheel on the corresponding side of the main gearing (*see* Fig. 1). In a three-turbine arrangement with single reduction, each turbine drives its own pinion so that the gearing consists of three pinions geared with one main wheel. Fig. 2 is an example of an installation of this kind, as fitted in a series of cargo boats for the Canadian Pacific Steamships, Ltd., in 1927.

Before the introduction of mechanical gearing, the steam turbine was only able to enter the field of low speed propulsion of cargo vessels by being applied as an adjunct to the reciprocating engine in the form of an exhaust steam turbine, thus extending the range of expansion of the steam to a lower back pressure than was practicable with the reciprocating engine alone. Several notable vessels were so fitted. In the early proposals of this type the turbine drove its own propeller and there was still some considerable sacrifice of propeller efficiency. It was recognised that further improved performances would be obtained if the turbine propeller could be coupled to its turbine through some speed reduction device, and proposals on these lines were made by Sir Charles Parsons as early as 1906. In such a plant only one-third of the total power would have to be transmitted through the gearing, and this was an attractive feature at a time when it had not yet been proved that it was quite practicable to transmit the whole of the power of the vessel through mechanical gearing between engine and propeller shaft. Such installations can only be regarded now as temporary expedients. The low steam consumption rates just quoted for complete turbine installations will adequately explain why combined systems were not persevered with after mechanical gearing had been proved a successful means of coupling a high speed turbine to a low speed propeller.

Remarkable progress has been made during the last ten years in the economical operation of the propelling machinery of sea-going vessels, resulting in considerable reductions in the fuel consumption bill. The introduction of the use of high pressure steam appears to have set this wave of economical progress in motion. But it has gathered up in its stride the results of intensive search for economies in all directions, some of them, it is true, of minor importance, but of considerable cumulative effect.

It was the author's privilege to present a paper before this Institute in 1926 on the subject of the contribution which economical auxiliary machinery could make towards the overall efficiency of a high pressure marine installation, in which paper were given estimates of overall fuel consumption which the author considered was attainable if due care were given to the various points affecting the efficiency of auxiliary machinery as well as to the efficiency of boilers and main turbines. This was at a time when the use of high pressure for the main turbines was just coming into prominence. The results predicted in that paper were in advance of anything previously obtained, but they have since been realised in practice, and in fact, in ships of somewhat larger power, have been substantially surpassed.

Three types of auxiliary drive were discussed, the well established system of separately driven steam auxiliaries with economical use of their exhaust steam, electrically driven auxiliaries with their current supplied either from turbo generators or from Diesel engine generators, and auxiliary machinery driven from the main engines by suitable gearing and with suitable standbys. The inclusion of the last was made at the suggestion of the late Sir Charles Parsons and reference to it is perhaps not without interest in connection with what follows later in the present paper.

The progress in economy above alluded to has pervaded all classes of ocean-going vessels and in particular that class which is the subject of the present paper. The time-honoured triple or quadruple expansion engine which has held the field almost exclusively for this class of steamer in the past has proved powerless unassisted to maintain its position in this respect, wherefore many proposals have been made and actually carried into construction to attain increased economy by the addition to the reciprocating engine of a low pressure turbine, the power of which is utilised in various ways to augment the total output. Regarding this as a means of increasing the output or reducing the consumption of an existing reciprocating engine, opinions still differ as to whether the increased output or increased economy so obtained justifies the additional cost incurred, and it is easy to understand that the answer to this question will vary with the circumstances in each individual case. Such plants however do not stand in the front rank of economical performance. A complete installation of geared turbines gives a greater economy

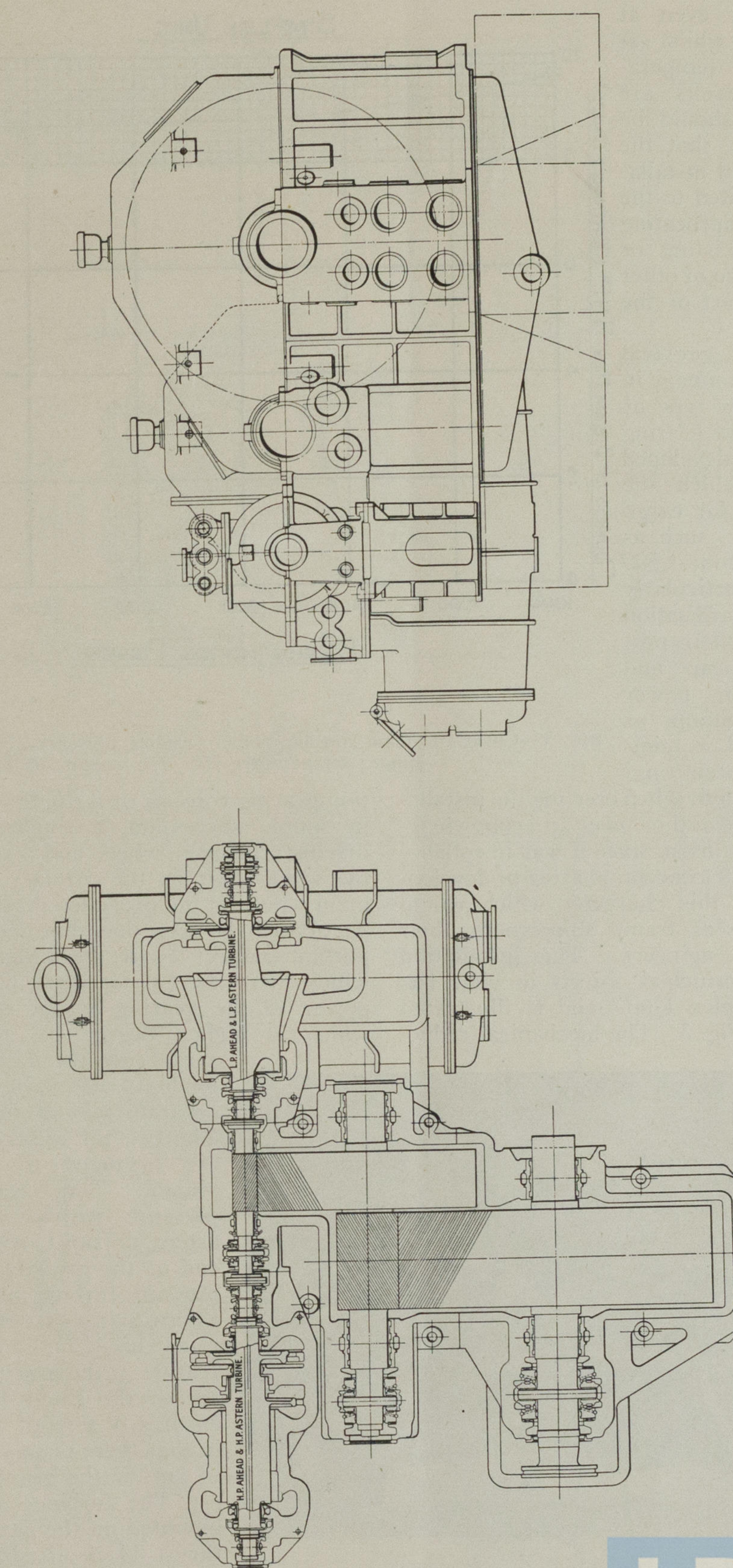

Fig. 3.—Simplex unit of geared turbines.

of steam and fuel, even at ordinary pressures, whilst at high pressures and temperatures still better results are being realised. It should be recognised, therefore, that the field of such combined installations is in reality limited to the cases where a reciprocating engine is already existing or predetermined by force of other circumstances as a part of the unit.

In expectation of a revival of demand for cargo tonnage in the near future a new type of design of turbines and gearing has been specially developed by the firm with which the author is associated, for cargo boats of small power, such as tramp steamers of from 1,500 to 2,000 s.h.p., particularly with a view to standardisation and simplicity of erection, providing a simple, cheap and reliable plant of the power required with a minimum of component parts and a minimum of assembly, connecting-up or alignment to be done when erecting the installation in the vessel. The author owes an acknowledgment here to Mr. J. Johnson, since it was in collaboration with him that the conception arose of developing a simple unit of this character which would secure the acceptance of tramp shipowners, their superintendents and engineers. The installation designed with these principal objects in view has been called the "Simplex Unit" and is illustrated in sectional drawing Fig. 3. The mechanical reduction gearing consists of a single train of gear wheels in simple succession, a single high-speed pinion driving a primary wheel, and a secondary pinion on the same shaft as the primary wheel driving the main wheel on the propeller shaft.

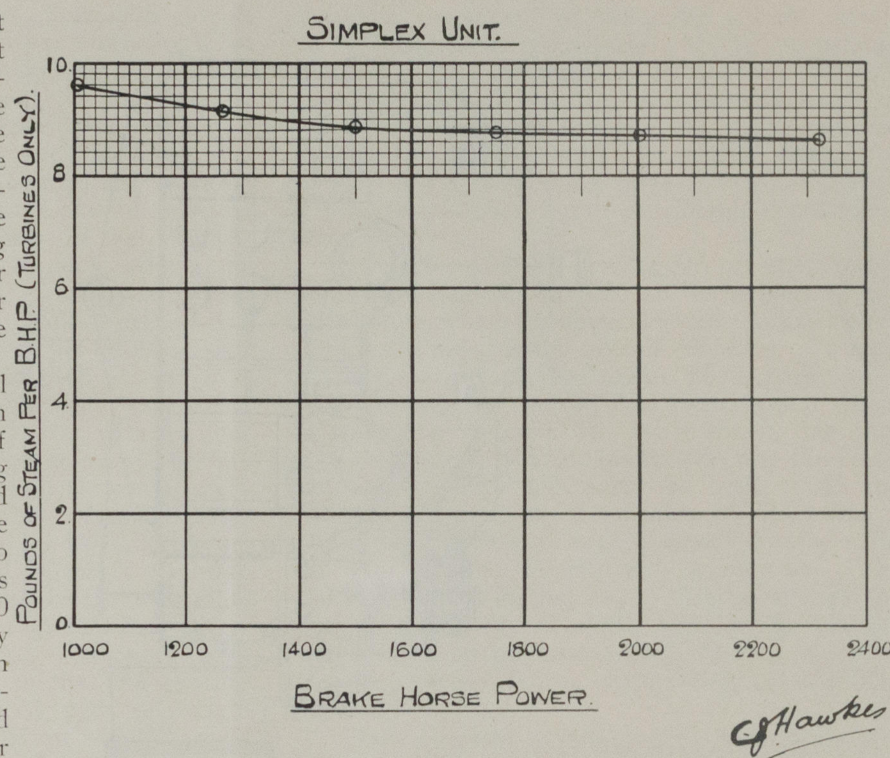

FIG. 5.—Curve of steam consumptions. (Engine pressure 275lb. per square inch gauge; temperature 750° F.; vacuum 28·75in.).

It will be seen that this unit differs in an important respect from the usual turbine drive in which there are two or more pinions transmitting power to the gearing at the same time, and in which a higher degree of accuracy is necessary, since the inertia of the turbines tends to maintain the speed of the separate pinions in constant relation. The two turbines of the Simplex unit are arranged to drive this single pinion. They consist of a high-pressure turbine, with ahead and astern portions, coupled at the after end of the primary pinion, and a low pressure turbine, also with ahead and astern portions, coupled at the forward end of the same pinion. Another feature in the gearing is that the teeth are of the single helical type. This ensures a smooth and positive drive in that there is no fore and aft motion of any of the gears.

The turbines and condenser are mounted on the gear case. The main thrust block is also incorporated in the gear case, so that the attachment of

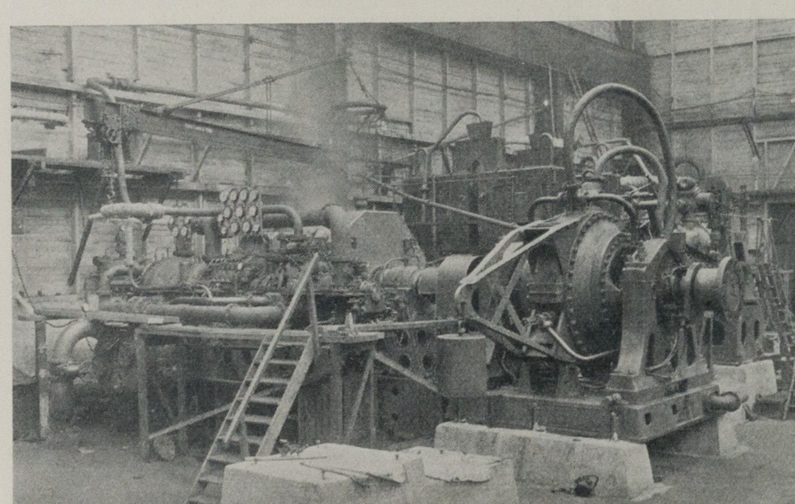

FIG. 4.—"Simplex Unit" built at Turbinia Works.

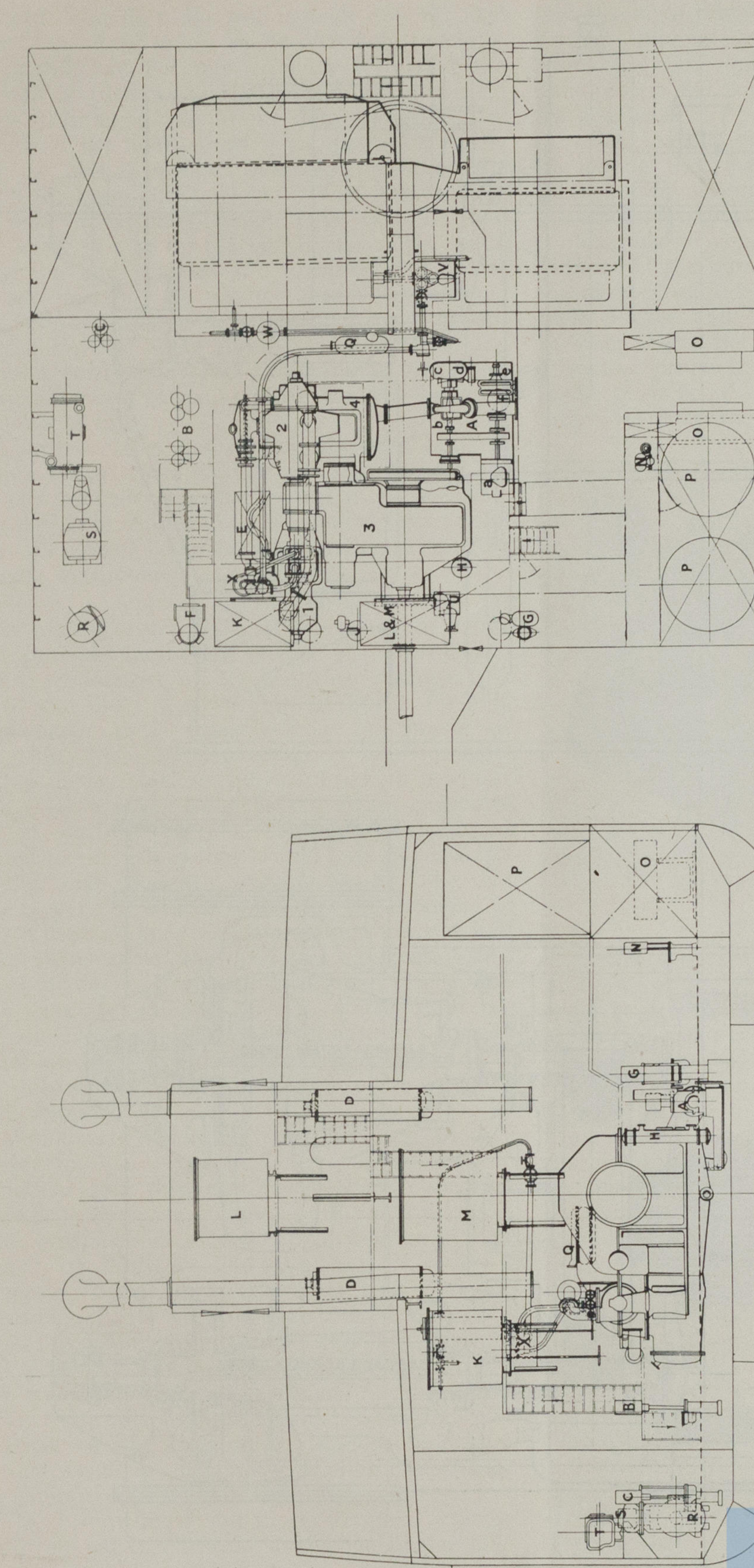

FIG. 6.—Arrangement of machinery.

1. H.p. ahead and h.p. astern turbine.
2. L.p. " l.p. "
3. Double reduction gearing.
4. Condenser.

A. Auxiliary unit { a. Engine. b. Circulating pump. c. Extraction pump. d. Main forced lubrication pump. e. Sanitary pump. f. Bilge pump. }

B. Main feed pump.
C. Aux. feed pump.
D. Feed heaters.
E. Filter tank.
F. Ballast pump.
G. Auxiliary forced lub. pump.
H. Forced lub. oil cooler.
J. " purifier.
K. " storage tank.
L. " gravity tank.
M. " reserve tank.
N. Oil fuel transfer pump.
O. Oil fuel burning units.
P. " settling tank.
Q. Air ejector.
R. Evaporator.
S. Generator.
T. Aux. condenser and drain collector.
U. Turning engine.
V. Fan engine.
W. De-superheater.
X. Manœuvring gear.

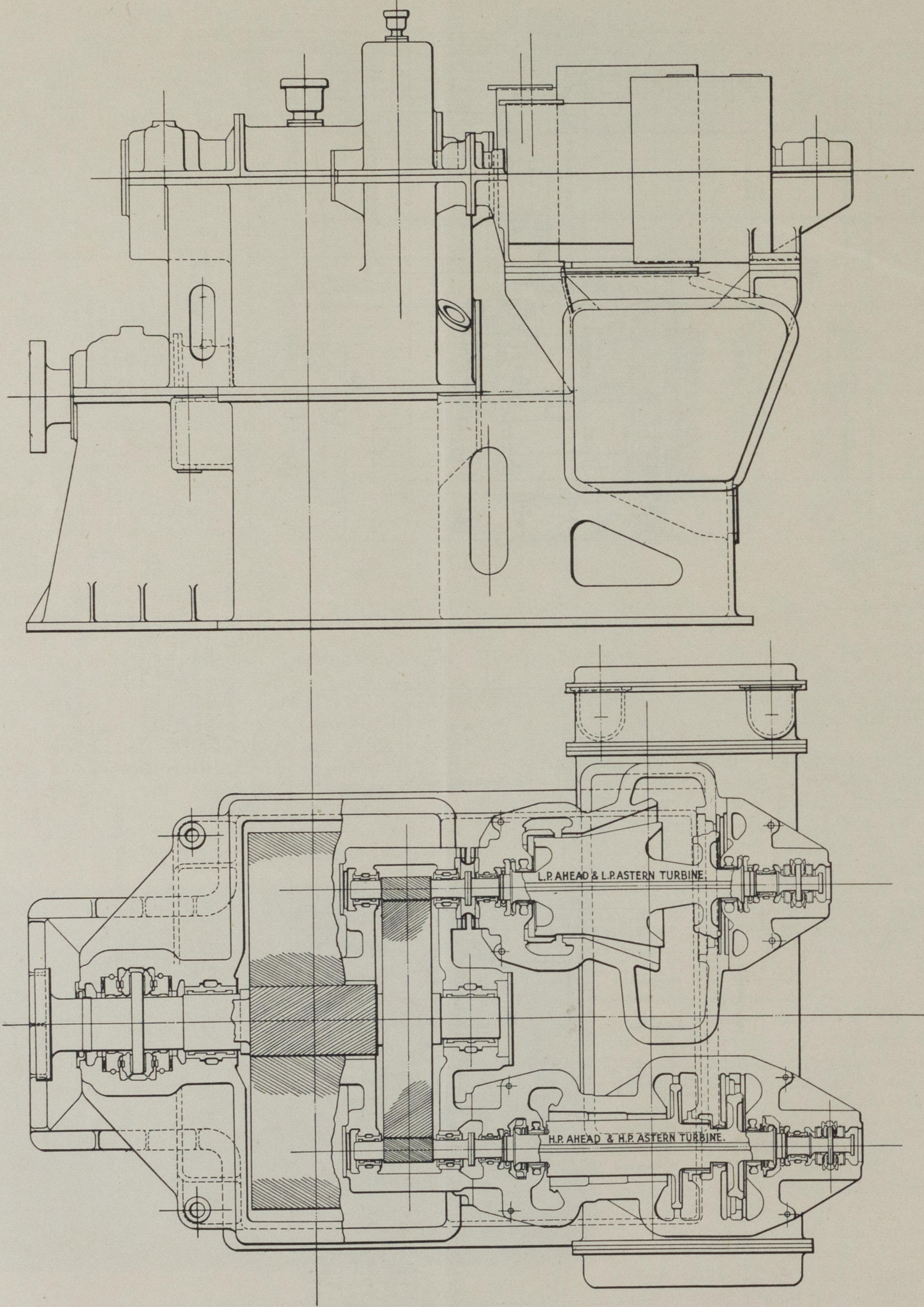

Fig. 7.—Alternative design of Simplex unit with two primary pinions.

the whole assembly to the ship is made only through the gear case feet, and a single operation of alignment is sufficient for this assembly. Further the alignment of turbines and gearing is not disturbed by any straining of the ship. The end thrust of the teeth of the main wheel is in opposition to the thrust of the propeller, reducing therefore the load on the main thrust block. The intermediate shaft and the primary pinion have each its own thrust block to take up the end thrust of the teeth. The pinion and each of the turbines runs in its own bearings, but the pinion shaft is connected to the turbine shaft on each side of it by an expansion coupling instead of rigidly, so as to avoid any accidental bending stresses occurring in the event of any difficulty in maintaining the six bearings accurately in line.

A unit of this description has been built at Turbinia Works for a total output of 2,000 to 2,250 s.h.p. at a propeller speed of 80 r.p.m. After erection it has been subjected to exhaustive tests at full power, the power being absorbed and measured by a Froude dynamometer (*see* Fig. 4).

Steam is supplied to the turbines from the Works' high-pressure boiler at a pressure of 270lb. per sq. in. and superheated to 750° F. The exhaust steam is condensed in the condenser, which is a part of the unit, at a vacuum of 28½in. to 29in. Tested under these conditions at full power of 2,000 s.h.p., the steam consumption is about 8¾lb. per s.h.p./hour, which is equivalent to 7¾lb. per i.h.p. Fig. 5 gives a curve of measured steam consumptions at various powers, with the revolutions adjusted to the values they would have for a ship's propeller, that is to say, varying as the cube root of the power. It will be noted that the economy of steam consumption is well maintained even at half power. This curve has been plotted from results of tests made by Professor Hawkes.

A special auxiliary unit to which reference will presently be made has been designed to go with this set of main machinery, and it is intended to erect and test the whole installation in the works as a self-contained unit.

A moderate steam pressure has been adopted in order that any type of boiler can be used in conjunction with this machinery. Fig. 6 shows a general lay-out for a steamer of 8,500 tons deadweight, with boilers of the Howden-Johnson type designed by Messrs. The Wallsend Slipway & Engineering Co., Ltd., adapted for both coal and oil burning. With preheated air in the heaters as shown it is estimated to obtain a boiler efficiency of 80 per cent. and this in conjunction with the steam consumption above mentioned and a suitable allowance for driving the auxiliaries should give an overall consumption under 1lb. coal per i.h.p. The total weight of machinery is 140 tons less than for a similar outfit with reciprocating engines.

Fig. 7 showing a still more compact arrangement of geared turbines on somewhat similar lines will also be of interest. In this design there are two primary pinions driven by h.p. and l.p. turbines respectively and one secondary, the turbines being mounted on the condenser at the forward side of the gear case.

The main propelling unit being simplified in the manner described, it was natural to enquire into the possibility of making a similar simplification for the auxiliary pumps and fans. For this purpose it is desirable to consider how far it is possible to reduce (1) the number of units to be installed, (2) the number of independent operations required for their control, and (3) their steam consumption, or in other words the cost of driving them. It is an attractive proposal, and one which has often been made, to drive all the auxiliary plant by gearing or otherwise from the main engine. Another equally

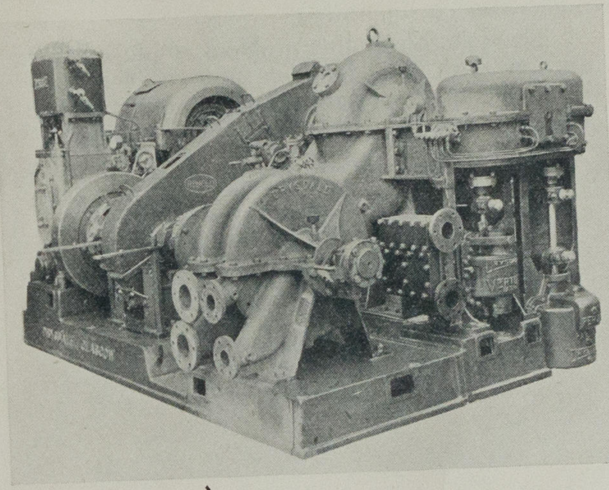

Fig. 8.—Auxiliary unit.

attractive suggestion that has been advanced is the grouping of the various auxiliary units together in order to drive them all from a single engine with a system of countershafts and pulleys analogous to the overhead shafting of a machine shop.

On considering the characteristic duties of the various pumps in respect of their output and the head against which they discharge, it will be seen that for the majority of them a rotary drive from the main engine cannot be suitable at all speeds of the ship, since a constant head of discharge is required whatever the speed and direction of the main engine. This is the case with the condensate and feed pumps, the forced lubrication pump and the bilge and sanitary pumps.

At first glance it might appear that the circulating pump and the fans were suitable for driving in this manner, because in these units both the required head of discharge and the required quantity diminish in such a way that a speed reduced in proportion to the speed of the main engine is sufficient to maintain them. But in the case of the circulating pump there is the difficulty when reversing that if this pump were driven from the main engine the vacuum would fall off and stopping power be lost at the moment when the engine came to rest, to avoid which it would be necessary to bring the ballast pump into operation when manœuvring or preparing to manœuvre; whilst in the case of the forced draught fans independent regulation is of considerable value for maintaining the correct proportion of combustion air. From these considerations it appears that a simple system in which the above auxiliaries are driven from the main engines under all conditions is hardly practicable. For all manœuvring conditions these auxiliaries must be independently driven. A system however in which for the sake of economy of overall voyage consumption the auxiliaries were driven from the main engine at full speed ahead, and stand-by auxiliaries provided for other conditions, would both add to the initial cost and be cumbersome in operation.

The solution of this problem employed in conjunction with the Simplex unit is a combined arrangement of certain of the auxiliaries in a group unit, driven by the main engine at full power and by a separate engine when manœuvring. The circulating pump, condensate pump, forced lubrication pump, bilge and sanitary pump are driven in this manner, by a chain drive and friction clutch from the main engine at full power, and through another friction clutch from the auxiliary engine under all other conditions. The feed pump and forced draught fans are not included in the system, but for the sake of independence of control are separate steam driven and motor driven units.

Fig. 8 is a photograph of such an auxiliary unit which has been designed and manufactured by Messrs. Drysdale & Co. to work in conjunction with the main unit described above.

In conclusion the author desires to express his thanks to the Parsons Marine Steam Turbine Co. for facilities in connection with the experiments described, to his colleagues at Turbinia Works, to Mr. Johnson, of the Canadian Pacific Steamships, Ltd., and to Messrs. Drysdale & Co. for photograph and slide of Fig. 8.