Föttinger Transformers

□ for □ □ □

Steamships

□ □ □ 1914

THE FÖTTINGER TRANSFORMER FOR STEAMSHIPS.

The necessity for high revolutions in the turbine and low revolutions in the propeller in order to obtain the maximum efficiency of both, necessitates the adoption of some system whereby these conditions are produced. The Föttinger Hydraulic Transformer has been designed to meet these conditions, and the results of experiments and trials of ships so fitted have borne out in a marked degree the expectations of the designers as regards economy, weight, and space occupied by machinery.

The Föttinger Transformer consists essentially of a primary wheel keyed to a primary shaft, and a secondary wheel coupled to a secondary shaft. The primary shaft is bolted to the turbine or prime mover, and the secondary shaft transmits the power directly to the propeller. The main feature of the machine is the provision of a distinct water circuit for each of the two directions of rotation of the propeller shaft. The whole machine is mounted in one single casing, separated into two parts by a hollow partition. The water circuit for running ahead is on the secondary side, and that for running astern is on the primary side. Plate 1 shows a longitudinal section through the transformer, illustrating clearly the ahead and astern running circuits. They may be described briefly as follows :—

AHEAD RUNNING CIRCUIT.—The primary wheel A is keyed to the primary shaft X, which is driven by the turbine. The secondary rotor for running ahead, which consists of two wheels B and D, which is bolted to the secondary or propeller shaft Z. Between the secondary wheels B and D, stationary guide blades C are introduced.

ASTERN RUNNING CIRCUIT.—The primary wheel M for astern running is also keyed to the primary shaft X. The secondary rotor, consisting of two sets of blades O and Q, is coupled up to the first ahead running secondary wheel B, and through this to the propeller shaft. Two sets of guide blades N and B are introduced in this circuit between the secondary wheels.

The action of the machine is as follows:—If the circuit for running ahead be first taken, and be considered as filled with water, so that this space is under atmospheric pressure throughout, apart from the effects of mere differences of level, then, owing to the rotation of the primary shaft X, which may be reckoned soon to reach a constant speed, pressure differences are established between the inlet and outlet of the primary wheel A. These result in the setting up of a current which immediately leads to a circulation inside the wheels, whereby the water finds its way back from the outlet of the primary wheel A, through the sets of blades of the hitherto stationary secondary wheels B and D, and the sets of guide blades C, to the entrance in the primary wheel. The reaction set up by the water in its passage upon the blade surfaces of the secondary wheels soon sets these in rotation, the speed increasing until the condition of uniform motion is reached.

In the astern circuit conditions are very similar, with the difference, however, that in this case the primary wheel M is not surrounded by a rotating wheel, but by fixed guides N, the object of which is to reverse the direction of motion of the water which flows out of the primary wheel, and to reverse thereby the direction of rotation of the secondary rotor as compared with the primary wheel. The secondary rotor of the astern circuit O and Q has also two stages. The second guides P in the astern circuit play a similar part to the single set of guides C in the ahead circuit. It will be seen from the above that when manœuvring, the main turbine can be kept running at a constant speed in one direction.

The pressure distribution in the circuit leads to certain leakage losses, since the packing of the shafts is not absolutely tight, and there is also some leakage between the secondary rotor and the intermediate partition. These leakages might result in the gradual loss of water and entrance of air, and the attempt to work with such a mixture would, as time went on, greatly reduce the economical working of the machine. These leakages have therefore to be made good, and this is provided for by the Make-up Pump, which is of the centrifugal type, having its shaft vertical, and driven by a small independent impulse steam turbine. The pump chamber is submerged in the tank which supplies water to the transformer, and into which the leakages from the latter drain. The pump is shown on Plate II.; it draws from the tank and discharges into the annular chamber K formed round the secondary stuffing box, and thence through the ports in the hub of the second secondary wheel of the ahead circuit. The leakage loss and its compensation by the pump adds an auxiliary circuit to the main working circuit.

Besides maintaining the water in the transmitter at the required pressure by compensating for the leakages, the make-up pump serves also to supply, in the first instance, either circuit on starting, thereby acting as a manœuvring pump. Since for this it has in a very short time to deliver a larger quantity of water than that required merely for making up the leakages, its speed has to be increased for this particular purpose. The speed of the pump, when making up leakages in the circuit for running ahead and developing full power, is about 3,000 revolutions per minute, at which speed it maintains a pressure of about 50lb. to 60lb. in the chamber K. In manœuvring and reversing, the speed of the pump is increased according to the work required. On rapid reversing from full power ahead to full power astern, the pump runs at a speed of 3,000 to 3,500 revolutions per minute. Boiler feed water is used for the transformer, and is being constantly heated owing to the work done upon it in the transformer. In order to save this heat, and put it back into the boiler, part of the water from the air pump discharge is admitted through a regulating valve to the transformer tank, and an equal amount is drawn off (by means of a branch in the discharge pipe which leads from the make-up pump to the transformer), and is led to the main feed pump suction tank. The feed water-heating system is clearly shown in the diagram on Plate III., where it will be noted that the transformer pumps are cross-connected, and that a duplicate system of pipes is fitted for supplying the transformers alternatively with boiler feed water and with sea water. There is an indicator above the engine-room floor which shows the water level in the transformer tank, so that it may be seen that the amount of water sent back to the boiler from the transformer is equal to the amount put into the tank.

The temperature of the water in the transformer is usually regulated to about 170° Fahr. In addition to the gain due to saving this amount of heat for the boiler, it is also found that there is a considerable gain in the efficiency of the drive by using water at this high temperature, owing to the viscosity of the water being less than at low temperatures.

The governor and control gear is represented diagrammatically in Plate II., Fig. 4. The problem resolves itself simply, so far as reversing is concerned, into emptying the side which happens to be in operation, and in charging the other which is required to commence work. For this purpose there are two balanced slide valves, of which one, marked A, is the inlet valve, and the other, marked B, the outlet valve. Both are so coupled together by means of a lever, the central point of which is located underneath the hollow casing for the primary bearing (see Plate II., Fig. 4), that their respective positions always correspond in such a way that the outlet valve holds the outlet port closed so long as the inlet valve holds the inlet port open for connecting the circuit on that side with the make-up pump, and vice versa. There is also a stand-by position in which the inlet valve cuts both circuits off from the make-up pump, whilst the discharge valve holds both circuits open. The flow past the discharge valve runs direct into the tank. There are two large-diameter connections on each side of the casing for taking the valves; those for the inlet lead the chambers K and K_1, those for the outlet into the annular spaces S and S_1 (Plate I.). The valves are operated hydraulically, the piston of the inlet valve acting also as a relay for working all the valve mechanisms. For this purpose water under pressure is admitted to both sides of the inlet valve piston through the action of a small governing valve C located at the back of the inlet valve. The make-up pump itself supplies the water under pressure. By means of this device the operation of the large valves is carried out most easily from the engineer's platform by acting upon a single hand lever, the total travel, of about 400mm. (15¾in.), of the piston valve taking about two to three seconds. Reversing under the heaviest loads from "full speed ahead" to "full speed astern" is effected in about thirteen seconds from the moment the order is given from the bridge; in some instances it has been effected in a shorter time than this. Reversing from astern to ahead is quicker than from ahead to astern. During these manœuvres the running of the steam turbine is not interfered with in the least.

The ratio of reduction—i.e., the ratio of the turbine revolutions to the propeller revolutions—varies according to design from 1 : 1 to 6 : 1. This ratio can be temporarily increased for manœuvring purposes by slowing down the make-up pump, which causes the water wheel to cavitate. The make-up pressure is regulated according to the desired number of secondary revolutions. A thrust block is fitted aft of the transformer, which takes up any difference of thrust there may be between the propeller shaft and the secondary stage water wheels in the transformer. There is also a thrust bearing fitted on the forward end of the turbine shaft to take up the difference between the steam thrust in the turbine and water thrust in the primary water wheel of the transformer. It will be observed that the thrust caused by the reaction of the water in the second secondary wheel D acts in the direction opposite to the propeller thrust, thus decreasing the load on the thrust block. It is advisable that the steam should be admitted to the aft end of the main turbine, as by so doing the steam thrust counteracts the thrust caused by the reaction of the water in the primary wheel A.

The engineer's platform is provided with (a) the hand-wheel operating the steam turbine stop-valve ; (b) the transformer reversing lever, which has three positions—" ahead," " stop," and " astern " ; (c) a lever operating a sluice valve in front of the steam nozzles on the make-up pump ; and (d) as a stand-by gear, for reversing, a hand lever on a threaded spindle for operating by hand the inlet and outlet valves on the transformer should the lever under (b) refuse to act.

The various manœuvres take place as follows :—

(1) The reversal from " full speed ahead " to " full speed astern," or vice versa, can be made with perfect safety without touching the stop valve of the steam turbine. The reversing lever being shifted, and the lever for accelerating the speed of the make-up pump operated, leads to the answering of the transformer in the shortest possible time.

(2) The variation in the ship's speed is generally obtained by varying the steam pressure in front of the steam turbine nozzles in the usual way followed where no transformer is fitted.

(3) In the manœuvres for varying both the ship's speed and the direction of travel, the reversing lever is first placed for obtaining the desired direction of travel ; the lever for operating the make-up pump is then placed in the accelerating position, and the steam pressure in front of the steam turbine nozzles is altered as required.

(4) For stopping when the ship is running in either direction, in many cases it is advisable to brake the shaft by moving the reversing lever to set up running in the reverse direction, as obtains under (1).

(5) When it is necessary for the ship to carry out many successive manœuvres, the running of the make-up pump is permanently accelerated, all the manœuvres being then easily carried out by simply moving the reversing lever and regulating the steam pressure at the steam turbine stop valve. When in such cases a temporary variation in the direction of travel is required, the steam turbine stop valve can remain untouched, the reversing lever being brought into an intermediary position. In this latter case the transformer is not completely full of water, its power is less, the

speed of the secondary rotor falls off, and the efficiency of the machine decreases somewhat.

On Plate IV. is shown the arrangement of the engine-room of a cross-Channel steamer of 6,000 s.h.p. for a speed of 20 knots. Fig. 1 shows turbine machinery with double helical gearing, and Fig. 2 shows similar turbines with Föttinger Transformers. It will be noted that about eight feet is saved in the length of the engine-room, and the table below gives the saving in weight and coal effected.

Plate V. shows arrangement of the engine-room of s.s. "Konigin Luise," which is fitted with Föttinger Transformers.

Plate VI. illustrates the engine-room of an intermediate liner, assuming 20,000 s.h.p. for a speed of 20 knots. In this case there are two shafts in the Föttinger design (Fig. 2), against four in the direct drive arrangement (Fig. 1), and twenty-one feet is saved in the length of the engine-room.

Plate VII. similarly shows the comparison for a high-speed liner of 60,000 s.h.p.

The table here given indicates the economy and saving in weight obtained by the use of Föttinger Transformers for ships of the types illustrated :—

TYPE OF SHIP.	For Arrangement of Machinery see Plate.	Weight (in tons).		Coal Consumption per S.H.P. per hour (in pounds). (Best Scotch Coal)				
				Saturated Steam.		Super-heated Steam. (For Föttinger Drives only.)		
		Föttinger Drive.	Direct Drive.	Föttinger Drive.	Direct Drive.	100° F. Superheat.	150° F. Superheat.	200° F. Superheat.
Cross Channel	IV.	200	230*	1·42	1·55	1·31	1·25	1·2
Intermediate Liner	VI.	2600	2980	1·29	1·34	1·2	1·15	1·1
High-Speed Liner	VII.	6890	7930	1·28	1·32	1·19	1·14	1·09

* This refers to helical-geared turbines, as shown on Plate IV.

For the coal consumption, 90 per cent. efficiency is taken for the transformer, this figure having been attained in many experiments which have been made. To this is added 2 per cent. for feed water heating, 1 per cent. for windage of astern turbine, and 1 per cent. for thrust block losses, thus making the efficiency for purposes of comparison 94 per cent. In addition to the advantages of higher economy, less weight, and less space occupied by the

Föttinger system over the direct turbine-driven shafts, there are others which merit attention. They may be enumerated as follows:—

(1) Rapid manœuvring qualities, as the transformer, by the mere shifting of a lever, reverses in a period of not more than ten to thirteen seconds.

(2) Superheating may be adopted without incurring any risk, as the turbine always rotates in the one direction, and uniform temperature conditions prevail.

(3) No astern turbine is required, and there is entire absence of sudden reversals, involving rapid change of momentum and water-hammer, due to sudden entry of steam, which occur in direct-driven and gear-driven installations. In the latter installations this change in momentum and water-hammer tends to strain the turbine blades with an eventual danger of stripping. These difficulties are absent in a turbine with Föttinger drive on account of its rotating constantly in one direction.

(4) The turbine is of very small dimensions, and has very few blades, which are short, and have a strong section.

(5) Astern power equal to 90 per cent. of ahead power can be obtained if required.

EXPLANATION OF THE HIGH EFFICIENCY OF THE FÖTTINGER TRANSFORMER.

The hydraulic engineer when considering the efficiency of the Föttinger Transformer is apt to fall into the error of referring to the measured and known efficiencies of some well-known type of centrifugal pump and water turbine, and then deduce or predetermine the efficiency of the Föttinger Transformer by the product of two such efficiencies. Such engineer would doubtless take 88-89 per cent. as the best-known figure in the case of large hydraulic turbines, and about 86 per cent. for centrifugal pumps, and thus only arrive at a maximum efficiency for the transformer of about 76 per cent.

In deducing the efficiency in the above manner, he will, however, overlook a number of important factors ; all of which cause the working conditions in a transformer to differ considerably from those prevailing in any combination of centrifugal pumps and hydraulic turbines.

The primary portion of the transformer is not an ordinary centrifugal pump, but merely an impeller which works on the centrifugal pump principle, and whose only losses consist (1) in the friction of the water within the retaining walls of the impeller, and (2) the losses which are caused by the passage of the water in and out of the guide ducts. In the transformer these ducts are made as short as possible, having due regard to the curvature of the blades. Further, the blades are polished to smooth surfaces, and the edges fined down. Hence these losses are exceedingly small, so that the efficiency of the primary wheels, per se, is from 97-98 per cent. This agrees with the result obtained from measurement of efflux or outflow nozzles fitted to efflux tanks for measuring quantities of water. The value of the efflux coefficient of such nozzles lies between 0.96 and 0.99. The blade duct of a transformer primary wheel, on account of the close adaptation of its shape to the conditions of flow of the water practically does not differ from such an efflux nozzle.

It is obvious that the impeller of an ordinary centrifugal pump can by itself be designed for the same high efficiency, but in such a pump additional losses occur after the water leaves the wheel. The energy contained in the water, at the point of efficiency, is mainly due to its velocity. Where centrifugal pumps are in use, the exit velocity of the water cannot be directly utilised. Hence it is necessary to change this velocity into pressure by passing the water through some special device, such as a guide apparatus, a diffuser, a spiral casing, etc., all of which can only conduct the efflux energy by gradually retarding the velocity of flow.

The conversion of the efflux energy of the water is the cause of the greater part of the losses of a centrifugal pump.

There is no necessity for such conversion of the energy in the case of the transformer, because the velocity of the water, on leaving the primary wheel, is directly utilised for the purpose of impelling a turbine wheel, which concentrically surrounds such primary wheel.

Where the secondary turbine is of the single stage type, a fixed guide vane is interposed between the primary wheel and the turbine. Such guide vane, however, does not retard the velocity of flow of the water, but, on the contrary, imparts to it a still higher velocity. As the water is thus further accelerated in the turbine wheel relatively to the enclosing walls of the blade ducts, and as, further, there is no exit loss in this turbine wheel, because the water flows back directly to the primary wheel with the remaining energy of flow, this cycle of operations reduces the losses to a minimum, so that they are not greater in the case of the above-mentioned secondary turbine than in the case in which the primary wheel alone is considered, assuming that the same degree of workmanship is applied in both cases.

If the secondary turbine has two stages, the conditions are still more favourable, because there is no necessity for guide vanes in the first stage, so that the proportion of frictional loss is still further reduced. In this case the primary wheel is intimately surrounded by a concentric secondary rotor wheel. The inherent velocity of the water on leaving the primary wheel is here directly applied to the useful propulsion of the secondary wheel. Thus a highly economical conversion of the kinetic energy of the water into mechanical work takes place in the secondary wheels, instead of a very uneconomical conversion of velocity into pressure.

Moreover, the volume of water and the difference of head (whose product determines the power of the transformer) can be so chosen with regard to the required number of revolutions, and the transformation ratio, that the velocity of the water in the transformer circuit is not too high as compared with the circumferential velocity of the rotor wheels. We thus possess another means of attaining maximum efficiency by preventing the frictional losses becoming too great in proportion to the head generated by the primary wheel.

Taking all these facts into consideration, we obtain an efficiency of 97.5 per cent. for the primary wheel, and an efficiency of 91.2

per cent. for the secondary wheel. The last figure is based on the ascertained efficiency of hydraulic turbines of 88.5 per cent. on the assumption that the turbine exit losses amount to about 3 per cent. This, therefore, is the amount by which the efficiency of the secondary turbine, with the medium speed of, say, 5 : 1 ratio, can be increased as compared with the ascertained efficiencies of existing hydraulic turbines. The product of both efficiencies—i.e., of primary wheel and secondary—is thus $97.5 \times 91.5 = 89$ per cent.

The actual efficiency attained by a small transformer of about 1,350mm. diameter, having a speed ratio of 3.5 : 1, and transmitting only 600 s.h.p., was 88.2 per cent., the latter including the friction of the four transformer bearings, as well as that of two bearings for the brake-testing arrangement.

In the case of larger sized transformers for larger powers, all the frictional losses are proportionately smaller, (1) because the ratio of the surface of the hydraulic circuit in contact with the water becomes smaller as the transformer becomes larger; (2) because with larger sizes higher velocities are obtainable, which again diminish percentage losses.

In the case of transformers of large power, it is therefore possible to guarantee an efficiency of 90 per cent., even with a transformer ratio of 5 : 1 or even 6 : 1. This is borne out by the latest trials of the 10,000 s.h.p. transformer for a 20,000 s.h.p. liner now building—the efficiency of which, including thrust block losses, shows 90.3 per cent.

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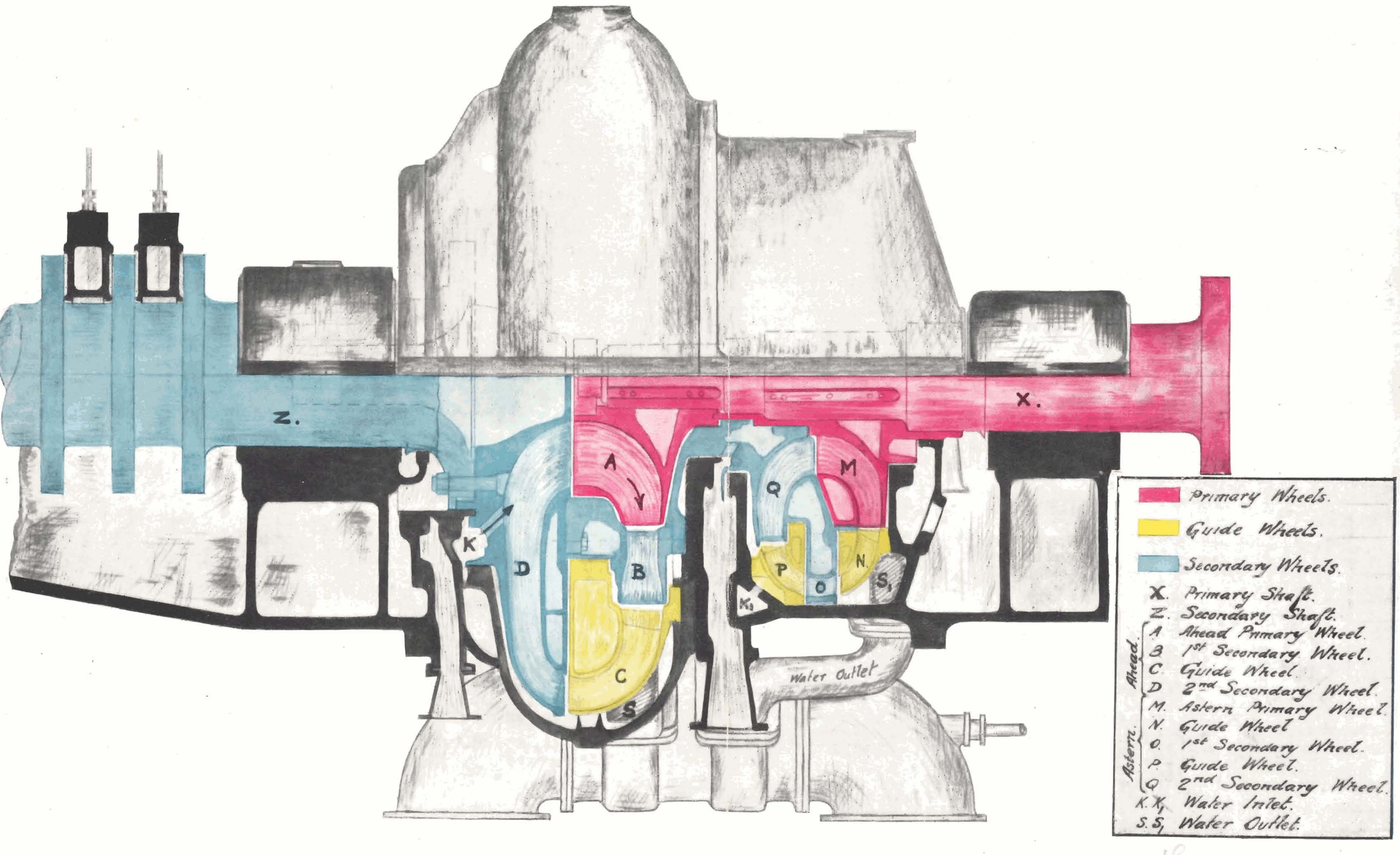
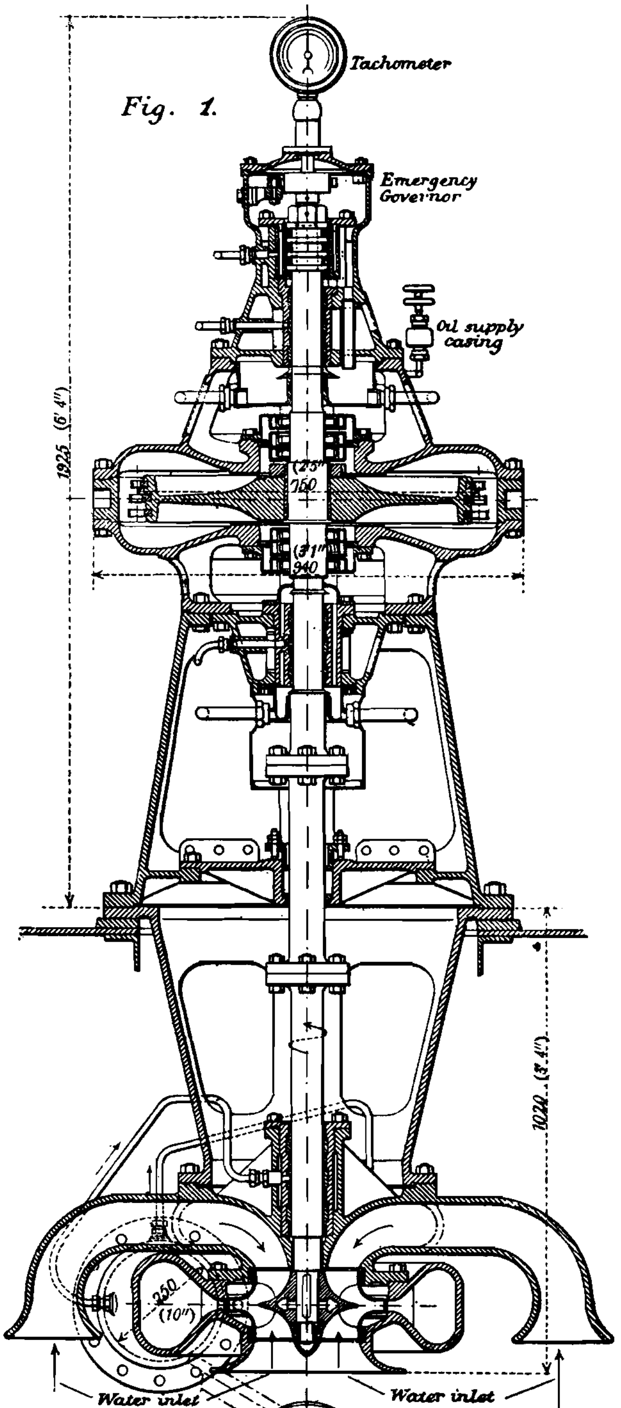
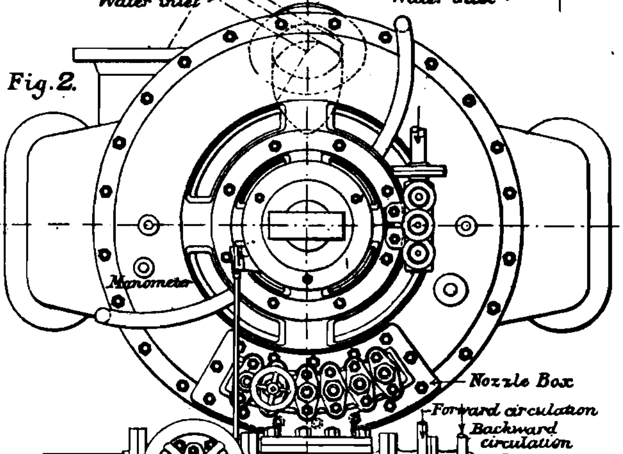
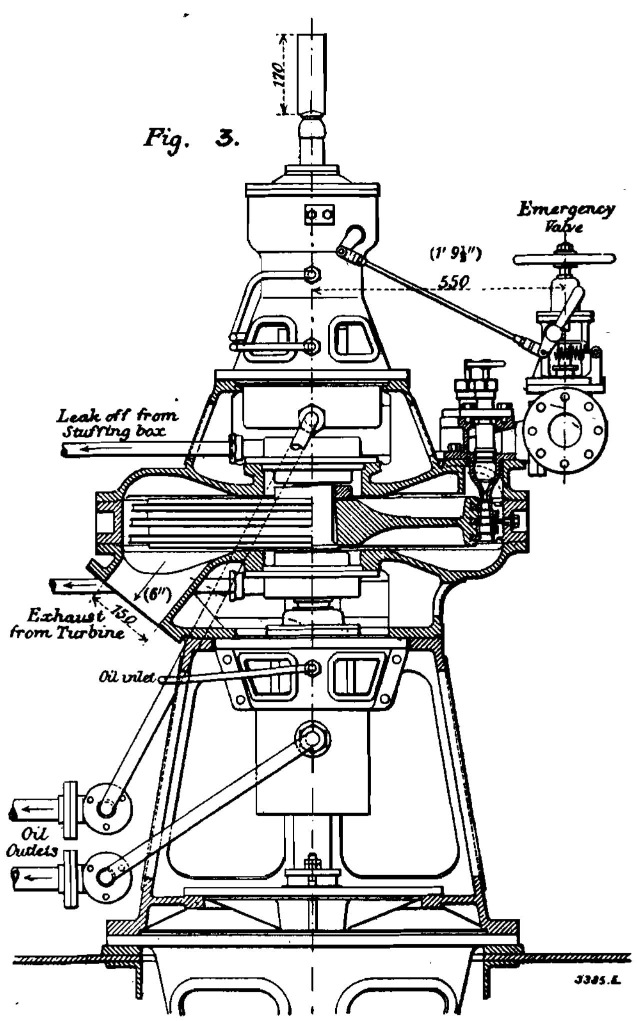
PLATE I.

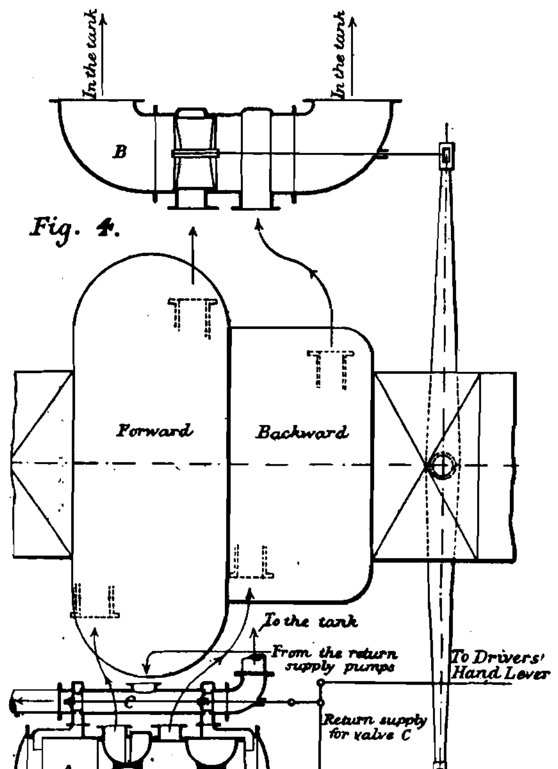


LONGITUDINAL SECTION THROUGH FÖTTINGER TRANSFORMER.

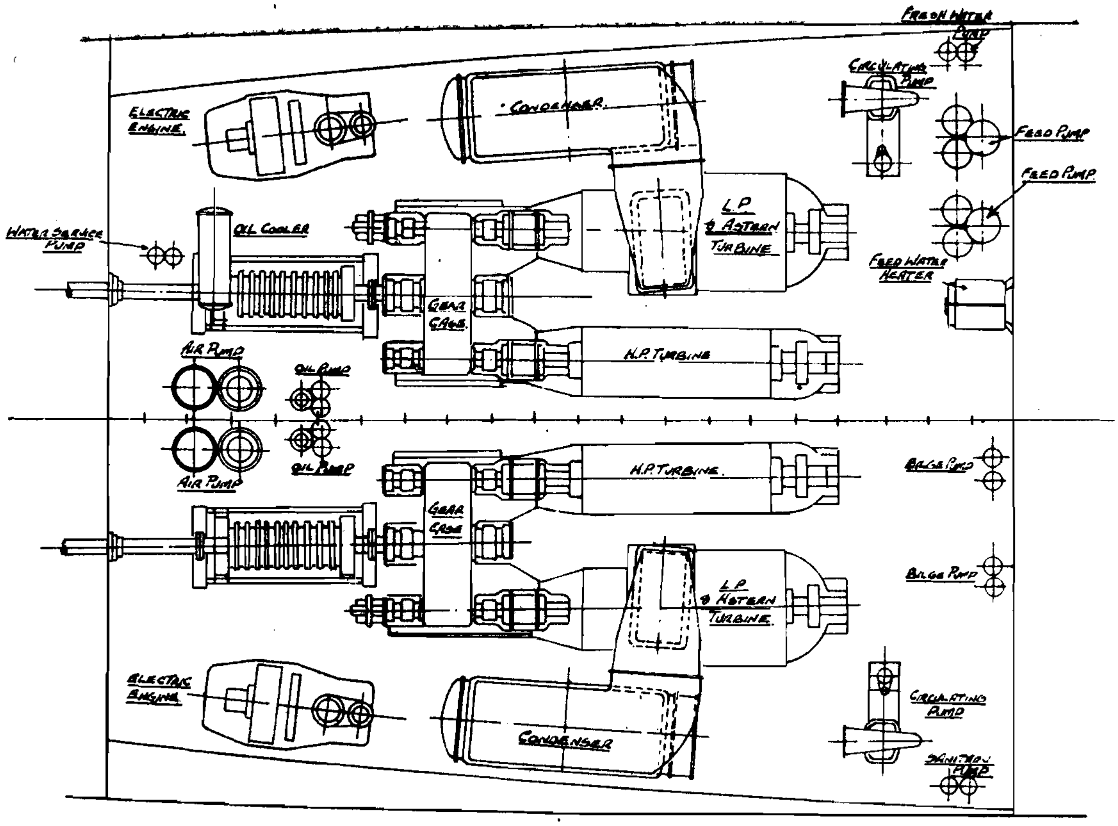






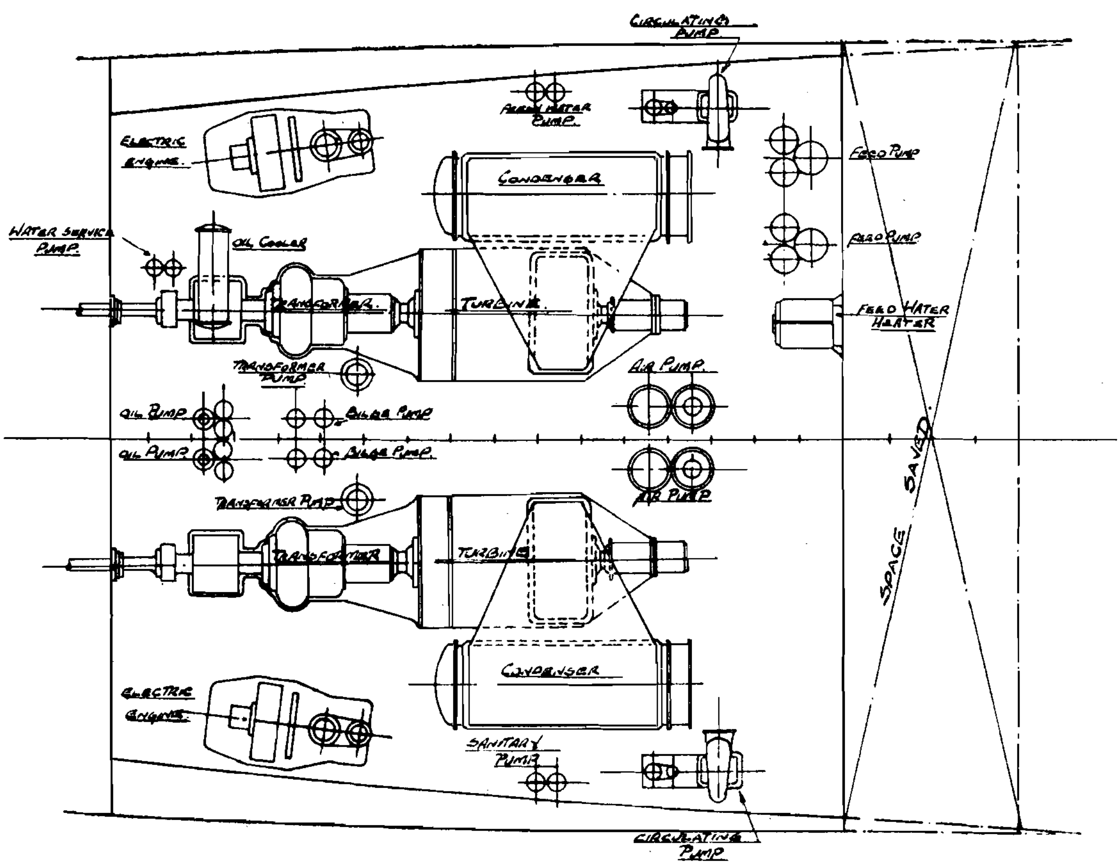


PUMP FOR MAKING UP LEAKAGE LOSSES IN FÖTTINGER TRANSMITTER.



REVOLUTIONS.

H.P. Turbine	-	1,990.
L.P. Turbine	-	1,360.
Propellers -	-	310.



REVOLUTIONS.

Turbine	- -	1,800.
Propellers -	-	450.

PLATE IV.

CROSS - CHANNEL STEAMER.

Comparison of Mechanical Geared and Föttinger Geared Turbines.

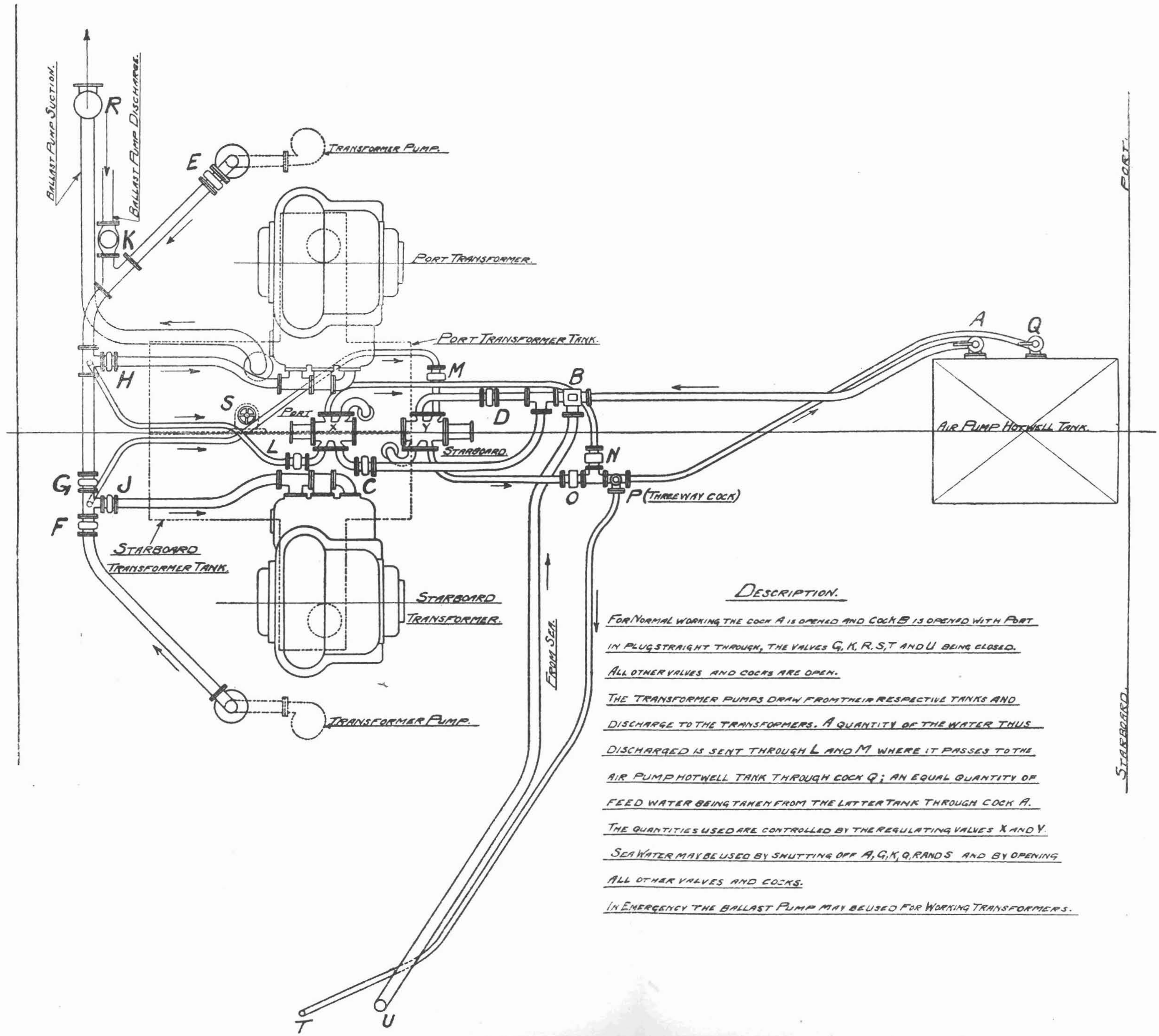
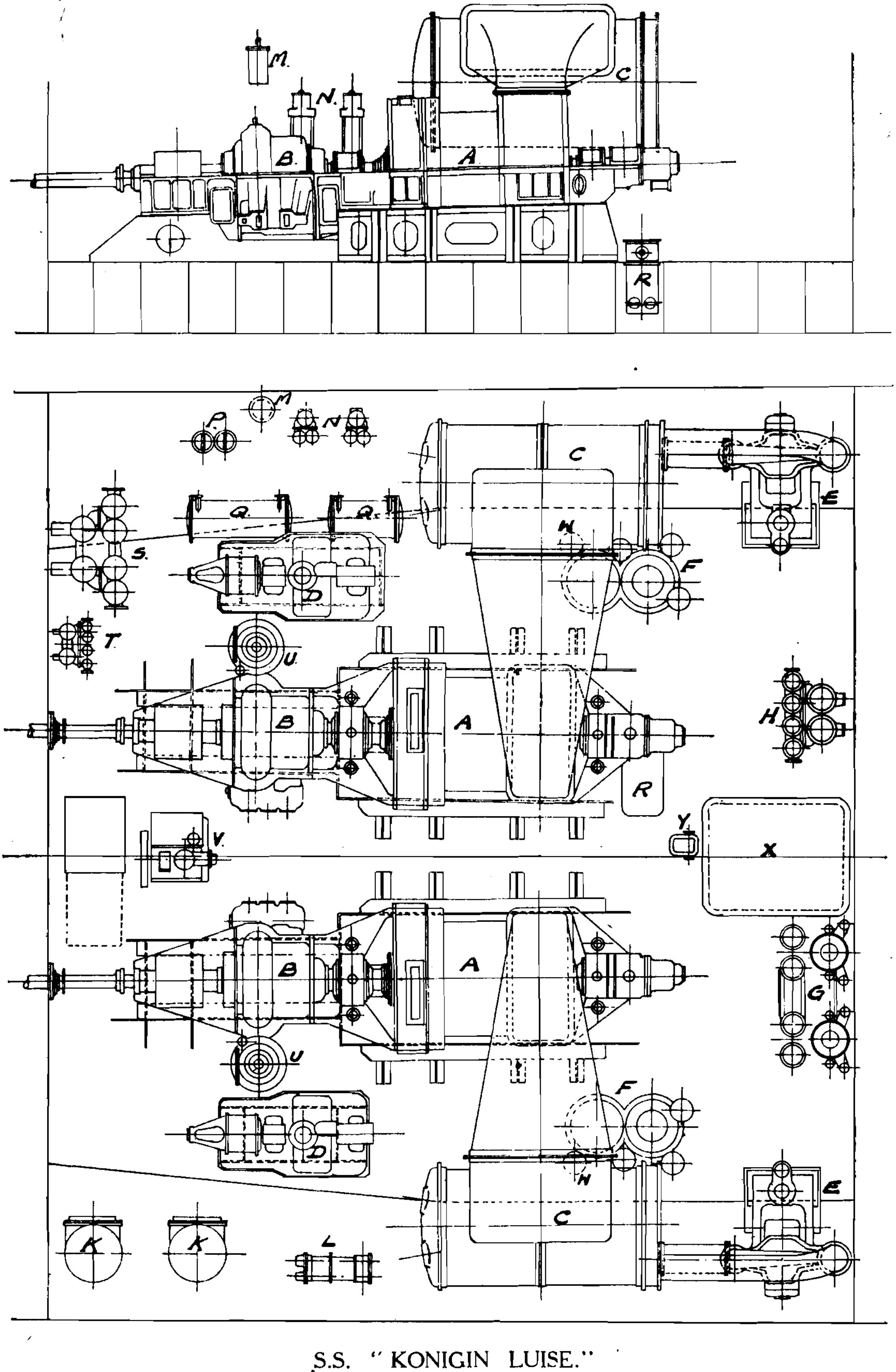


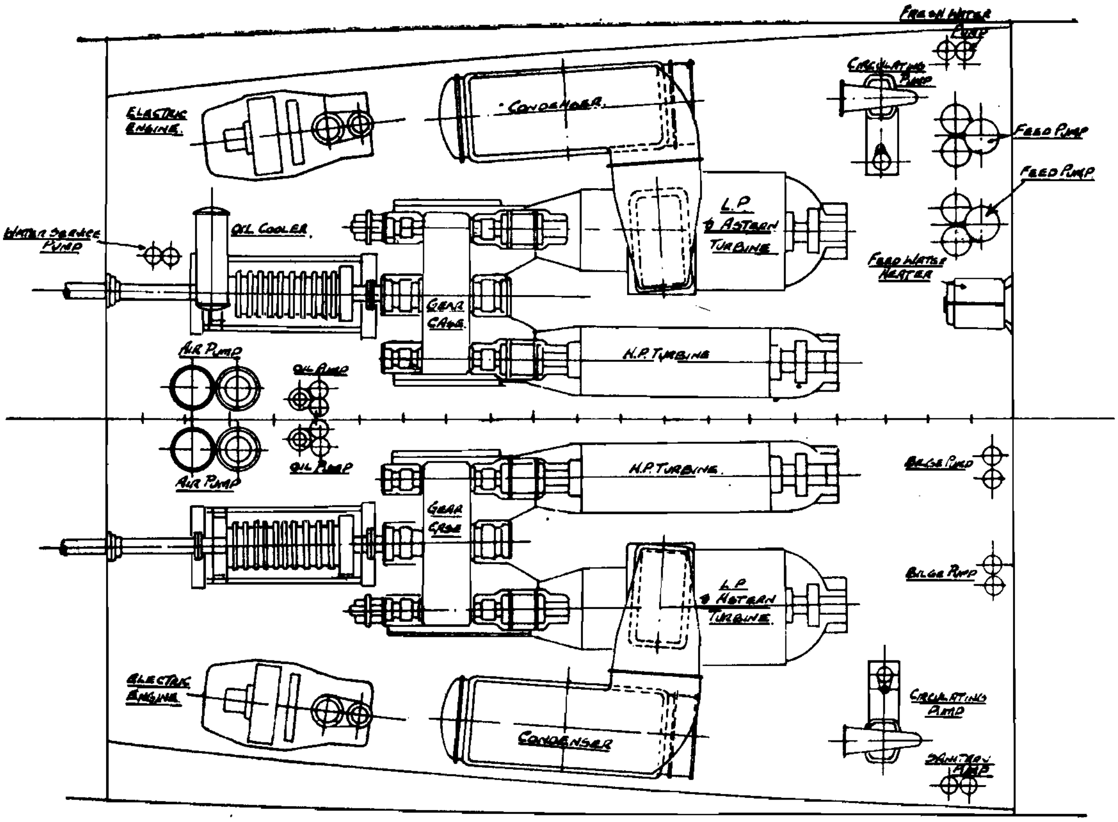
DIAGRAM OF FEED WATER HEATING SYSTEM.



S.S. "KONIGIN LUISE."

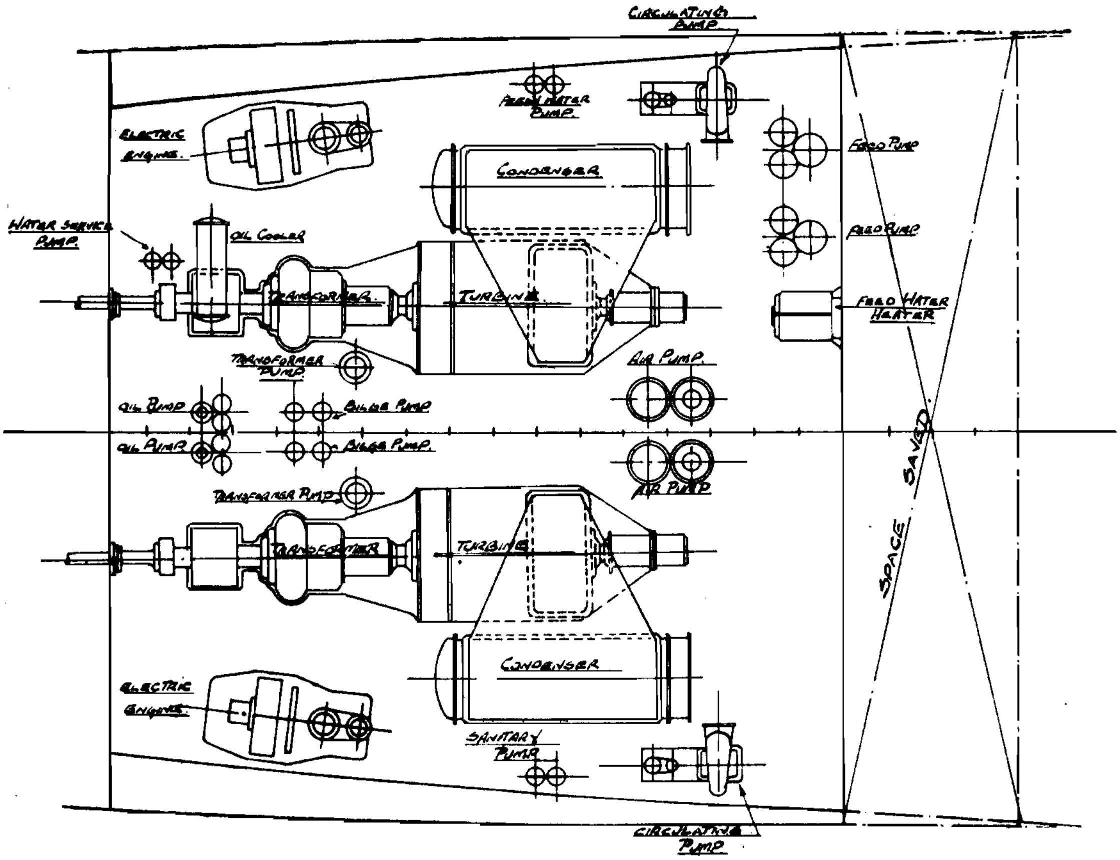
Arrangement of Machinery in Engine-Room.

A Turbines.
B Transformers.
C Condensers.
D Turbo Dynamos.
E Centrifugal Pumps.
F Air Pumps.
G Main Feed Pump.
H Auxiliary Feed Pump.
K Evaporators.
L Fresh Water Pump.
M Oil Settling Tank.
N Oil Pumps.
P Oil Filters.
Q Oil Coolers.
R Oil Drain Tank.
S Ballast Pump.
T Sanitary Pump.
U Transformer Pump.
V Ice Making Machinery.
W Air Pump Cooler.
X Feed Tank.
Y Mud Box.



REVOLUTIONS.

H.P. Turbine	-	1,990.
L.P. Turbine	-	1,360.
Propellers	-	310.



REVOLUTIONS.

Turbine	-	1,800.
Propellers	-	450.

PLATE IV.

CROSS - CHANNEL STEAMER.

Comparison of Mechanical Geared and Föttinger Geared Turbines.

REVOLUTIONS.
Turbine - - 1,160.
Propeller - - 185.

FIG. 1.

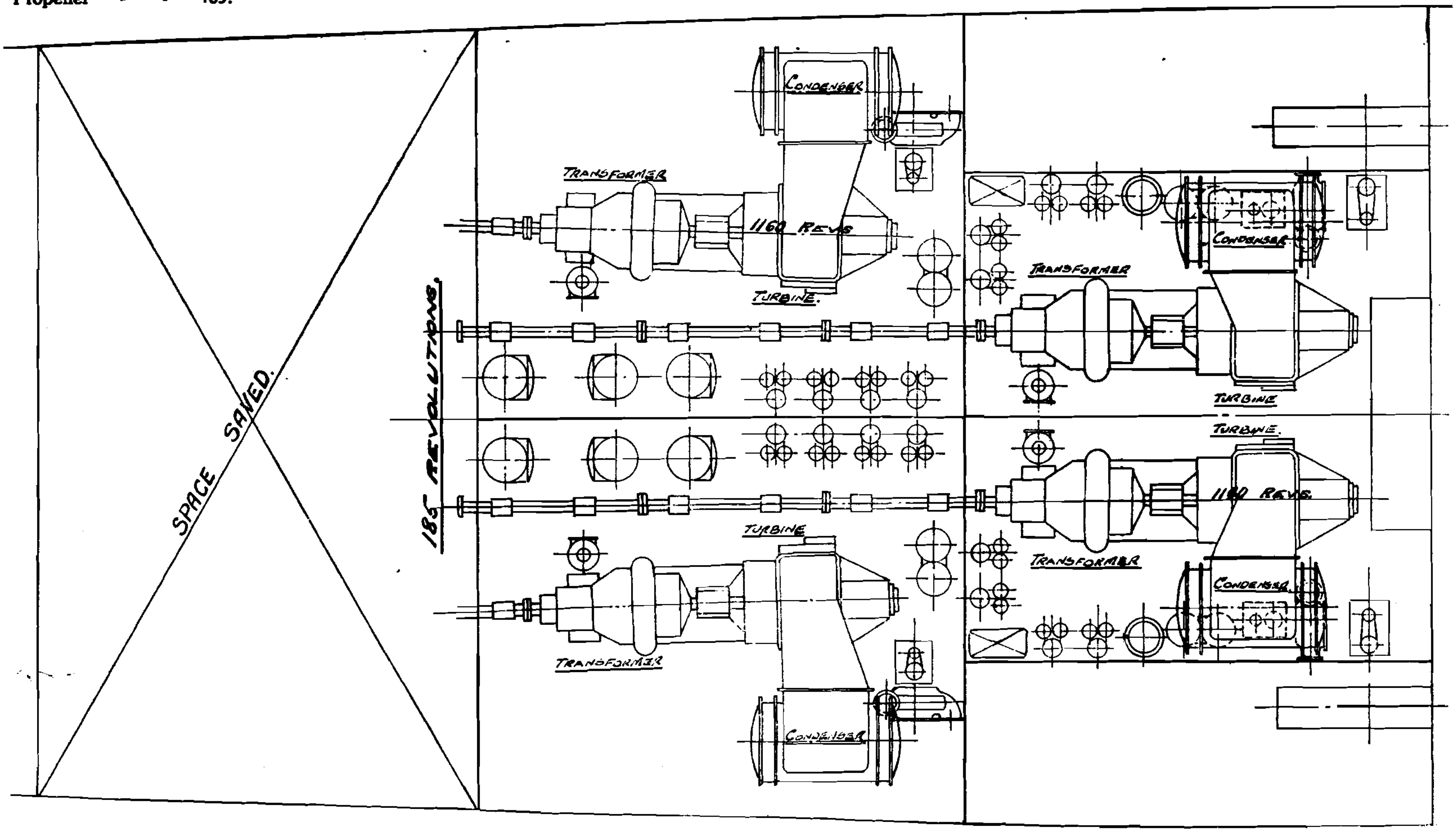


FIG. 2.

HIGH - SPEED LINER.

Comparison between Direct Turbine Drive and Föttinger Geared Drive.

PLATE VII.

185 Revolutions.

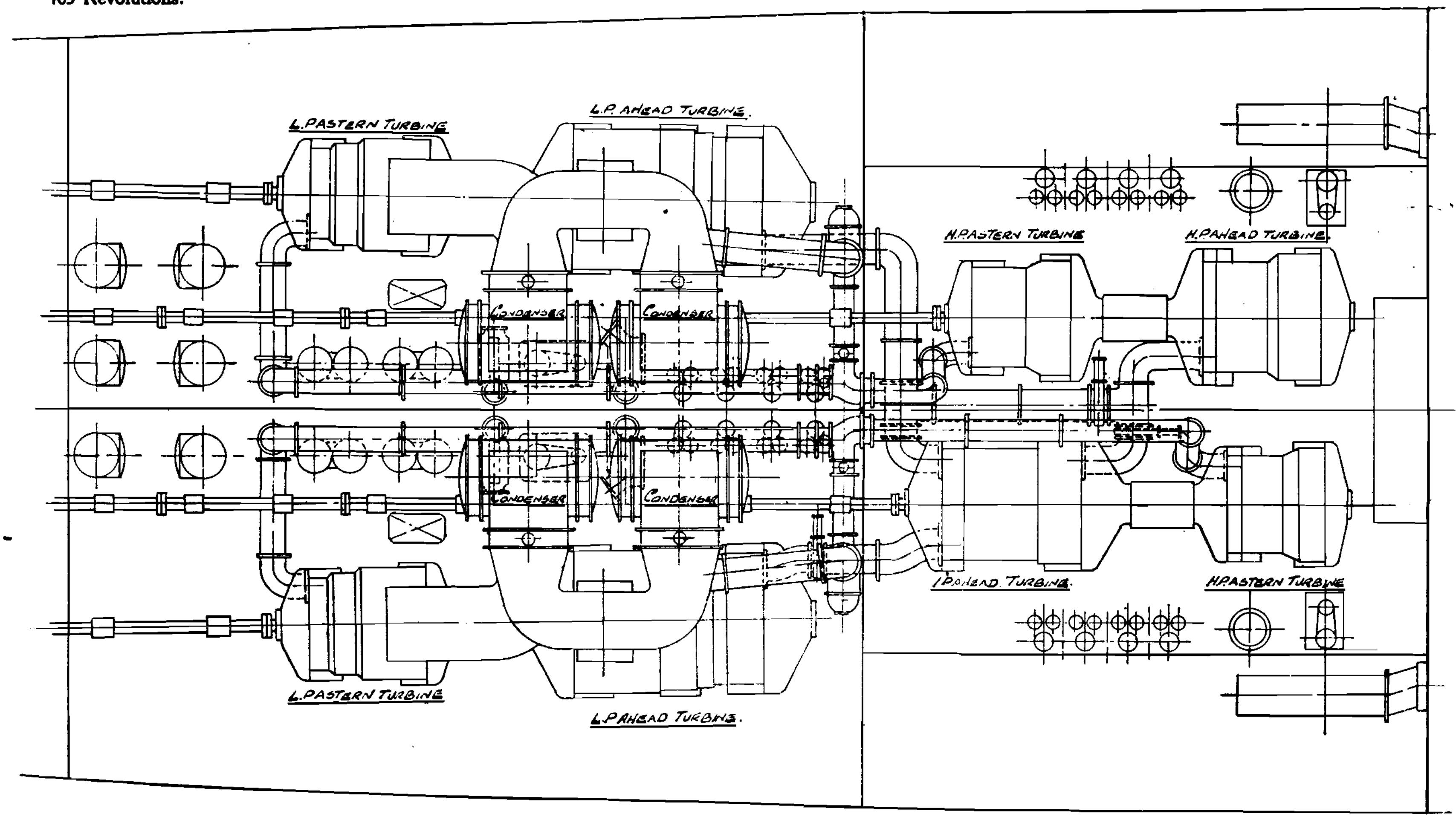


FIG. 1.

REVOLUTIONS.