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ROTARY PUMPS FOR AUXILIARY SERVICES

Steam-driven reciprocating auxiliary machinery, although giving good and reliable service, suffers from certain disadvantages which have led in an increasing degree to its supersession by rotary engines in the modern British high-powered war vessels.

The chief reasons for the change are as follows :—

(1) The vibration which was often caused by the high-speed reciprocating engines, especially fan engines, was a source of interference with fire control instruments.

(2) In general, especially in the larger units, the weight of the turbine-driven auxiliaries was less than that of corresponding reciprocating-driven auxiliaries.

(3) With the adoption of superheated steam, the need for a separate saturated steam pipe arrangement for the reciprocating auxiliaries entailed increased weight and complication.

(4) Some contamination of the exhaust steam from oil used for lubrication is inevitable with reciprocating engines and elaborate filtering arrangements are required to ensure that the boiler feed is free from this contamination.

(5) The rotary engines are inherently more flexible and lend themselves better to automatic control, a feature which can hardly fail to find increasing use.

The change from reciprocating to rotary auxiliary machinery was anticipated to some extent by a change from reciprocating to rotary pumps for a variety of services. The type of pump employed differs with the service required, and it is the purpose of this article to discuss the characteristic features of the different types of rotary pumps and the services for which they are suitable.

These pumps can be classified broadly under two main headings :

(1) Centrifugal pumps.
(2) Rotary displacement pumps.

Centrifugal Pumps.—In this type of pump fluid is discharged from the periphery of the impeller at a high velocity and subsequently in the volute chamber some part of the head, due to velocity, is transformed into pressure, some part is lost by eddy making, etc., and some remains as the velocity head which is required under the conditions of pumping.

The Centrifugal principle is a very old one, centrifugal fans being used for mine ventilation in the sixteenth century or earlier. Various types of centrifugal pumps were invented during the seventeenth and eighteenth centuries, but there is no evidence of their practical use until 1818 when the Massachussetts pump was sometimes used in America. The first really successful pump of this type was designed by J. G. Appold and one of his pumps was shown at the 1851 Exhibition. An Appold pump was fitted in H.M.S. *Enterprise* in 1862.

The efficiency depends upon the relationship between output and head at any given speed of rotation, and if the efficiency is a maximum at one speed, and the conditions are such that output and speed of rotation vary together, it will be found that the efficiency remains constant and head varies as the square of the speed. The curves in Fig. 1 show the variation of head, output and efficiency in a typical case at one speed. At other speeds corresponding relationships between $\frac{\text{Output}}{\text{Speed}}$ and $\frac{\text{Head}}{(\text{Speed})^2}$ will give the same efficiency.

Centrifugal pumps are capable of application to almost any conditions under which liquids have to be dealt with, but from an efficiency point of view they have their limitations. Thus it is not economical to use such a pump for small capacities at high pressure, or for viscous fluids, since the internal friction tends to increase rapidly and to increase the driving horse-power as the viscosity increases.

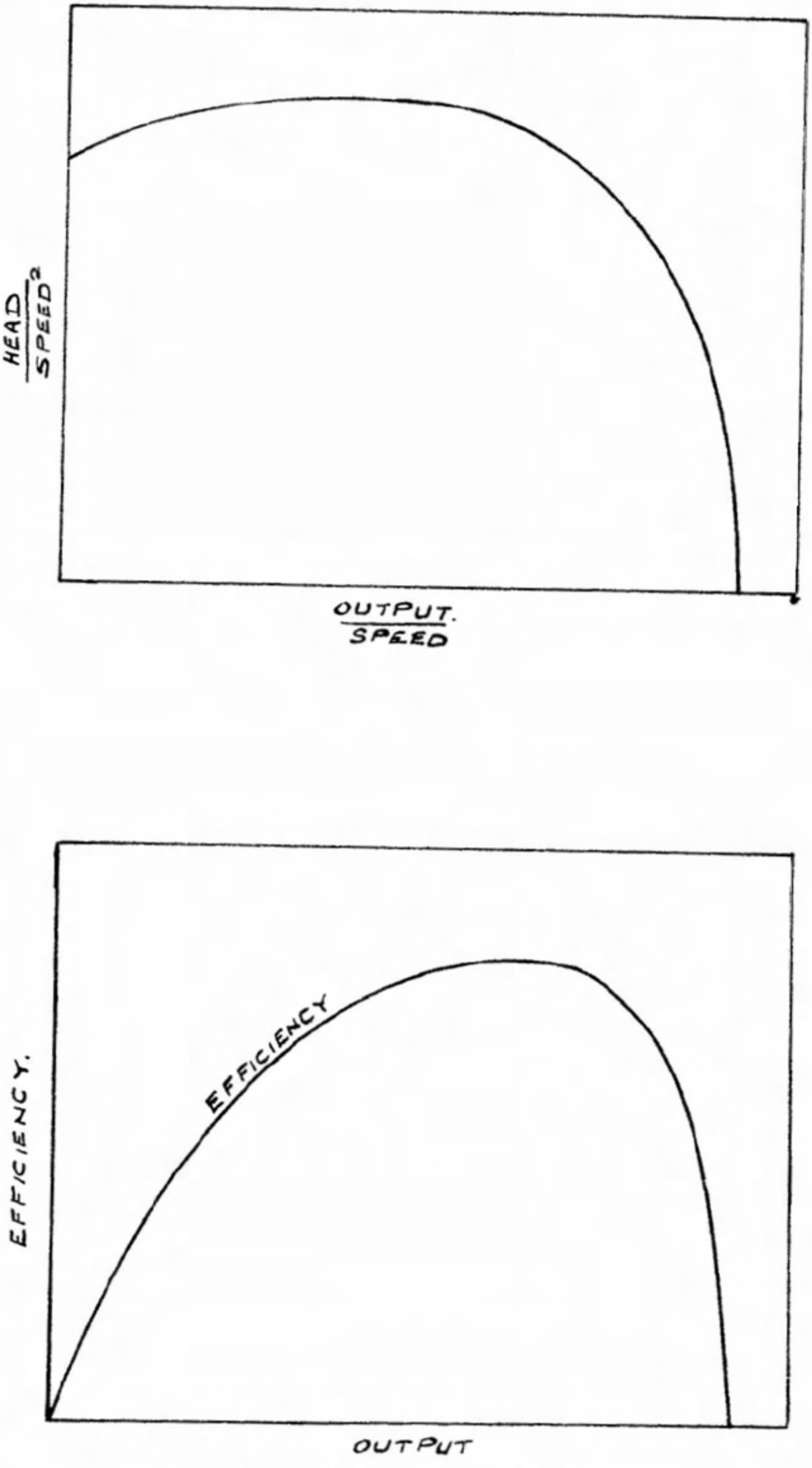
If the impeller sucks air instead of water, it acts as a fan and can only produce a very small suction head at its eye and for satisfactory operation it is therefore necessary that the impeller should be "drowned."

For this reason, centrifugal pumps for dealing with aerated fluids or for suction lifts must be made self-priming by means of a suitably designed exhauster. This takes the form of a reciprocating air pump driven off the pump spindle and which creates a vacuum in the suction. The addition of an exhauster in no way affects the characteristics of the pump but obviously entails greater weight and added complication.

The governing of turbine-driven centrifugal pumps may be effected in two ways: (*a*) to run at constant speed and (*b*) to discharge at constant pressure. Both methods are very compact and reliable, but the method to be employed for any particular pump is determined by the required operating conditions.

To assist the transformation of velocity head into pressure head, stator guide blades are often fitted to pumps which always work with a certain designed output and head, but in service pumps where the working conditions are variable, these are not fitted and the transformation takes place in the volute casing.

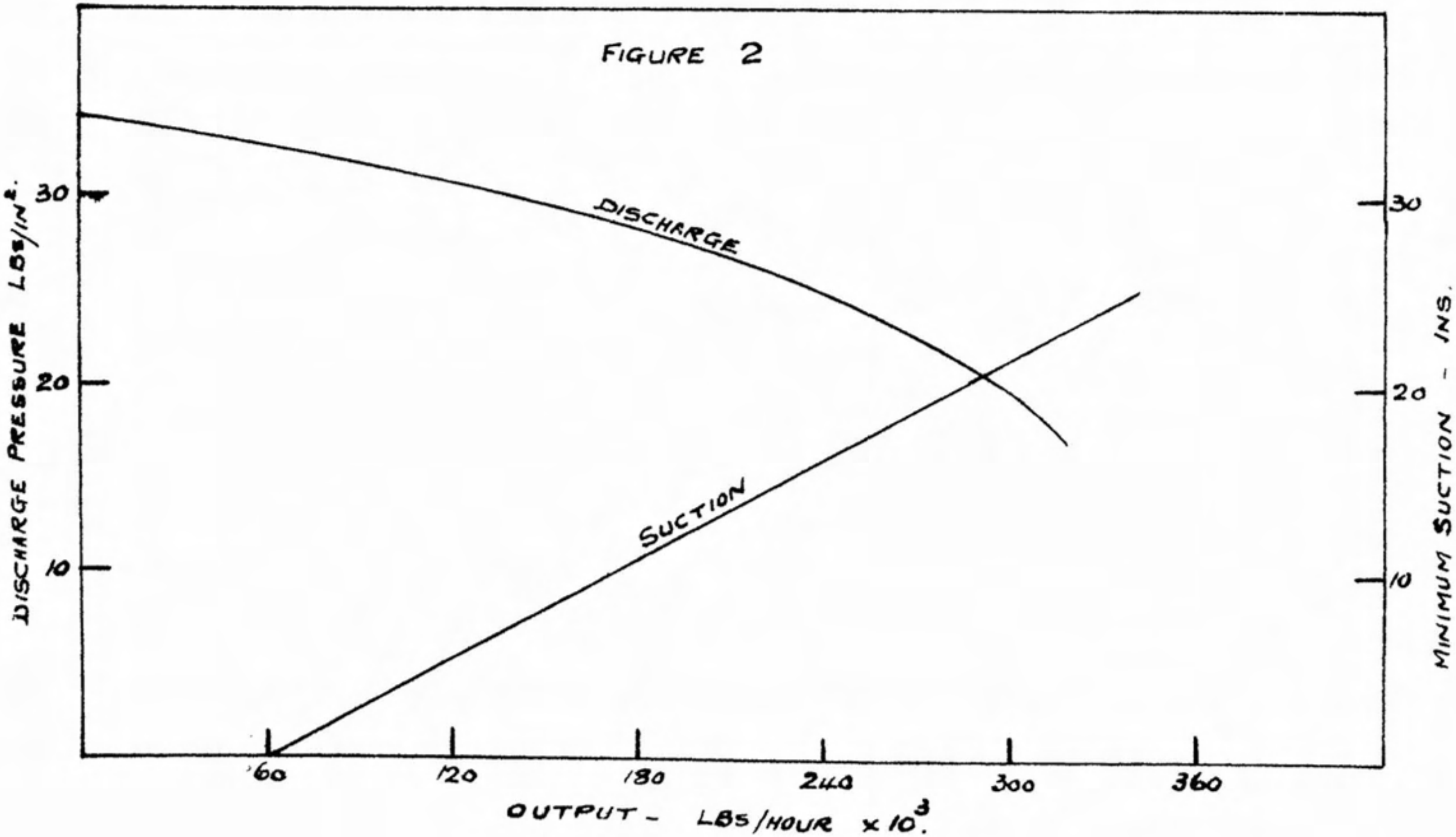
The maximum efficiency of well-designed pumps without stator guide blades is about 80 per cent. and is somewhat lower than that of a reciprocating pump working under its best conditions.



CHARACTERISTIC CURVES.

FIGURE. 1

FIGURE 2


DISCHARGE
SUCTION
DISCHARGE PRESSURE LBS/IN².
MINIMUM SUCTION - INS.
OUTPUT - LBS/HOUR x 10³.
30
20
10
60
120
180
240
300
360

Rotary Displacement Pumps.—This type of pump has characteristics very similar to that of a normal reciprocating pump, but the leakage is generally greater. The efficiency of the pump is reduced: (1) by friction which varies with the pumping speed and viscosity of the fluid pumped; and (2) by leakage which varies with the pumping pressure and inversely with the viscosity.

They are most suited for pumping oils which lubricate their internal working parts and are chiefly used for heavy oils whose viscosity is too great for centrifugal pumps to deal with economically. Compared with centrifugal pumps they are slow running and are in general heavier for a given output.

Owing to their small working clearance, displacement pumps are not suitable for use with dirty or gritty fluids which will cause rapid wear in pumps of this type. They should not be worked as bilge pumps for instance.

Water Extraction Pump.—With modern closed feed installations it is impossible entirely to dissociate the functions of the extraction pump and the feed pump, although the requirements of drawing water from the condenser and of feeding the boilers are widely different.

An extraction pump discharge pressure of about 30 lbs./in.^{2} is usually arranged for whilst the suction head is limited by the space available below the bottom of the condenser, which should be made as great as circumstances permit. The low suction head, and the fact that the water is nearly at its boiling temperature under the conditions of vacuum obtaining, has a very important bearing upon the design of the pump. To avoid cavitation water velocities must be kept as low as possible, which leads to a slow-running pump of large diameter with consequent extravagance in weight.

The pumps are fitted with two impellers, which are either in series or in parallel; in the former type the first impeller is fitted at the bottom and is designed chiefly to avoid cavitation and imparts but a moderate increase of head, the upper impeller does the majority of the actual pumping work.

As they must be capable of delivering any increase of output with the least possible delay, these pumps should run at practically constant speed in order to avoid changes of inertia of the moving parts. Typical constant speed characteristic curves are shown in Fig. 2. The suction head characteristic is of particular interest in this case. Corresponding to every rate of output of the pump there is a perfectly definite minimum limit to the suction head necessary. Now, provided the pump output, which is indirectly controlled by the boiler feed regulator, does not exceed the limit imposed by the suction head available, the discharge pressure will conform to the discharge characteristic curve, but if the output equals, or closely approaches, this limit, fluctuations of discharge pressure will occur which may possibly cause the feed pump to trip or, at any rate, will temporarily curtail the supply of feed water. Thus a sufficiently high water level in the condenser must be maintained to enable the pump to deliver its full output not only when on an even keel, but also with some degree of heel either way. The water level in the condenser is controlled by float-gear fitted in a box in connection with the condenser and operating make-up and overflow valves in connection with the feed tank.

Particular attention must also be given to the pump glands since, owing to the low pressure, the leakage of even small quantities of air have a considerable effect on the pump performance. As with reciprocating air pumps, it is usual to water seal these glands and, on account of the vortex effect due to the peripheral speed of the shaft, a definite pressure is required in the gland for effective sealing, this pressure being provided from the pump discharge.

Main Feed Pumps.—The main requirement of a feed pump is that it should be capable of feeding the boiler at all powers with a reasonable margin to maintain the boiler water level when suddenly easing down from full power, but, at the same time, its capacity must be less than that of the extraction pump.

The feed pump capacity is usually specified to be 50 per cent. in excess of the full output of the boilers.

The pump must be capable of delivering this quantity against the maximum boiler pressure, plus the feed line pressure drop. Referring to Fig. 3, the advantage of pressure control is clearly shown. AC is the feed line characteristic, the difference between this line and the boiler pressure AB being the pressure drop in the feed discharge pipe, valves, feed heaters, etc. At full power the feed pump discharge pressure must be in excess of C by an amount equal to the pressure drop in the feed regulator valve, *i.e.*, CE. If the pump were speed controlled the discharge pressure at low outputs would be excessive, such as F, involving heavy gauge discharge piping, etc., whereas the pressure required is only D. The pump characteristic curve DE has been shown to be falling off slightly. This is necessary for stable governing.

Although the pressure head is very high for a single-stage pump, a satisfactory pump of this type has been produced and is generally used in the Naval Service, as it has the advantage of low weight, compactness, and high speed so that it can be driven directly by a turbine. Multiple-stage centrifugal pumps are often used for boiler feed pumps in power stations, etc.

In order to provide rigidity it is essential that these pumps should be mounted horizontally on a stiff bed-plate.

The method of balancing the rotor and impeller thrusts is of interest. Discharge pressure is admitted to the space A, Fig. 4, at the back of the impeller with a leak off through the annular space B. Any lack of balance causes the impeller to move axially forward or aft so that the leakage past B maintains a pressure behind the impeller to balance the rotor and impeller thrusts.

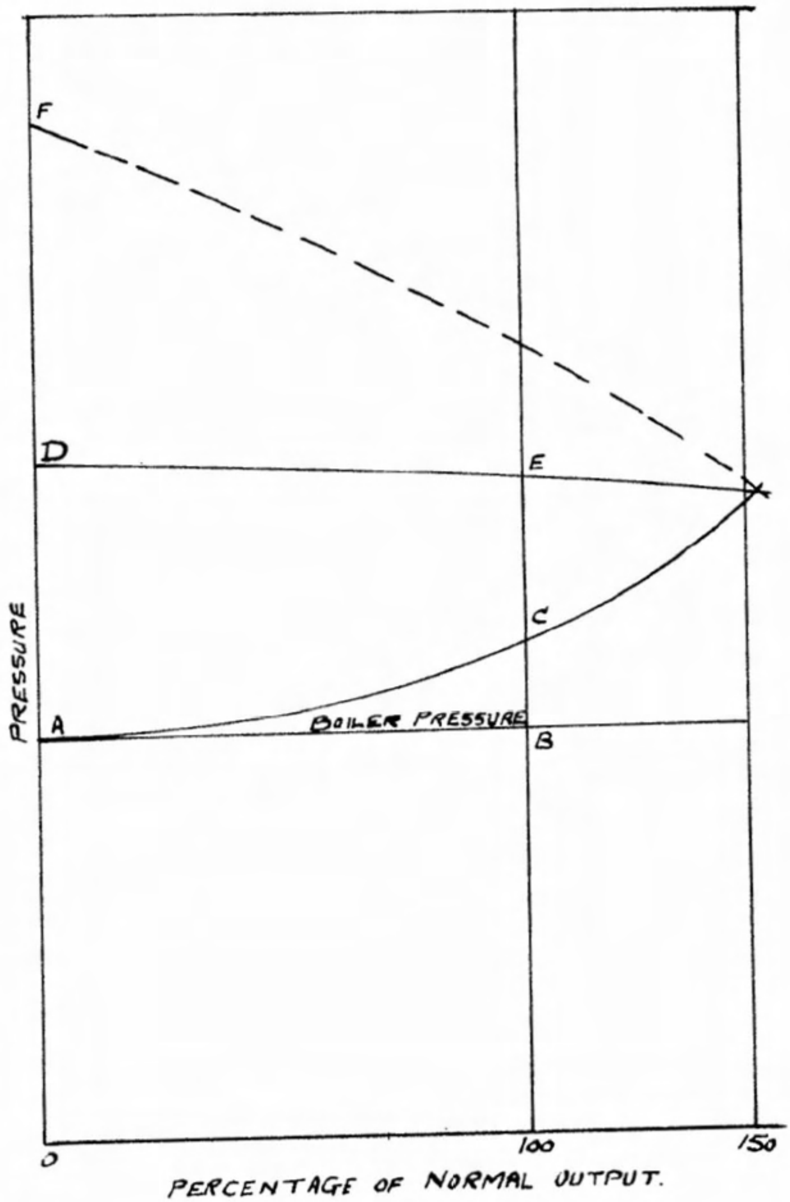

F
D
E
C
A
BOILER PRESSURE
B
PRESSURE
0
100
150
PERCENTAGE OF NORMAL OUTPUT.

FIGURE 3

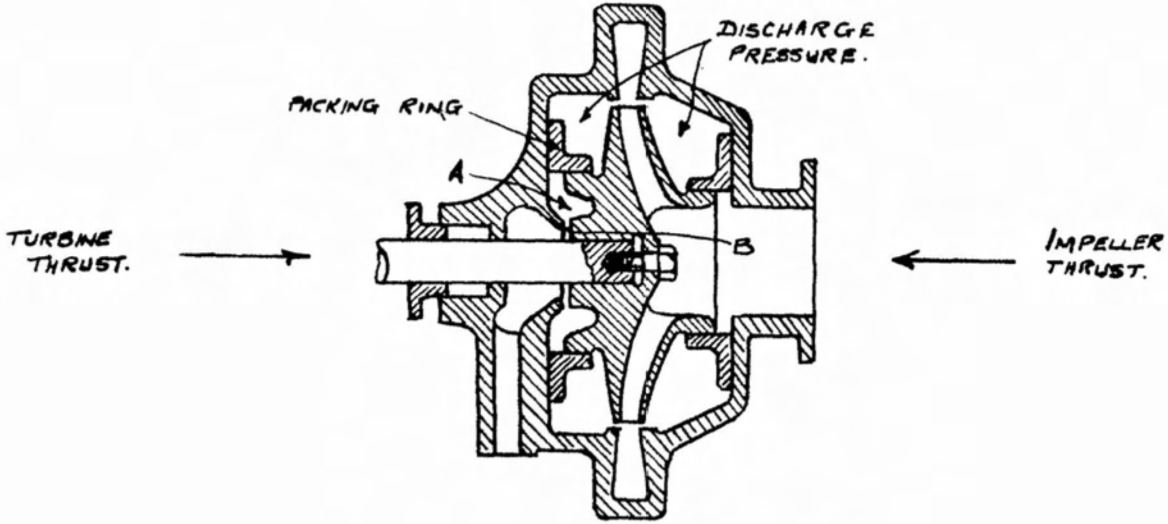

DISCHARGE
PRESSURE.
PACKING RING
A
B
TURBINE
THRUST.
IMPELLER
THRUST.

FIGURE 4

It is interesting to observe that the pump efficiency of a boiler feed pump is unimportant, as the losses go towards heating the feed water.

Main Circulating Pumps.—Centrifugal pumps have been in use for this service for many years now, although it is only recently that turbine drive has been adopted. The requirements of a circulating pump, that is a very large capacity at a low head, render the use of the centrifugal type essential. They are necessarily of large diameter and moderate speed. To obtain maximum efficiency from both turbine and pump, high-speed turbines with reduction gearing are necessary.

It should be noted that in the condenser and its associated pipes we have a system ideally suited to a centrifugal pump, as the resistance which has to be overcome by the pump varies as the square of the velocity of the water through the tubes, so that $\frac{\text{output}}{\text{speed}}$ and $\frac{\text{head}}{(\text{speed})^2}$ will be constant and the pump efficiency will be the same at all outputs. Thus providing the pump is correctly designed to suit the head-output ratio obtaining at full speed, it will remain efficient at all speeds. It is unfortunate, however, that the deposition of scale in the tubes increases the resistance for a given output and upsets the designed relationship. To counteract this effect, it is usual to specify that the pump should deliver its full output against a head somewhat higher than that to be expected with clean tubes under maximum efficiency conditions and as a margin that it should be capable of delivering its full output against a higher head still, but not at its best efficiency.

A different type of pump that has been developed recently is the axial flow pump. In this type the pump casing is eliminated, the impeller being situated in the circulating water inlet pipe with guide vanes above it. The form of the impeller is something between a ship's propeller and the ordinary centrifugal (or radial flow) pump impeller. The particular advantage of this type is the greatly reduced resistance to flow when trailing circulators, apart from the added advantage of less weight and space.

Bilge Pumps.—Centrifugal bilge pumps are always electrically driven, as this is more economical for such intermittent operation and also enables the pumps to be started readily at any time.

A bilge pump works under different conditions from those of the water pumps that have so far been considered. It may be called upon to deal with either clean or dirty water, to discharge at high pressure when used as a fire pump or at low pressure with possibly a high suction lift as a bilge pump.

Such pumps are usually two-stage pumps with change-over arrangements, so that the impellers may either be run in series or parallel, giving a large output at low pressure, or small output at high pressure.

In order to cope with the high suction lift when in use as a bilge pump, these pumps must be self-priming. A part sectional elevation of the type of pump fitted is shown in Fig. 5. The exhauster, or air-pump, by creating a partial vacuum in the suction chamber causes the water to rise up the chamber, whence it flows over a weir into the impeller. At the top of the suction chamber is a float-operated valve in connection with the air pump, the valve being closed when, if no air is present, the chamber is full of water, thus preventing access of the water to the air pump.

In some designs of self-priming pump a rotary exhauster is fitted, but the reciprocating type is preferred, as the former is liable to damage if water gets access to it.

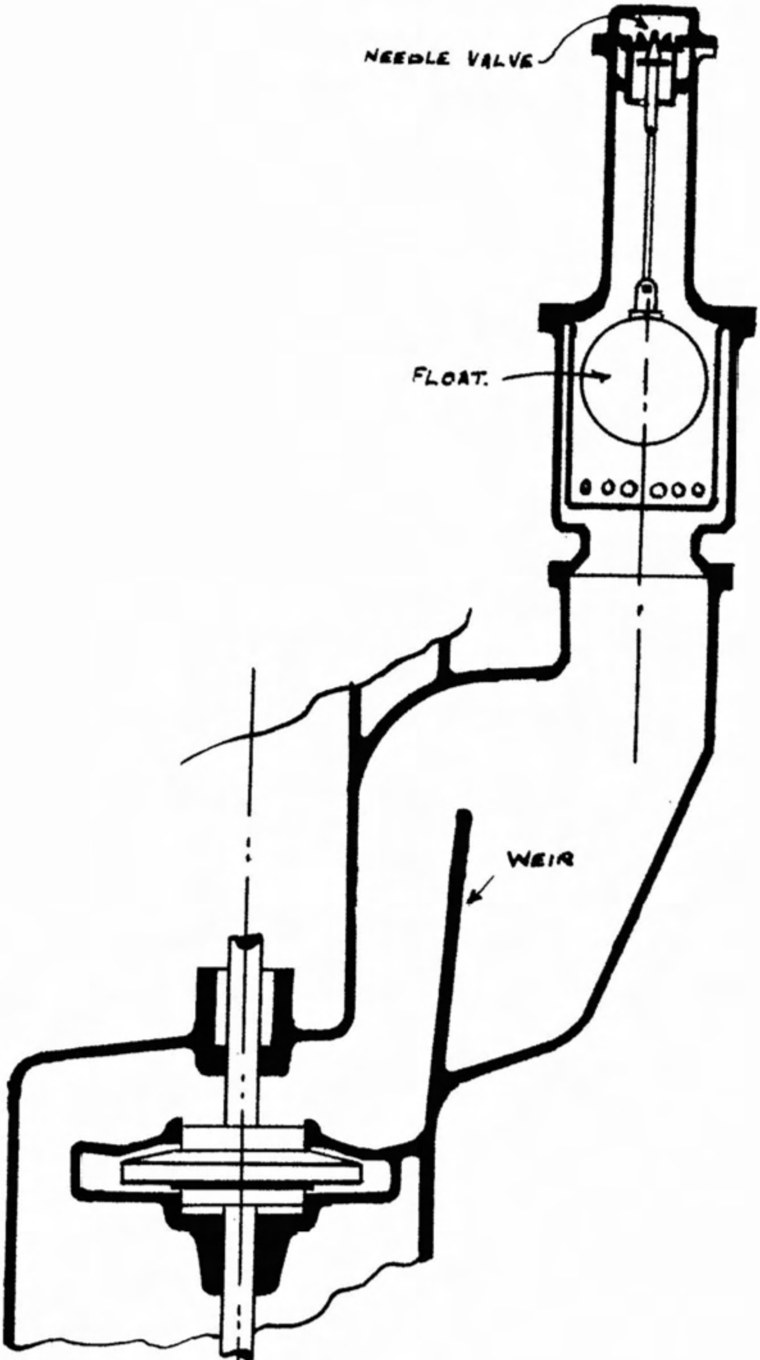
Forced Lubrication Pumps.—Forced lubrication pumps are essentially pumps of moderate capacity and low head, and either rotary displacement pumps or centrifugal pumps are suitable for this service. The latter are, however, in general lighter and cheaper, and are therefore used.

When dealing with a viscous liquid such as oil, reduction of frictional losses is important. These losses depend upon the peripheral speed of the impeller, so for direct-driven turbine pumps running at about 1,800 r.p.m., impellers of small diameter are essential, and it is usual to arrange two impellers in parallel with a common inlet between them, the unit being arranged vertically.

An arrangement with the impeller situated in the oil drain tank with the eye as low as possible in order to ensure an adequate supply of oil to the pump has advantages of simplicity and lightness, but confines the use of the pump to that particular tank, and in cases where this is inconvenient a self-priming pump must be used, situated above the tank, an advantage of this latter arrangement being that the deaeration of the oil increases its lubricating properties and its useful life.

Oil Fuel Pumps.—The centrifugal pump is entirely unsuited to oil fuel installations owing to the high viscosity of the oil and to the need for independently variable output and pressure. The reciprocating pump maintained its position for these services long after others had been replaced by turbine-driven centrifugal pumps, but it has now given way to the rotary displacement pump, which, as before stated, has characteristics very similar to the reciprocating pump, with all the advantages attending the rotary principle.

The most usual form of rotary pump is the gear wheel type, with which everyone is familiar. To maintain a high efficiency, the leakage of oil between the gear wheels and the casing must be reduced to a minimum, and accordingly clearances must be kept fine. The leakage through any clearance will depend upon the pressure drop across that clearance, and in consequence of the high discharge pressure, viz., up to 150 lbs./in.^{2}, two stage pumps have



PART SECTION THROUGH BILGE PUMP, SHOWING PRIMING ARRANGEMENTS.

FIGURE 5.

been adopted, thus halving the pressure drop and thereby reducing the leakage.

The older types of gear wheel pump had teeth of involute form, but with this form of tooth the space available for the fluid decreases as the teeth come into mesh, resulting in high local pressures and high loading on the pinion bearings. The latest pumps have specially formed teeth to overcome this objection and thus reduce the wear and tear.

These pumps must run at comparatively low speeds to minimise wear and to maintain the pump of such size that the normal working clearances are relatively small. Reduction gearing therefore becomes essential and in pumps running at 400 r.p.m. to 500 r.p.m., with the turbine running at 4,000 r.p.m. worm-reduction gearing has been adopted.

The pump discharge pressure can be adjusted by hand to any value between 25 and 150 lbs./in.^{2}, and this pressure is maintained by means of a pressure governor, similar to that fitted to feed pumps, at any output of the pump. A speed control governor is also incorporated to come into action only at the maximum designed speed of the turbine, as well as the usual emergency trip governor.