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Marine Engineering

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MARINE ENGINEERING

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MARINE ENGINEERING

1. INTRODUCTION

1.1 Definition

Marine engineering is the branch of engineering technology that deals with machinery used on board ships.

1.2 Classification

1.2.1 Classification by purpose

The marine engine comprises a main engine, an auxiliary engine and auxiliary machinery.

a) Main engine and auxiliary engine

The main engine is used for the propulsion of the ship, and is sometimes called "propulsion engine". The ship's speed is controlled by means of changes in the engine's revolution, or, in the case of a controllable pitch propeller, by changes in propeller pitch. The auxiliary engine is always kept at a constant revolution for operating the electric generator.

b) Auxiliary machinery

The auxiliary machinery comprises pumps, the water distilling plant, the air conditioning plant, steering gear, deck machinery, etc. The purpose of the auxiliary machinery is to assist the ship's smooth operation.

1.2.2 Kinds of main engines and auxiliary engines

Main and auxiliary engines are divided into three groups, as follows:

(1) External-Combustion Engine

(a) Steam reciprocating engine (compound engine, triple-expansion engine, quadruple-expansion engine and uniflow engine)

(b) Steam turbine (impulse, reaction, compound turbines)

(2) Internal-Combustion Engine

(a) Diesel engine (2- and 4-cycle engines)

(b) Spark ignition engine (2- and 4-cycle engines)

(c) Gas turbine (open, closed, semi-closed types)

(3) Nuclear power

Fig. 1.1 shows some kinds of main engines.

1.2.3 Comparison of steam and diesel engines

(1) Fuel consumption

The fuel consumption of diesel engines is lower than that of steam engines, because in the diesel engine the fuel oil is burnt in the cylinder (combustion chamber) itself, while in steam engines, including steam turbines, the fuel is burnt in another part of the equipment such as the furnace of a water boiler the latter being equipped with feed-water and steam piping systems; hence there is greater thermal loss in steam engines than in diesel engines. Table 1.1 shows fuel consumption and thermal efficiency.

Table 1.1

Kind of engine	Rate of fuel consumption (kg/P.S.[1])	Thermal efficiency (%)
Steam engine (Reciprocating)	0.4 - 0.6	12 - 20
Steam turbine	0.21 - 0.4	20 - 30
Diesel engine	0.16 - 0.22	30 - 45

1/ P.S. denotes Pferdestaerke.

(2) Running distance

Under the same conditions, the diesel engine has an advantage over other engines because of lower fuel consumption.

(3) Equipment

Diesel engines have a further advantage in that equipments such as a water boiler, feed water and steam piping systems are not necessary. Diesel engines simplify the engine operating system; on the other hand, the structure of diesel engines is more complicated.

(4) Number of crew

A ship equipped with a diesel engine can operate with a smaller number of engine crew, owing to the diesel engine's equipment being less complicated than that of a steam engine.

(5) Preparation time before starting engine

For steam engines the boiler is first fired to evaporate the water, then the engine is warmed up. This operation requires many hours. On the other hand, the diesel engine can be started at any desired time without warming up.

(6) Operation at low revolution

The steam engine can be operated within any range of low revolution, while the diesel engine cannot be operated at low revolution because misfiring occurs.

(7) Turning torque

Since the diesel engine changes the turning torque very often in the course of its revolution, it causes engine vibration which, if excessive, results in engine trouble. The operation of the steam engine, on the other hand, can be carried out very smoothly.

(8) Power capacity

In terms of power capacity per unit, the steam turbine has advantages over the diesel engine and steam engine. The steam turbine develops several tens of thousands P.S. per unit, whereas only 36,000 P.S. per unit are obtained from the diesel engine.

(9) Weight and capacity

Fig. 1.2 indicates the weight and P.S. of main engines. As shown in Figs. 1.2 and 1.3, the steam turbine is the lightest and the steam reciprocating engine is the heaviest. As regards diesel engines a non-clutch diesel engine (direct propulsion engine) is heavier than the reduction gear type. A reduction gear is used in a high speed engine; consequently, it is lighter than the non-clutch type. As regards capacity, the order is as follows: the steam turbine has the highest capacity, followed by the diesel engine and the steam reciprocating engine.

(10) Reversing methods

Steam and diesel engines can easily be reversed by means of a change of the revolution or reversing gear, but steam turbines cannot be reversed without the aid of a reversing turbine.

(11) Ease of manufacture and operation

Steam engines are easier to manufacture than steam turbines and diesel engines, and, briefly stated, the same order applies as regards ease in operating these engines.

(12) Marine engines should meet the following requirements:

(a) The engine should possess a high thermal efficiency to reduce operating costs.

(b) The engine should possess high reliability and durability.

(c) For ease of operation, structure and equipments should not be complicated; the engine should not require frequent overhauls, and overhauling should be made simple.

(d) The engine should be such that it can be operated with a small number of engine crew, thus reducing personnel expenses.

(e) The engine should be light and small in size.

(f) The engine should yield high horse-power per unit.

(13) Manufacturing costs and service life

The manufacturing costs of the steam engine are the lowest followed by the steam turbine and the diesel engine; as regards service life, the same order applies.

2. AUXILIARIES

2.1 Pumps

2.1.1 Operating principles and head

2.1.1.1 Operating principles

If mercury is filled into a glass tube closed at one end, and the tube is inverted in a basin containing mercury, the mercury column in the tube will drop to a level 760 mm above the surface of the mercury in the basin, and a vacuum is produced at the top of the tube. This vacuum is known as the "Torricellian vacuum". The mercury column in the tube is balanced by the atmospheric pressure; that is, the mercury column is sucked up by the vacuum at the top of the tube. If fresh water is used instead of mercury, the height of the fresh water column will be 10.33 m (0.7 m x 13.6 (specific gravity of mercury)).

A pump acts on this principle: It creates a local vacuum in a vessel to develop a differential pressure with the atmospheric pressure. It can therefore be used for sucking up water from a low place. The pump exerts a pressure on the water to bring it up to a high place or a place having a higher pressure than atmospheric.

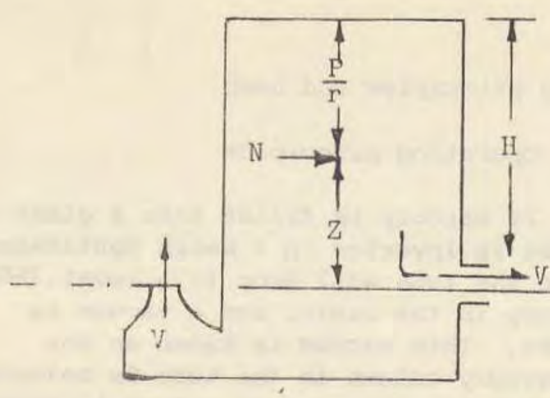
2.1.1.2 Head

With reference to Fig. 2.1, the perpendicular distance h_s (m) from the pump center to the water surface level of the water source below is called "suction head"; the perpendicular distance h_d (m) from the center of the pump to the water surface level in the water tank above is called "delivery head", and the total ($h_s + h_d = h$ (m)) is called "total head" or "actual head".

In Bernoulli's theorem,

$$H = \frac{V^2}{2g} + \frac{P}{r} + Z = \text{Constant}$$

Fig. 2.1.1



where $\frac{V^2}{2g}$ is Velocity head

$\frac{P}{r}$ is Pressure head

Z is Potential head

H is Total head

While the delivery head of a pump can be increased up to whatever value its prime mover can achieve, the suction head is limitative. As already explained, the water can theoretically be sucked up to a height of 10.33 m by the force of a perfect vacuum. For the following reasons, however, more than 6 to 7 m of suction head is impractical:

(a) It is almost impossible to establish a perfect vacuum inside the pump because it is difficult to maintain airtightness in the pump.

(b) Water contains a slight quantity of air which, when evacuated, forms water vapour to meet water temperature, thus reducing the degree of vacuum inside the pump.

(c) Head loss is caused by friction in the suction tube and the valve, etc.

Table 2.1 shows the relationship between water temperature and maximum suction head on the assumption that neither air leakage nor frictional loss occur.

Table 2.2 shows the relationship between the change in the atmospheric pressure owing to change in altitude and the maximum suction head for fresh water with the atmospheric temperature at $10^{\circ}C$.

The maximum theoretical suction head of liquids other than fresh water is given by the following formula:

Suction head,

$$h = \frac{10.33}{r} \text{ (m)}$$

where r is specific gravity of liquid

For example, gasoline, which has a specific gravity of 0.7, has a maximum suction head of 14.76 m

$$(h = \frac{10.33}{0.7})$$

Table 2.1

Water temperature, °C	0	10	20	30	40	50	60	70	80	90	100
Head of vapour corresponding to water temperature, m	0.00	0.12	0.24	0.43	0.75	1.30	2.00	3.20	4.80	7.10	10.33
Max. suction head, m	10.33	10.21	10.09	9.90	9.58	9.03	8.33	7.13	5.53	3.23	0.00

Table 2.2

Height above sea level, m	0	100	200	300	400	500	1000	1500
Atmospheric pressure (Hg), cm	76.0	75.1	74.2	73.3	72.4	71.6	67.4	63.5
Max. suction head, m	10.33	10.20	10.08	9.97	9.83	9.70	9.00	8.60

2.1.2 Classification of pumps

Pumps are roughly classified into rotary and reciprocating types.

2.1.2.1 Classification by structure

Pumps are also classified by structure and application into several varieties, as follows:

(a) Reciprocating pump

(b) Centrifugal pump

(c) Axial flow pump

(d) Rotary pump

(e) Jet pump

(f) Special pump

In fishing boats, mostly diesel engines are installed as main and auxiliary engines, and the pump is generally driven by the main engine in the case of small vessels and by motor-power from a generator driven by an auxiliary engine in the case of larger vessels.

2.1.2.2 Classification by methods of creating vacuum

(1) Reciprocating pump

Pumps creating a vacuum by the reciprocating motion of piston, bucket, plunger, etc., can be classified as follows:

(a) Piston pump (Fig. 2.2)

(b) Bucket pump (Fig. 2.3)

(c) Plunger pump (Fig. 2.4)

These pumps are subclassified by the number of delivery strokes as follows:

(a) Single-acting pump

(b) Double-acting pump

(2) Centrifugal pump

The centrifugal pump gives water a centrifugal force by rotary motion, and converts the velocity energy thus obtained into pressure energy to deliver the water to a high place or to a place whose potential is higher than the water source. The centrifugal pump is classified into the following three types according to whether the water discharged by the impeller is collected and directly sent into the delivery pipe, whether there is provided a centrifugal casing where velocity energy is converted into pressure energy, or whether guide vanes are attached:

(a) Volute pump (Figs. 2.5 and 2.6)

(b) Vortex pump (Fig. 2.7)

(c) Turbine pump (Fig. 2.8)

Pumps are also classified into the following two types according to whether the water is sucked up from one side or both sides of the impeller:

(a) Single-suction pump (Fig. 2.5)

(b) Double-suction pump (Fig. 2.9)

Pumps are also classified by the number of stages of impellers as follows:

(a) Single-stage pump (Fig. 2.50)

(b) Multi-stage pump (Fig. 2.49)

(3) Axial flow pump

This pump is not provided with a centrifugal casing, but has a propeller-shaped impeller to cause the liquid to flow in the axial direction. Fig. 2.51 shows an axial flow pump.

(4) Rotary pump

This is a pump in which the rotary motion of a moving device does the same action as the piston or plunger used to produce a vacuum in the reciprocating pump. It dispenses with valves that complicate the pump mechanism and may sometimes be a cause of trouble. Besides, it can deliver a uniform flow of liquid at a high rotating speed, considering that its weight and volume are small relative to its output. For this reason, the rotary pump is widely used for highly viscous liquids like oils.

The following is a selection of the great variety of rotary pumps:

(a) Sliding vane pump (Fig. 2.10)

(b) Gear pump (Fig. 2.52)

(c) Screw pump (Fig. 2.53)

(d) Viking pump (Fig. 2.11)

(e) Lobe pump (Fig. 2.12)

(f) Nash pump (Fig. 2.13)

(5) Jet pump

This pump develops a vacuum locally around a jet nozzle, using steam or water, to suck up water from a low place and convey it by a high velocity jet stream to the desired place. The jet pump is subdivided into:

(a) Steam jet pump (Fig. 2.14)

(b) Water jet pump (Fig. 2.54)

(6) Special pumps (Fig. 2.15)

In addition, the following special pumps exist:

(a) Friction pump

A rotor having grooved surfaces is run in a casing to pump up water by the frictional force developed by the turbulence of the water over the grooves of the rotor. A typical example is the Wesco pump (Fig. 2.16).

(b) Variable delivery pump

This is a pump which, while running at a constant speed in a specified direction, permits the change of delivery direction and delivery rate by means of a simple control. The variable delivery pump is widely used for hydraulic rudder control equipment. The Hele Shaw pump and William Janney pump are typical of this type (Fig. 2.15).

2.1.3 Kinds of valves

2.1.3.1 Reciprocating pump

A reciprocating pump is provided with a suction valve and delivery valve at the inlet and outlet of the pump cylinder. The valves are required to work smoothly, quickly and reliably, have a sufficient lift and area to minimize resistance for smooth water flow and have well-lapped valves, which will not hit the valve seat and will prevent any leakage. The pump valves are classified as follows according to their design and shape:

(a) Disc valve

The disc valve consists of a disc-like valve made of rubber for low-pressure application, and a spring. The valve is opened by the pressure of the flowing water which overcomes the spring force. An example of a disc valve is shown in Fig. 2.17. Fig. 2.18 shows a kind of disc valve called "kinghorn valve". It is used for low-pressure application as in an air pump. As illustrated, it comprises three sheets of brass sheet of some 1.5 to 3 mm in thickness with different diameters. The two lower sheets have holes at different distances from the center. When the three discs are overlapped, they work to maintain airtightness as if they were a single valve. In the case of a blocking operation, the three discs can work independently of each other depending on the pressures acting on the top and bottom surfaces of the valve, making it easy for air or water to pass through. Thus, positive airtightness can be achieved without the valve hitting the valve seat.

(2) Conical valve

The conical valve has a countersunk valve seat as shown in Fig. 2.19. Compared with the disc valve, this valve changes the direction of the water flow to a lesser degree and as a result, it has lower frictional resistance. In order to guide the valve operation correctly, the valve is usually provided with three to four guide vanes. The valve is usually made of bronze and is heavy; its closing operation is therefore easy. For this reason, in some valves the spring is omitted.

(3) Ball valve

Fig. 2.20 shows a ball valve. Since a ball is used, the valve moves freely within the casing. It is suitable for highly viscous liquids like heavy oil and lubricating oil, but is not used for high-pressure service since lapping is difficult. The valve is made of brass or steel, and is usually small in size.

(4) Ring valve

Fig. 2.21 shows a ring valve. It is composed of a valve seat having one to three concentric grooves to which a valve having an annular passage is opposed. The advantage of this valve is that the lift can be made small.

(b) Flap valve

Fig. 2.22 shows a flap valve. It is used as a foot valve to be installed at the bottom of a suction pipe, as a check valve to be attached to the root of the delivery pipe or as a bucket valve for a manual pump. It comprises a leather or rubber seat, and an iron sheet flap riveted to it, one end being so attached as to allow the valve to move freely like a hinge.

2.1.3.2 Valve diameter and lift

The diameter of the valve seat, d_o(m), can be determined by the following formula if the mean velocity, v_o(m/sec), of water passing through the valve port and the flow rate, Q(m^3/sec), are specified:

$$Q = \frac{\pi}{4} d_o^2 \times v_o \quad \text{..............} \quad (2.1)$$

If the width, b, along which the valve comes in contact with the valve seat, is determined, the valve diameter, d, can also be determined. Assuming that the velocity of water at the valve port, v_o (m/sec), is equal to the velocity of water passing through the valve, v(m/sec), the valve lift, h, can be determined if the area of passage is considered the same throughout.

Usually, $v = v_o \div 0.6$ to 2 m/sec.

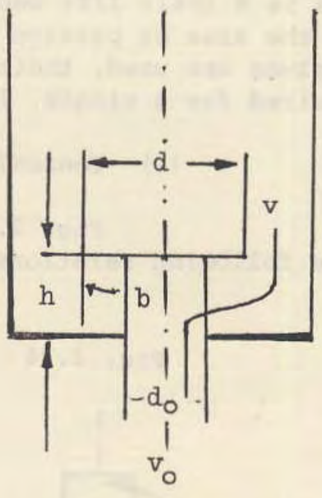
If the valve diameter thus determined is too large, the valve weight will become heavy and thus the lift will become large. This will cause a delay in valve operation and a considerable shock on the valve seat. In order to overcome this problem, a group of small-sized, low-lift valves should be used (Group valve).

(a) Disc valve

With reference to Fig. 2.23, the flow rate at the valve seat is equal to that in the valve, and the following relationship is established:

$$\frac{\pi}{4}\ d_o^2\ v_o \ = \ \pi\ d_o\ hv \qquad .... (2.2)$$

Fig. 2.23



If $v_o = v$, the above equation can be rewritten as follows:

$$h \ \div \ d_o/4 \qquad .... (2.3)$$

Although the lift, h, for the disc valve is theoretically required to be $d_o/4$, it is usually set within the range of $d_o/8$ to $d_o/4$ for practical purposes. On the other hand, the valve contact width, b, is set to $d_o/10$ to $d_o/5$, and the valve diameter, d, to $d_o + 2b$.

(b) Group valve

Given: d: diameter of small valve; D: diameter of large valve; h: lift of small valve; H: lift of large valve; N: number of small valves.

Assuming $\frac{\pi}{4}\ D^2 = N \times \frac{\pi}{4}\ d^2,\ \ H = D/4$ and $h = d/4$,

the ratio of the lift of the group valve to that of the single valve is given by the following formula:

$$\frac{\pi}{4}\ D^2 = N \times \frac{\pi}{4}\ d^2 \qquad D/d = \sqrt{N}$$

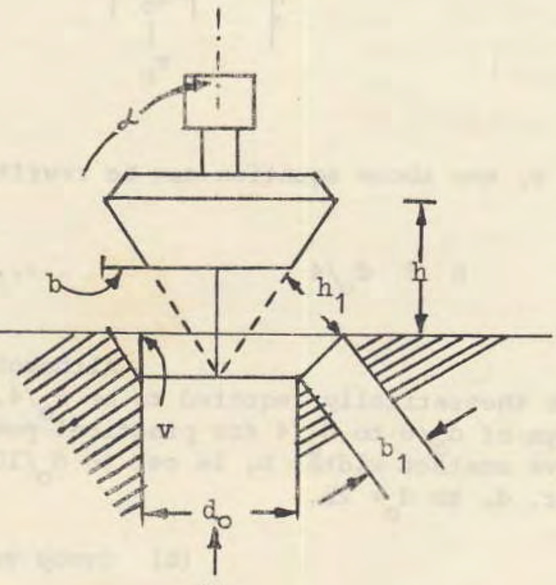
$$h/H = d/4\ /\ D/4 = d/D = 1\ \sqrt{N},\ \ h/H = 1\ \sqrt{N}\ \ldots\ (2.4)$$

Equation 2.4 proves that if the number of group valves is N their lift becomes $1/\sqrt{N}$ times that of a single valve although the area of passage is the same. For example, if 9 units of group valves are used, their lift is reduced to one third of the lift required for a single, large valve.

(c) Conical valve

Fig. 2.24 shows an outline of a conical valve, and the following relationship is obtained:

Fig. 2.24



$$\frac{\pi}{4}\ d_o^2\ v_o = d_o\ vh \sin \alpha$$

Usually, sin α is 45^o. If $v = v_o$, the above relationship may be rewritten as follows:

$$h = d_o/4 \sin 45^o = 0.35d_o. \quad \text{..........} \; (2.5)$$

If the valve seat hole is blocked some 20% by the guide vanes as illustrated in Fig. 2.24, then

$$0.8 \times \frac{\pi}{4} d_o^2 v_o = \pi d_o vh \sin 45^o$$

$$\text{Hence,} \quad h = \frac{0.8d_o}{4 \sin 45^o} \quad \text{..........} \; (2.6)$$

In actuality, h is planned to be $d_o/10$ to $1.5_d/10$. The contact width, b, is also designed to be about $d_o/5$ to $d_o/10$, and the lap width, b_1, is preferably set at 1 mm or less.

2.1.4 Piston, Plunger and Bucket type pumps, and Air Chamber

2.1.4.1 Piston Type

The piston reciprocates in a pump cylinder, and with the help of suction and delivery valves performs suction at the bottom and delivery at the top of the cylinder. There is always a pressure difference between the top and bottom of the piston. Accordingly, the piston should be so designed as not to increase leakage along its piston trunk nor to cause power loss and wear due to friction of contact surfaces. Figs. 2.25, (A) and (B) illustrate two types of piston; (A) does not use packing, but is provided with deep grooves around the piston trunk to increase resistance because of the expansion and contraction of water when clearing through the grooves. Accordingly, the thickness of the piston is larger than in other types; this piston is usually applied for low-pressure service. (B) is a piston with a ramsbottom type piston ring. The piston ring is made of cast iron, brass, bronze, ebonite, graphite or leather, depending on the liquid handled.

2.1.4.2 Plunger Type

Like the piston, the plunger moves in the cylinder to carry out suction and delivery. While the piston type is usually of the double-acting type, the plunger type is generally of the single-acting type and its delivery action is once per two strokes. As illustrated in Fig. 2.26, the plunger is constructed as a solid block for small capacity applications, and it is connected to a mild steel rod with a wedge or by screwing. For medium size or larger capacity applications, a hollow cylinder is used with both ends shrink-fitted with caps, and it is connected to a rod. Because of its hollow structure, its weight is reduced. Materials used for this plunger include cast iron, bronze, brass and special bronze.

2.1.4.3 Bucket Type

The bucket type pump is used mainly as a low-pressure vertical air pump as shown in Fig. 2.27. It is provided with bucket valves P as group valves. Its periphery is sealed with a packing ring for ensuring airtightness.

2.1.4.4 Air Chamber (Fig. 2.4)

In the case of reciprocating pumps, the ratio of the maximum instantaneous discharge rate to the mean discharge rate is large because of its construction characteristics. Since power consumption is increased, troubles may occur. Therefore, the pulsation of the pump discharge rate should be reduced. There are various ways to solve this problem: one is to equalize the overall discharge rate by combining several pumps and another is to provide a sizeable air chamber to reduce pulsation. The air chamber should be installed on the delivery pipe as close as possible to the pump. When the water flow rate is larger than the mean flow rate, part of the water will enter the air chamber to increase the water level in it. On the other hand, when the flow rate is lower than the mean value, the water in the air chamber will be forced out by the expansion of air to make up the deficiency. In this way, the flow rate in the delivery pipe can be kept constant.

The same pulsations in the water flow as in the delivery pipe are also caused in the suction pipe. In order to reduce shocks in the suction pipe and pressure change in the pump cylinder, an air chamber is sometimes provided in the suction line. In this case, the pressure in the air chamber is produced by the vacuum, and the air chamber is therefore called "vacuum chamber".

2.1.5 Capacity of Reciprocating Pump and Control of Delivery Rate

2.1.5.1 Capacity of Reciprocating Pump

The reciprocating pump is widely used for vessels, because its pressure can be changed within a wide range and because its efficiency is less affected by the changes in flow rate since the number of strokes per unit time can be regulated. The delivery rate of a reciprocating pump can be determined according to the following formula:

$$Q = \frac{2ALNn}{60} \quad \text{(double-acting)} \quad \text{or}$$

$$Q = \frac{ALNn}{60} \quad \text{(single-acting)} \quad \text{............} \quad (2.7)$$

where
- Q is actual pumping rate, m^3/sec
- L is stroke, m
- n is number of pump cylinders
- A is cylinder bore, m^2
- N is number of revolutions per minute
- ηv is volumetric efficiency (0.85 - 0.97)

From the above equation, it is evident that control of the delivery rate during operation can be exercised by changing L, N and/or ηv.

2.1.5.2 Control of Delivery Rate

Control of the delivery rate is usually carried out in the following ways: (Fig. 2.28)

(a) A method in which the effective suction rate is changed by controlling the opening of the suction stop valve;

(b) A method in which the delivery rate is changed by regulating the piston stroke (e.g. Hele Shaw pump);

(c) A method in which delivery water is partially returned through a bypass valve;

(d) A method in which the revolution of the prime mover is changed.

2.1.6 Pump Theory

A pump is a device which adds to the energy of a liquid or gas causing an increase in its pressure and a movement of the liquid. The liquid is made to flow into the impeller, when the impeller is rotated at a constant speed ω, that is, the liquid at point A (impeller-inlet side) is transferred to point B (impeller-discharge side), owing to its having been pushed by the impeller AB (curve AB indicates the impeller).

The relative process of the liquid transferred is shown by curve AB, and the absolute process is shown by curve AC (Fig. 2.29).

2.1.6.1 Moment (M)

The moment (M) given from the impeller to the liquid is determined as follows:

$$M = \frac{R\,Q}{g} (C_2\,\gamma_2 \cos\alpha_2 - C_1, \gamma_1 \cos\alpha_1) \quad \ldots\ldots\ldots\ldots (2.8)$$

where Q is delivery volume of liquid per unit time

R is specific weight

2.1.6.2 Energy (E)

The energy (E) given from the impeller to the liquid is given by:

$$E = M\omega = \frac{R\,Q}{g} (U_2, C_2, \cos\alpha_2 - U_1, C_1, \cos\alpha_1) \ldots\ldots (2.9)$$

$$(\gamma_2\omega = U_2,\ \gamma_1 \cdot \omega = U_1)$$

2.1.6.3 The work of the Impeller (W) and Theoretical Heak (Hth)

The work done by the impeller in lifting the liquid is determined as follows:

$$W = E = M\omega = RQHth \quad \ldots\ldots\ldots\ldots (2.10)$$

$$Hth = \frac{1}{g} (U_2, C_2 \cos \alpha_2 - U_1, C_1 \cos \alpha_1) \ldots\ldots. (2.11)$$

The low of cosines is used in the above formula as follows:

$$w_2^2 = C_2^2 + U_2^2 - 2 C_2, U_2 \cos \quad 2$$

$$w_2^2 = C_1^2 + U_1^2 - 2 C_1, \cos \quad 1$$

$$\text{Therefore,} \quad Hth = \frac{U_2^2 - U_1^2}{2g} + \frac{w_1^2 - w_2^2}{2g} + \frac{C_2^2 - C_1^2}{2g} \quad \ldots\ldots\ldots (2.12)$$

where the first term is pressure increased by centrifugal force; the second term is pressure absorbed due to reduced velocity; and the third term is increased velocity head.

2.1.6.4 Maximum head (Hm)

When the entrance angle of impeller α_1 is equal to 90°;

$$Hm = \frac{R\,Q}{g} (U_2 C_2 \cos \alpha_2) \quad \ldots\ldots\ldots. (2.13)$$

2.1.7 Characteristics of pumps and efficiency

In the centrifugal and axial pumps, generally, the revolutions of the pumps are kept constant. Figs. 2.30 and 2.31 show the curves of the head, power and efficiency.

Fig. 2.32 shows the characteristics curves of a gear pump.

2.1.7.1 Centrifugal pump

Figs. 2.33 and 2.34 show the characteristics curves of a centrifugal pump. In Fig. 2.33, Hth is ideal total head, Hth is theoretical total head, H is Hth (minus) all losses, that is, actual total head.

a) Kind of losses and total head

The losses are divided into fluid and mechanical losses.

1) Fluid loss is subclassified as follows:

(a) loss in the suction side passage

(b) loss in the impeller blades

(c) loss in the guide blades

(d) leakage loss

(e) loss in the vortex or volute chambers, etc.

2) Mechanical loss is subclassified as follows:

(a) loss in the stuffing box (packing box)

(b) loss at the bearings

(c) other friction losses

These losses reduce actual total head and efficiency, but increase the horse power required.

b) Shaft Horse Power (S.H.P.)

As shown in Fig. 2.34 shaft horse power (S.H.P.) is water horse power plus the above mentioned losses.

2.1.7.2 Water Horse Power (W.H.P.) and Efficiency

1) Pump efficiency ($\eta\rho$)

Efficiency is the ratio of useful work performed to power input. Therefore, pump efficiency is determined as follows:

$$W.H.P. = \frac{R\ Q\ H}{75 \times 60}\ P.S.$$

where, W.H.P is water horse power in which the pump has done work (P.S.); R is specific weight, kg/m^3; H is total head, m; Q is delivery quantity, m^3/min. Assuming that the supplied horse power to the pump is S.H.P.,

$$\eta\rho = \frac{W.H.P}{S.H.P} = \frac{R\ Q\ H}{75 \times 60/S.H.P.}$$

2) Volumetric efficiency ($\eta\nu$)

When the theoretical delivery quantity is Qth, and the actual delivery quantity is Q,

$$\eta\nu = \frac{Q}{Qth} = \frac{Qth-ql}{Qth} = 1 - \frac{ql}{Qth}$$

where ql is a leakage loss.

3) Manometric efficiency (η man)

Manometric efficiency is the ratio of the actual total head H to Hth, that is, $\eta\ man = \frac{H}{Hth}$, where Hth is theoretical total head.

4) Hydraulic efficiency (ηh)

In the theoretical work of the pump, the pump can do the work of Hth x Qth. That horse power is called pump horse power (P.H.P.). The ηh is determined as follows:

$$P.H.P. = \frac{RQth\ Hth}{7t \times 60}\ \text{, and}\ \eta h = \frac{W.H.P}{P.H.P} = \eta\nu \times \eta\ man$$

Namely, W.H.P. is actual work, and P.H.P. is theoretical work.

5) Mechanical efficiency (ηm)

Mechanical efficiency is the ratio of the S.H.P. to the P.H.P. and is given by:

$$\eta m = \frac{P.H.P.}{S.H.P.} = \frac{S.H.P. - Pl}{S.H.P.} = 1 - \frac{Pl}{S.H.P.}$$

where Pl is mechanical loss in the pump.

2.1.7.3 Outline of centrifugal pump

Centrifugal pumps comprise a variety of types. Fig. 2.35 illustrates the pumping equipment used by a centrifugal pump.

With the pump casing filled with water, the impeller (1) is driven by a motor or a diesel engine or other suitable prime mover. The water within the impeller is forced out by the centrifugal force and sent to the desired place via the vortex chamber (2), volute chamber (3) and delivery pipe (8).

After displacement of water from the impeller, a vacuum is developed in the center of the impeller to induce water through the filter (15), check valve (14) and suction pipe (13), thus continuing water delivery.

The vortex chamber (2) is so designed as to increase the areas of the volute sections in proportion to their angular advance, and is capable of converting the velocity head of the water into the pressure head.

The volute casing collects the water driven out of the vortex chamber or impeller and guides it to the delivery pipe. It also, partially converts the velocity head of the water into the pressure head.

Since the centrifugal pump cannot operate unless it is filled with water, it is important to prime it fully prior to start-up. For this purpose, the centrifugal pump is provided with a priming valve (10) and an air cock (11) at the top of the volute casing and a check valve, called foot valve, at the bottom of the suction pipe to check the draining of water when the pump is stopped.

2.1.7.4 Component parts and their construction

As illustrated in Figs. 2.36 (A) (B) (C) and (D), the impeller is composed of a boss set on a shaft, and blades.

(A) shows an open type impeller, which is used only for special applications.

(B) is used for the single-suction type centrifugal pump; suitable measures must be taken to offset the thrust pressure, which is created across the impeller by high pressure water on the righthand side and low pressure water on the lefthand side (suction side) and which tends to drive the impeller leftwards. There is provided a mouth ring (2) for the purpose of making an opening (3), so that the rotation of the impeller is not hindered, and that the pressure water forced out of the impeller does not turn back towards the suction side.

(C) and (D) show the double-suction type, which is designed so as to apply the speed of the prime mover used. The pressure of delivery water and delivery rate is determined by its shape; namely, (C) is designed to have a large diameter because of slow impeller speed, while (D) is used for a pump delivering a large quantity of water at a low head.

In the double-suction type, in which both ends are joined to the suction port, both ends should be provided with a mouth ring. Most impellers are made of bronze, except in special cases. Fig. 2.37 shows the shapes of impellers of a centrifugal pump.

(b) Vortex casing and volute casing

As shown in Fig. 2.5, the volute pump collects in the vortex casing the water discharged from the impeller and then delivers it to the delivery pipe. It is used for low pressure water conveyance.

Fig. 2.38 illustrates volute and vortex casings arranged around the impeller which has the effect of increasing the delivery pressure.

In Fig. 2.8 is shown a turbine pump using guide blades around the impeller for the purpose of attaining a higher delivery pressure. The vortex casing, volute casing and guide blades are usually made of bronze.

(c) Stuffing box (packing box)

As shown in Figs. 2.39 and 2.40, the part of the pump casing where the shaft passes out through the casing is provided with packing to prevent water leakage or penetration of air.

Fig. 2.39 (A) shows the most typical type. Fig. 2.39 (B) is specially designed to prevent the penetration of air into the pump, and is equipped with a lantern ring required for inducing water over the entire periphery of the shaft. A packing is provided on each side of the water-filled lantern ring to prevent air penetration. Moreover, a mechanical seal is used to perfect the prevention of leakage. The polished or lapped surfaces, which are of dissimilar materials, are held in continual contact by a spring, forming a fluid-tight seal between the rotating and stationary members with very small frictional losses. (see Fig. 2.41)

(d) Bearings

Bearings can be classified into fluid film bearings and bearings with roller ball contact. Fluid film bearings can also be divided into plane and thrust bearings. Plane bearings, according to their function, may be journal bearings cylindrical in shape, carrying the rotating shaft. Thrust bearings, the function of which is to prevent length-wise motion, usually do not rotate with the rotating shaft. In most pumps rolling-contact bearings rather than plane bearing are used.

Rolling- or ball-contact bearings. Rolling- contact bearings are designed to support and accommodate rotating shafts or rotating parts in a machine, to transfer loads between the rotating and stationary member, and to permit free rotation with a minimum of friction. They are composed of rotating elements interposed between an outer and inner ring. Separaters, sometimes called carges or retainers, are used to space the rotating elements (Fig. 2.42).

Bearings for centrifugal pumps. All types of bearings are used in centrifugal pumps. Even the same basic design of pump often provides for two or more different bearings, required by varying service conditions. Two external bearings are used for the double-suction single stage general-service pump, one on either side of the casing. In horizontal pumps with bearings at each end, the inboard bearing is the one between the casing and the coupling, and the outboard bearing is located at the opposite end. Pumps with overhung impellers have both bearings on the same side of the casing. The bearing nearest the impeller is the inboard, and the one farthest away the outboard bearing.

Ball bearings are the most common anti-friction bearings used on centrifugal pumps. Roller bearings are used less often, although a special roller bearing is used frequently for large-size shafts. Ball bearings used in centrifugal pumps are usually grease-lubricated, alghough some services use oil lubrication. Sleeve bearings are used for large heavy-duty pumps with shaft diameters of such proportions that the necessary antifriction bearings are not commonly available. Another application is for high pressure multistage pumps operating at high speed. Still another application is in vertical submerged pumps, such as vertical turbine pumps, in which the bearings are subject to contact with water. Most sleeve bearings are oil-lubricated. Thrust bearings used in combination with sleeve bearings are generally Kingbury or Kingbury-type bearings.

Fig. 2.42 Shows roller ball bearings.

Fig. 2.43 Shows a plane bearing.

(e) Priming device

The centrifugal pump will fail to suck up water if its system is not filled with water. Prior to starting, it is necessary to fill up the pump casing with water by making use of a priming device. The priming methods are roughly classified into the following three:

(1) A method in which the impeller is always set below the water level of the source;

(2) A method using a foot valve and a priming valve; and

(3) A method using a vacuum pump or a jet pump for priming.

Method (3) is subdivided into two: one in which each pump is provided with a vacuum pump of its own; and the other in which a vacuum pump with a vacuum tank is provided common to a number of pumps requiring priming; it is automatically driven whenever the vacuum in the tank is lowered in order to maintain it in a specified range for the purpose of making ready the start-up of the desired pump. The Nash pump or similar pumps are usually employed as a vacuum pump.

2.1.7.5 Prevention of shaft thrust

As referred to in the preciding paragraph, the impeller of the single-suction type centrifugal pump or multistage turbine pump receives a shaft thrust force acting towards the suction side. Since the impeller comes in contact with the casing, the latter will be abraded and eventually damaged, leading to the break-down of the pump. Also, the dislocation due to the thrust force will result in staggering the position of the impeller outlet and guide blades, thus reducing the water flow rate or lowering the pump's efficiency. These damaging effects should be dealt with accordingly.

In practice the following methods are applied:

(a) Use of double-suction type impeller

(b) Use of balancing hole or balancing pipe (Fig. 2.44)

(c) Use of thrust bearing

(d) Installation of a balancing disc (Fig. 2.45)

(e) Balancing as a whole of thrust forces by properly arranging the impellers if the multistage type is used (Fig. 2.46).

In a large-sized pump, the casing consists of two halves, and those bearings that come in contact with sea water are covered with a sleeve in which pieces of lignum vitae are set to allow the sea water to pass through little by little.

A sealing water pipe is led from the volute casing to the gland to send pressure water to prevent the intrusion of air as well as to lubricate the lignum vitae.

Fig. 2.47 shows a volute pump, which is installed in an engine room as a water circulating pump. This is a vertical type, whereas the horizontal type is shown in Fig. 2.48. The vertical type requires less installation space than the horizontal type, and is widely used for ships.

Fig. 2.49 shows a six-stage turbine pump.

It has already been explained that in a turbine pump guide blades are provided in the volute casing in order to increase the delivery head.

When the delivery pressure required exceeds a certain limit, it is difficult to reach this high pressure if the impeller is of the single-stage type. In such a case, a number of identical impellers should be arranged in series to increase the delivery head in each impeller stage in order to attain the required pressure at the outlet of the ultimate stage (use of multistage type). Fig. 2.50 shows a single-stage centrifugal pump.

2.1.7.6 Capacity of centrifugal pump and control of delivery rate

The usual practice is to express the capacity of the centrifugal pump by the outside diameter (in millimeters) of its delivery pipe.

This is because the flow velocity, v_d, within the pipe is usually selected within the range of 1.5 to 3 m/sec., and the delivery quantity, Q (m^3/min), can simply be determined by the following equation if the outside diameter of the delivery pipe of a centrifugal pump is known.

Namely, the delivery quantity can be given by the following formula if the outside diameter of the delivery pipe is taken as d (mm):

$$Q = \frac{\pi}{4} \left(\frac{d}{1,000}\right)^2 \times v_d \times 60 \ (m^3/min) \qquad \text{..........(2.14)}$$

The regulation of the delivery quantity of a centrifugal pump can be accomplished by regulating the pump speed or by controlling the opening of the delivery stop valve; the latter is preferred because it is the ideal method.

Start-up is carried out by fully opening the suction stop valve while totally closing the delivery stop valve. When it is assured that the pump operation is properly regulated at a specified speed, the delivery stop valve is opened gradually to attain a required level of water supply.

2.1.7.7 Specific speed and similar pump

(a) Similar pump

A similar pump is a pump which is of the same design as another pump and whose coefficiency of velocity shows a similar characteristics curve and whose efficiency curve is equal to another pump.

(b) Specific speed

In the similar pump, as the coefficiency of velocity is the same, therefore, it is

$$Q \propto D^2 \propto D^2 \sqrt{H} , \qquad \text{............ (2.15)}$$

where D is the impeller diameter
H is head
Q is delivery quantity.

$$ND \propto \mu \propto \sqrt{H} , \qquad \text{............ (2.16)}$$

where N is r.p.m.
μ is circular velocity.

As a result of the above two formulars,

$$Q \propto \frac{H^{\frac{3}{2}}}{N^2} \qquad \text{............. (2.17)}$$

That is, the following relation exists between the two similar pumps:

$$\frac{N_1 \sqrt{Q_1}}{H_1^{\frac{3}{4}}} = \frac{N_2 \sqrt{Q_2}}{H_2^{\frac{3}{4}}} \qquad \text{............. (2.18)}$$

Assuming that the delivery quantity is one (m^3/min), the head is one (m), r.p.m. is N_s and that, in the other similar pump, delivery quantity is Q, head is H, r.p.m. is N,

$$N_s = \frac{N \sqrt{Q}}{H^{\frac{3}{4}}}$$ obtained from equation (2.18), ... (2.18)

The N_s is called the specific speed.

Equation (2.19) is for the single suction and one-stage type.

For the multistage type $Nst = \frac{N\sqrt{Q}}{(ZH)^{\frac{3}{4}}}$, and for the double suction one-stage type it becomes where Z is number of stages.

$$Nst = \frac{N\sqrt{2Q}}{H^{\frac{3}{4}}}$$

Fig. 2.30 shows the characteristics curves.

Fig. 2.37 shows various shapes of impellers adapted to the purpose of the pump.

2.1.8 Axial flow pump

2.1.8.1 Outline

The axial flow pump is not provided with a vortex casing, but drives water in the axial direction by means of a propeller-type impeller.

In size it is smaller than the centrifugal pump, its volume being about one half for the same capacity. In addition, its construction is very simple, and the pump can be connected to a comparatively high-speed prime mover.

The efficiency of the axial flow pump is less affected by the change of head. For this reason, the axial pump is widely applied wherever there is a large water supply at a low head.

Fig. 2.51 shows an axial flow pump: since the water forced out rightwards by the propeller type impeller is whirling, it must be rectified by guide blades (5) so that its flow does not become turbulent on the downstream side.

In the center of the guide blades, an inner bearing using lignum vitae or rubber is set to prevent vibration.

The number of impeller blades is 2 to 3 for the high-speed type and 4 to 5 for the low-speed type. The blades are often integrated (solid type) with the boss by casting and, in some cases, they are built up with the boss machined independently.

The built-up type can be designed so that the flow rate and head are alternated by changing the rake angle of the blades by means of a controllable pitch impeller. However, the integrated type is usually preferred.

2.1.8.2 Head

As shown in Fig. 2.31, the head of the axial pump changes more sharply, when the flow rates are increased, than in the case of the centrifugal pump; its head is also smaller than that of the centrifugal pump.

2.1.8.3 Shaft Horse Power (S.H.P)

As shown in Fig. 2.31, the S.H.P decreases slowly followed by an increase in flow rate.

2.1.8.4 Efficiency

The efficiency curve is lower than that of the centrifugal pump, and the range of high efficiency is narrower. The revolution curve rises rightward.

In conclusion, Fig. 2.31 indicates the head, efficiency and S.H.P curves, and shows that the axial pump can be applied in the case of a low head, a large quantity of water and a frequently changing head.

2.1.9 Rotary pump

2.1.9.1 Gear pump

A gear pump is illustrated in Fig. 2.52. It has two identical gears which are meshed together and run while keeping a small clearance with reference to their casing.

When the pump is started, fluid will flow into the teeth on the suction side. This is due to the volumetric change as in the reciprocating pump where fluid runs into the cylinder when the piston is on the suction stroke. As a pair of gears run in the direction shown, fluid will be scooped up into the teeth and conveyed towards the delivery side as it is impounded by two teeth and the casing.

Since the delivery side and suction side are separated at the mesh point, the fluid sent to the delivery side cannot turn back, but is forced towards the delivery pipe.

In the rotary pump, including the gear pump, the delivery pressure can be increased to a considerably high pressure. Considering that the leakage from the delivery side to the suction side increases with delivery pressure, it is not possible to increase the delivery pressure to an unlimited extent. The gear pump is not provided with a valve, can run at high speed, and is able to supply a large quantity of water in spite of its small size.

The reciprocating pump is not suitable for pumping up viscous liquids as its valve will fail to follow the motion of the piston. On the other hand, the centrifugal pump will also fail to deliver a required amount of liquid because of high viscosity. Of all these pumps it is better to use the gear pump for viscous liquid.

Fig. 2.32 shows the characteristics curves of the gear pump. An advantage of the gear pump is elimination of the priming divice. Unlike other types of pump, the gear pump does not cause vibration. However, it develops noises emanating from gear meshing. Also, worn-out gear may cause considerable leakage. In order to prevent leakage, the gear is usually made of bronze or hard material like hard steel.

2.1.9.2 Screw pump

The screw pump is classified into three types: one having a single screw rotor accommodated in a casing, one having two rotors, and one having three rotors. They are called "single-screw pump", "double-screw pump" and "triple-screw pump", respectively.

Fig. 2.53 shows a double-screw pump comprising a main driving shaft (2), which is driven directly by a prime mover or through a reduction gear, and an idle screw (3) engaged with (2) in the casing (1); (2) and (3) run at the same speed as the timing gear (6) and the liquid supplied from the suction port (4) is diverted in two ways: conveyed to the center by the screw's action,and forced out of the delivery port (5).

The threaded part of each rotor is divided at the center into a righthand threaded section and a lefthand threaded section. This is for the purpose of forming a double-suction scheme to offset axial thrust.

The screw pump has no sophisticated valves, is simple in construction and suitable for high pressure application, can easily handle a large capacity for its size, and is high in efficiency. For these reasons, the screw pump is frequently used for handling fuel oil and lubricating oil.

2.1.9.3 Jet pump

Fig. 2.14 shows a steam jet pump. The steam supplied from the port (4) is jetted out at a high velocity from the nozzle (3). The jet stream first evacuates the surrounding air, causing a vacuum in the suction port (5). Thus, water is sucked into the chamber (5). If this water comes in contact with the jet stream, the steam will condense and join the water flow.

At this stage, the kinetic energy of the steam is given to the water flow, which therefore runs at a considerably high speed. When the water steam runs through the nozzle (diffuser) (2), it is decelerated while increasing in pressure. Therefore, the jet steam pump is able to pump water up to the head corresponding to this pressure.

The jet pump has a low efficiency and is uneconomical as a water delivery pump. However, it is small in size and simple in construction since it has no moving parts. For this reason, it is widely used for boiler water feeding and bilge-removal.

The steam jet pump can be of the "ejector" or "injector" type depending on its application.

The ejector is used for the purpose of pumping up, drainage, venting, etc., and is classified, according to the substance to be removed, into feed water ejector, ash ejector, bilge ejector, air ejector, etc.

The injector is a steam jet pump which is used to force substances into a high-pressure vessel such as a boiler. The water jet pump is shown in Fig. 2.54.

2.2 Pipes and fittings

2.2.1 Outline

Pipes, valves, cocks, pipe joints, etc., carry and control the flow of various types of fluids at different, often varying, pressures and temperatures; the fluids may be corrosive, erosive, flammable or benign. Their functions, the requirements arising from ship construction, the nature and arrangement of the machinery, and regulations of certifying authorities, create situations in which systems, basically simple, become complex and bring into use a variety of materials and fittings. The term "fittings" covers valves, cocks, expansion pieces, etc., in short, everything in a system which is not a pipe.

2.2.2 Pipes and materials

2.2.2.1 Steel pipes

(a) Seamless steel pipes

The seamless steel pipe is manufactured by either method of hot or cold drawing with a high quality open furnace steel or electric furnace steel.

The seamless steel pipe is used for various high pressure and temperatures such as steam pipes, compressed air pipes, fuel oil pipes, refrigerator oil, gas pipes, etc.

(b) Gas pipe

A gas pipe, which is seamless, is manufactured by either method of forging or electric resistance welding and the steel is produced from open furnace, or electric furnace.

A gas pipe galvanized to improve its anti-corrosion properties is called a a "white pipe" and a non-galvanized pipe is call a "black pipe". A gas pipe is used mainly for low pressure and low temperature steam pipes, water pipes, oil pipes, etc.

(c) Seamed steel pipe

The seamed steel pipe is made by riveting or welding the seam, and it is usually used when the required diameter is 500 mm or more.

2.2.2.2 Copper pipe

The copper pipe is produced without seam by cold drawing or other methods. It is annealed to make it soft enough to take various shapes. The copper pipe has high reliability, is anticorrosive, and can withstand considerable pressure. It is widely used for sea-water cooling pipes, feed-water pipes and oil pipes of comparatively small size.

2.2.2.3 Brass pipe

The brass pipe is also produced without seam by cold drawing or other suitable methods. It is mainly used for small sizes. Its properties are almost the same as those of the copper pipe except as regards hardness. Brass is harder than copper. Brass pipes are often used for heater pipes, condensers, and oil cooler pipes.

2.2.2.4 Lead pipe

The lead pipe is produced without seam, by means of an extruder, from lead or a lead alloy. Its use for high pressure and high temperature pipes is prohibited; however, the lead pipe is highly resistant to acids. Its use is limited to special cases.

2.2.2.5 Cast iron pipe

The cast iron pipe is produced by means of casting by melting iron into a mould. Its marine use is limited to special cases.

2.2.3 Piping and fittings

2.2.3.1 Pipe joints

(a) Flanges (Fig. 2.2.1)

In order to obtain a certain length or direction of the pipe line, sizeable lengths of pipes are usually joined together with flanges. For steel pipes, steel flanges are attached on both pipe ends by welding or screwing, etc. For copper pipes, bronze and steel flanges are applied by gas welding or soldering.

(b) Screw threaded joints (Figs. 2.2.2 and 2.2.3)

Comparatively small-sized gas pipes and steel pipes are usually connected with screw threaded joints attached to both pipe ends.

2.2.3.2 Valves and cocks (Figs. 2.2.4 to 2.2.15)

Valves and cocks are used to control the inlet or outlet of water, steam, air, etc. These are available in a wide variety of types depending on the purpose. Most widely used types are stop valves, including globe valve, angle valve, and sluice valve which has a disk-like valve, moving up and down to open and close the fluid passage. Check valves are also used in special cases. Fluids flow straight into the cocks when the handle is turned ¼. The on/off control is easily performed, but the reliability is not high. For this reason, cocks are used mainly on small pipes for low pressure service. (Figs. 2.2.11, 2.2.12, 2.2.13, 2.2.14 and 2.2.15) Fig. 2.2.16 shows a diagram of a valve, Fig. 2.2.17 shows a pressure-reducing valve.

2.2.3.3 Expansion joints

At high temperatures, the pipe will expand and deform because of thermal stress, causing fluid leakage around the joints. For this reason, if high temperature fluids like steam or exhaust gas are to pass through the piping, expansion joints to relieve expansion and contraction are provided. The expansion joints are divided into bend pipe joints, sliding joints and corrugated expansion joint bellows, which are made of copper, or other metals. (Figs. 2.2.18 A, B and C)

2.2.3.4 Gaskets

The sheet-like packing used between static joints such as flanges is called "gasket". Non-metallic gaskets are made from soft rubber, hard rubber, synthetic rubber, asbestos composites, clinket made of asbestos and compressed rubber, paper, fiber, cotton, plastic, linen, etc. Metal gaskets are made of copper, lead, soft steel, monel, etc. Metal gaskets are used for high temperature gases and steam, and non-metallic gaskets for comparatively low temperature fluids. Prior to use, graphite is applied to metal, asbestos and clinket gaskets; red lead to lead gaskets and lead wire; and varnish, or oil, to paper gaskets.

2.2.4 Precautions with regard to pipings and fittings

2.2.4.1 Technology of pipings and fittings

The technology of piping is strictly controlled for the safety of a ship's operation. Accordingly, the rules and regulations concerning marine engines include provisions pertaining to piping and fittings. The following is a list of the main requirements:

(a) The pipes, valves and cocks shall be firmly installed and protected properly where they are considered liable to be damaged. Also, they shall be so installed as to permit easy access for inspection and maintenance.

(b) The pipes, valves, and cocks shall be firmly clamped in position while taking into account the expansion and contraction of the pipes.

(c) For those piping systems which may experience a higher pressure than designed, a relief valve or other suitable safety equipment shall be provided.

(d) The installation of piping around switchboards shall be avoided as far as possible. Under no circumstances shall pipe joints be installed near switchboards.

(e) The sea water and fresh water pipes shall be installed separately.

(f) The bilge pipes shall be installed independent of discharge or suction pipes of fresh water or oil.

(g) The lubricating oil pipes shall be installed independent of other pipe lines.

(h) The pipes connected to the fuel injection pump shall be installed independent of the pipes connected to feed-water, bilge, ballast pumps, etc.

(i) The pipes for the fuel oil equipment shall be installed independent of other pipes.

2.2.5 Arrangement of pumps

2.2.5.1 Two pumps system for emergency

If only a single pump is installed for a specific purpose, it is difficult to secure the safety of the ship's operation if there is a breakdown. For this reason, some important pumps are specified to be provided with two stand-by units each.

For other pumps also, the arrangement of piping and valves is so designed that they can be used for multiple purposes within the range specified in the relevant rules and regulations concerning marine engines.

2.2.5.2 Requirement of operator

Operators are required to be fully knowledgeable of pipe arrangements, so that they can take appropriate action and measures in the case of an emergency, apart from their being able to handle positive valve operation for pumping.

2.2.6 Precautions in checking and handling

2.2.6.1 Checking of pipings

(a) Pipes, if improperly supported or if their fittings are corroded, will crack owing to the vibration of the engine or hull, and leakage will occur. It should be borne in mind that proper maintenance of the pipings in the bottom of the vessel must be carried out and that they must be checked periodically,

(b) The work of rearranging, repairing or checking the pipings or accessary equipment should be easy to handle.

(c) The sludge box (filter) attached to the bilge-suction pipe, etc., should always be kept clean, and this should be done promptly.

(d) When leaks are found in the packing used for joints, valve covers, etc., the packing should be further tightened or renewed to avoid irreparable damage.

2.2.6.2 Handling of valves

(a) When opening a valve it is recommended first to open it fully, and then to turn it back slightly. The opening of the valve can be controlled by the installed valve spindle with indicator. For small valves, attention should be paid not to close them too tightly.

(b) In handling the valves in the common valve box for the connecting pipes for a double-bottom tank, etc., utmost attention should be paid not to let other fluids enter. For the actual piping on ships, details are given below under diesel engine.

2.3 Water Desalinization

Average sea water contains 35,000 p.p.m. of disolved solids such as sodium chloride (common salt), sulphate, magnesium, etc., equal to 3.5 per cent by weight of such solids, or 3.5 kg per 100 kg. In water desalinization, distillation or electrolysis methods are used to obtain freshwater from seawater. (Freshwater is 4-10 p.p.m.)

2.3.1 Outline of distilling plant

Usually, ships store freshwater for cooking, drinking, etc. If there is a shortage of freshwater because of a long voyage or heavy consumption for some reason or other, seawater will have to be distilled to make drinking and cooking water and for general services, etc.

Moreover, the feed-water for a high-temperature, high-pressure boiler is required to be distilled water of high purity. Accordingly, the water distilling plant is one of the most important auxiliaries. The water distilling plant is composed of an evaporator, distiller, water supply pump, fresh water pump and brine pump.

2.3.2 Structure and principal component equipments

2.3.2.1 Evaporator

Evaporators are classified into the high-pressure type and the low-pressure type according to whether the generated vapour pressure is higher than the atmospheric pressure or not. The evaporator shown in Fig. 2.3.1 is used for both high and low pressure applications. As illustrated, the heating tube, made of extruded copper pipe, is shaped in coils, and arranged in layers in the lower half of the evaporator. The heating steam is available reduced pressure steam or turbine-extract steam. The seawater is sent to the evaporator by means of the feed-water pump, where it is heated by the steam, and is separated into seawater and freshwater vapours. After this, the freshwater vapour enters the distiller. The vapour is cooled in the distiller and condenser, and the condensate is sent to the distilled water tank by means of the freshwater pump. When the distilled water is used as make-up water for the boiler, the steam generated in the evaporator may be condensed after heat exchange in the feed-water heater or main or auxiliary condenser. As the seawater is vapourized in the evaporator, its salinity becomes higher, and scaling is caused. To prevent this, the concentrated sea water is discharged from the bottom of the evaporator and then pumped overboard by means of a brine pump.

2.3.2.2 Distiller or distilling condenser

The distiller is an equipment to condense the steam generated in the evaporator. Its construction is almost the same as that of the condenser. Namely, a number of cooling tubes are arranged in a cylindrical vessel, and the seawater is made to flow through the cooling tubes for the purpose of cooling and condensing the steam flowing over the cooling tubes.

2.3.3 Type of distilling plants

2.3.3.1 Low-pressure type distilling plant using diesel engine cooling water

The low-pressure type distilling plant using to advantage the waste heat of the diesel engine cooling water has been widely used for fishing boats. In this system, salt-free water is produced by making use of the phenomenon that the vapourization temperature under a vacuum is lower than under atmospheric pressure. As shown in Fig. 2.3.2, seawater, which has been heated to 44 to 45°C as a result of cooling the main engine or generator, is sent into the feed-water inner tube in the bottom of the evaporator by the feed-water pump, and then is injected into the evaporator from the feed-water orifice. Since the pressure inside the evaporator is always maintained at 710 to 740 mmHg under atmospheric pressure by the function of the water ejector, the feed-water is forced into the evaporator when it is running through the orifice. Thus, its temperature is reduced from 38 to 22°C, which corresponds to that pressure. As a result, surplus heat is used as latent heat for vapourizing some of the water. The steam thus generated is passed into the steam separator where the sea water is separated from the steam; therefore, steam alone enters the distiller on top of the evaporator drum, and is cooled and condensed by the cooling seawater. The seawater in the evaporator which has not been evaporated is discharged by the brine pump through the brine pipe. The air separated from the feed-water and the air admitted through the connections are trapped in the top of the vessel. However, the air is purged out of the vessel by the function of the water ejector to maintain a specified degree of vacuum (710-740 mmHg) in the evaporator. In the distilling plant system, there is provided a water-quality alarm which, when the salinity of the distilled water exceeds a specified level (about 10 p.p.m), sounds an alarm or automatically discharges the distilled water into the bilge tank.

The distilling water capacity is about 0.5 to 75 tons per day. Unlike other types, this distilling plant is small in size and light in weight, capable of distilling even during fishing operations, and suffers hardly any scale deposition. Moreover, steam economy, which is the ratio of generated steam to supplied heat, is large and can produce high-quality distilled water at a low cost as against other types. However, as the system is complicated, operation of this type is more complex than that of other types.

2.3.3.2 High-pressure type distilling plant using diesel engine exhaust gas

As shown in Fig. 2.3.3, part of the seawater, which has cooled the main engine, is fed to the evaporator after running through a feed-water filter and automatic feed-water regulator. On the other hand, high temperature exhaust gas discharged from the main engine is supplied to the evaporator where heat exchange is done to generate steam. The steam thus generated runs into the steam separator, and then into the distiller where it is cooled and condensed. The concentration of seawater becomes higher as the evaporation follows, and concentrated seawater is continuously discharged to adjust the concentration of seawater in the evaporator at a proper value, and prevent priming. The air separated from the seawater is extracted by the gas ejector to always keep a low pressure in both the evaporator and distiller, in order to reduce the seawater temperature inside the evaporator. This also leads to the prevention of scale deposition and improvement of heating tube efficiency. However, scale deposition is much greater in this type of plant than in other types, and, as the steam economy is low, few ships use this distiller. If combined with 850 to 1,800 P.S. diesel engine, the distilling capacity is 1.2 to 2.2 tons per day.

2.3.3.4 Ion-exchange type distilling plant

An electrolysis method using a ion-exchange resin membrane can produce freshwater only by electricity, without heat sources.

Its operating principles are shown in Fig. 2.3.4. A number of anion (A) and cation (K) exchange-resin membranes are alternately arranged to form a number of cells (C) and (D), and two manifold pipes supply seawater to each cell. Since dc is sent to both terminals ((+), (-)), of ion-exchange resin membranes, anions (cl^-) in the seawater are attracted towards the anode (+), and the cations (Na^+) towards the cathode (-). Since the anion (A) exchange resin membrane allows the anions (cl^-) alone to pass through, and the cation (K) exchange resin membrane permits the cations (Na^+) alone to pass through, the ions (Na^+, cl^-) in the cells (D) can move into the cells (C), but the ions in the cells (C) cannot move into the cells (D). Thus, they remain in the cells (C), so that the seawater in the cells (C) is concentrated. In an actual system, a circulating tank is provided to reduce salinity by degrees as illustrated in Fig. 2.3.5. Desalinization is produced by a single passing through the cell to 500 p.p.m from an average seawater (35,000 p.p.m)

2.4 Ventilation and air-conditioning

2.4.1 Purpose of ventilation

The air in the hold of a ship is vitiated by the generation of noxious gases from cargo, bilge, etc, which are harmful to the human body. In the engine room, the rise in temperature and humidity constitutes a serious problem. In ships operated by internal combustion engines, there is a danger of toxic exhaust gas and inflammable gas being emitted. Thorough ventilation is, therefore, necessary to preserve provisions and cargo, protect the health of the engine crew, improve working efficiency, etc. The engine room, including the working space for engine crew, should be ventilated more thoroughly than areas occupied by crew members who are constantly engaged in deck work. Particularly for ships navigating in the tropical zone, it is necessary not only to keep the room air clean, but also to control temperature and humidity by air-conditioning equipment.

2.4.2 Ventilating methods

2.4.2.1 Natural ventilation

Natural ventilation, in which the movement of air is induced by natural convection produced by the difference in density due to the difference in temperatures, is used for the supply of air. This system is sometimes applied in the engine room and boiler room.

2.4.2.2 Mechanical ventilation in which air supply is done by blower, and exhaust gas is discharged by natural draught

This is a system in which air is forced, fed or induced by means of a blower; it is usually applied to the accommodations, galley, engine room, hold, etc. This system is used as a means of ventilation depending on the circumstances.

2.4.2.3 Mechanical ventilation in which exhaust is done by blower, and suction by natural draught

A blower is used for exhaust only. This system is used in the ventilation of bathroom, toilet room, galley, machine tool room, battery room, engine room, etc., where air is vitiated by heat, smell or noxious gases.

2.4.2.4 Mechanical ventilation in which both suction and exhaust of air are done by blowers

This is a combination of the methods described in paragraphs 2.4.2.2 and 2.4.2.3. This system is applied to confined spaces such as the engine room, galley, etc., where the air is seriously vitiated by high temperature and odors.

2.4.3 Head type ventilator

2.4.3.1 Classification

This ventilator is classified into several types according to the shape of its head. Of these types, the cowl head and mushroom head types are generally used.

(a) Cowl head type

The cowl head type is best applied to both air supply and exhaust as it is very efficient. If the head is directed towards the wind, it can effectively induce air. This type is mostly used for natural ventilation. Fig. 2.4.1 (A), (B), and (C) show cowl head type ventilators. In bad weather, however, rain drops and sea water splashes are liable to enter into the head since it is not equipped with a shield.

(b) Mushroom head type

The mushroom head type is protected from splashes by a shield; however, the air supply is reduced as compared with the cowl head type owing to the presence of a shield. This type is used for the mechanical ventilation of accommodations and hold. Fig. 2.4.1 (D), and (E) illustrate the mushroom head type.

2.4.4 Type of blowers and ducts

Blowers are classified into propeller type, centrifugal type, and axial-flow type. Blowers are usually driven by electric motors.

2.4.4.1 Propeller blower

The propeller blower is available at a low cost, and can drive a comparatively large volume of air with less resistance compared with other types of blower.

For this reason, it is often used on the wall of a galley to expel hot air. If it is installed at a place where it is affected by wind, its capacity decreases.

2.4.4.2 Centrifugal blower

The centrifugal blower carries air in the direction normal to its rotating shaft. Its impeller is provided with forward curved or backward curved blades. The blower which is equipped with broad forward curved blades is called "sirocco fan" and is widely used. Fig. 2.4.2 shows a sirocco fan.

2.4.4.3 Axial-flow blower

The axial-flow blower carries air parallel to its rotating shaft. If it is not provided with a guide vane, it can easily be converted into an air-feed type or exhaust type. The axial-flow type blower is used for the ventilation of engine room or hold. (Fig. 2.4.3)

2.4.4.4 Ducts

On a ship, the blower for ventilation is usually installed on the open deck, and ducts are extended to those places requiring air supply or ventilation from the blower. Fig. 2.4.4 illustrates a duct.

2.4.5 Humidity-control equipment

2.4.5.1 Need for humidity control

Ventilation is carried out to purge vapour from cargo in the hold. When navigating in waters where changes in ambient temperature and humidity are considerable, dehumidification will be incomplete if natural draught or mechanical ventilation alone is relied upon. For this reason, the humidity inside the hold may need to be controlled.

2.4.5.2 Methods of humidity control

The following two methods of removing water from air are applied:

(a) Method using adsorbent or absorbent

Adsorbents such as silica gel and alumina gel, or absorbents such as lithium chloride, lithium bromide and triethylene glycol are used to remove water from air before charging air into the hold. Of the various chemical agents for desiccation, silica gel is most widely used. The dehumidifier of this type is called "cargo care" or "desiccator".

(b) Method using a refrigerator

In this method, air is cooled to condense and remove water from it. The air thus dried is sent to the hold.

2.4.5.3 Humidity control apparatus

The humidity control system for the hold is composed of a dehumidifier, ventilator and recorder. Fig. 2.4.5 shows a "cargo care" using silica gel as a desiccant. The air in the hold is driven into the silica gel column (A) by means of a blower via the four-way damper (2) at the bottom. The air is rid of water in the column, and then sent into the air cooler through the four-way damper (1). Thus, the air is again forced into the hold. On the other hand, the air from outside is sent into the air heater by means of the blower, and, after being heated, is sent into the silica gel column (B) through the damper (2). Here the silica gel in the column is heated and reactivated. Thus the air fully laden with moisture is purged into the open air through the damper (1). The upper damper (1) and lower damper (2) are automatically on/off controlled to alternately switch columns (A) and (B) to dehumidification and reactivation, in order to continuously feed dry air into the hold.

The ventilator circulates air within the hold by means of a blower, and the recorder detects the conditions of the air inside and outside the hold. The recorder is installed at the bridge to automatically record the humidity and temperature of both the air inside the hold and the outside air.

2.4.6 Purpose of air-conditioning

The purpose of air-conditioning is to control and maintain the temperature, humidity and freshness of the air at the required degree in places where this is necessary.

As stated above air-conditioning means simultaneous control of the humidity, temperature, and freshness of the air. An air-conditioning system is usually composed of a blower, an air cooler, an air heater, a humidifier and an air filter. There are diverse types of air-conditioning systems but the following are the most widely used.

2.4.6.1 Systems of air-conditioning

Figs. 2.4.6 (a), (b), (c), (d) and (e) illustrate the following systems:

(a) A blower is provided for each zone, and fresh air from outside and recycled air are passed through the heating coil, cooling coil and reheating coil to each room. This system is called the zone reheating system. (Fig. 2.4.6 (a))

(b) A reheating coil using hot water (or steam or an electric heater) is installed at the air supply port of each room to reheat the room. (Fig. 2.4.6 (b))

(c) Air from outside, rid of dust, cooled and dehumidified by the main air conditioner, is sent into each room through a nozzle to circulate the room air by induction. (Fig. 2.4.6 (c))

The coil unit carries chilled water for cooling and hot water for heating. This system is called the high-pressure induction unit system and is available in a wide variety of types from the most sophisticated for passenger liners to the utility type for use in oil tankers and cargo ships.

(d) The air-conditioning unit in each room, consisting of an air filter, a heating or cooling coil and a blower, induces air inside the room to mix with fresh air from outside to cool or heat the room air. This system is used for the air-conditioning of a comparatively limited space. It is called the fan coil unit system. (Fig. 2.4.6 (d))

(e) One of two ducts carries chilled air, and the other hot air, and these two airs are suitably mixed in a mixing chamber and then sent to each room. This is called the double duct system. (Fig. 2.4.6 (e))

(f) For local air-conditioning of public rooms, galley, etc., a modification of the packaged air-conditioner widely used on land is installed.

2.4.6.2 Air-conditioning equipment

(a) Heating

Heating in a ship can be done in two ways: direct heating using a steam heater or an electric heater; and indirect heating, in which the heater is installed in the duct of the ventilating system to supply heated air to accommodations.

(b) Thermotank

This is a means for carrying out ventilation, heating and cooling of accommodations. As illustrated in Fig. 2.4.7 the thin pipes in tank (A) carry steam for heating or chilled brine for cooling. If the room air is liable to become dry, steam is charged around the thin pipes to control the humidity. The vitiated air in the room can be purged out by closing the door (D) and valves (E), and opening the valve (V) at the top of the tank with the air valve (C) opened towards the air passage.

2.4.6.3 Air-conditioning for accommodations

In recent years, almost all ships, including passenger liners, cargo liners and oil tankers, have installed an air-conditioning system for the purpose of improving the crew and/or passenger facilities.

2.5 Purifier

2.5.1 Purpose of separation or purification, and clarification

Since fuel oil contains water, and impurities such as sludge, combustion of the oil is affected. As a result, the cylinder liner wears down more quickly, the fuel injector is more liable to become choked up or damaged than if purified fuel oil were used.

Moreover, in lubricating oil used over a certain period of time residua, such as carbon and particles of metal are found. To avoid the ensuing problems as far as possible, the following methods are used:

2.5.1.1 Classification of purification methods used on board ships

(a) For fuel oil

(i) Gravity settling or settling tank method

This settling method uses the specific gravity of the impurities in the oil to separate them from the oil by static equipment.

(ii) Centrifugal settling method

This method follows the same principles as (i) above, but the equipment is dynamic, such as a centrifuge.

(iii) Combined settling methods (gravity and centrifugal settling methods)

This method is a combination of methods (i) and (ii) above.

(b) For lubricating oil

(i) Gravity settling or settling tank method

This is the same as (a-(i)) above

(ii) Mixed water or steam settling method

The lubricating oil is mixed with water or steam, then stirred up.

(iii) Centrifugal settling method

This is the same as (a-(ii)) above.

(iv) Combined settling method (gravity and centrifugal settling methods)

The method is the same as (a-(iii)) above.

As mentioned above, many methods are used for oil purification, but most marine engines are equipped with the centrifugal settling or combined settling devices.

2.5.1.2 Principles of a centrifuge

The centrifuge is an apparatus that uses a high velocity rotating bowl to separate impurities (residua) and water from the oil in order to clean the oil. That is, the centrifuge utilizes centrifugal force to separate the impurities; it follows the same principles as gravity settling. Settling means the separation of a substance having a lighter specific gravity, such as oil, from substances having a heavier specific gravity, such as impurities. When centrifugal force is used it is called centrifugal settling; while the other method is called gravity settling.

Assuming that in a rotating bowl the weight of the substances in the oil is W (gr), effective radius from center of bowl to the substance is r (cm), and angular velocity is ω (rad/sec), then the centrifugal force of substance F will be

$$F = \frac{W}{g} r\omega^2, \quad \omega = \frac{N}{30} \qquad \text{(N is revolution per min.)}$$

$$F = 1{,}118 \; WrN^2 \; 10^{-5}$$

2.5.1.3 Working of centrifuge

The work of a centrifuge is divided into separation or purification, and clarification.

Separation or purification means the process of separating the water from the oil. The equipment is called a "separator" or "purifier".

Clarification is the process by which sludge (residuum) is separated from the oil. The equipment is called a "clarifier".

(a) Clarification

Figs. 2.5.1, (a), (b), (c) and (d) show a diagram of the cylindrical-type bowl and the disc-type bowl, as well as the operating principles of each of these bowls.

As shown in Fig. 2.5.1 (a), a liquid containing impurities is poured into a bowl through inlet (a) to level (h). The liquid being lighter flows out from (h) and the heavier impurities settle at (d); the lighter impurities settle at (d) and (f) somewhat later than the heavier ones.

Figs. 2.5.1 (c) and (d) show cross-sections of the cylindrical-type bowl, and the disc-type bowl respectively.

(b) Purification or separation

Figs. 2.5.2 (a) and (b) show the operating principles of the cylindrical-type bowl and the disc-type bowl separations. Figs. 2.5.1.3 (c) and (d) show cross-sections of the cylindrical-type bowl and the disc-type bowl used for separation.

The difference between these bowls and those shown in Fig. 2.5.1 is that the former are provided with a damper (lx). Water is poured into the bowl up to level (h), then the oil is added. The oil in the bowl is prevented from flowing into the water by damper (lx) as the constant separating level (e) is maintained owing to the balancing pressure at the inlet and outlet. Thus water and oil in a suspension liquid can be separated since the constant separating level (e) never changes. Figs. 2.5.2 (c) and (d) show a cross-section of a cylindrical-type bowl (c) and of a disc-type bowl (d).

2.5.1.4 Classification of centrifuges

(1) By process of separation

As explained above, a cylindrical-bowl centrifuge or a disc-bowl centrifuge are used for this process.

(2) By cleaning methods

(a) Manually cleaned centrifuges

a-1 De Laval centrifuge

a-2 Sharples centrifuge

(b) Self-cleaning centrifuges

b-1 Gravitrol centrifuge (gravity controlling centrifuge)

b-2 Self-jector centrifuge (self-injecting centrifuge)

Manually cleaned centrifuges have been used for several decades, but since higher-powered engines are now employed, the centrifuge is also larger; therefore, the cleaning of centrifuges requires more time and labour. To save labour the self-cleaning centrifuge is in current use.

2.5.2 Piping and structure

2.5.2.1 Piping

Fig. 2.5.3 shows the piping arrangement of a large-sized diesel engine. The engine uses crude oil and is equipped with a purifier and clarifier. In the case of fishing boats, which use light grade heavy oil or gas oil, the engine is provided with a purifier only.

Fig. 2.5.10 shows the piping of a gravitrol centrifuge.

2.5.2.2 Structure

(a) Manually cleaned centrifuge

(1) De Laval centrifuge

Fig. 2.5.4 shows the structure of the De Laval centrifuge. This centrifuge is driven by an electric motor through the worm gear (2); the revolution is 6,000 - 8,000 r.p.m., and the diameter of the bowl is 300 - 500 mm. The centrifuge is used for both purifier and clarifier. Fig. 2.5.5 shows the bowl of the De Laval centrifuge.

(2) Sharples centrifuge

Fig. 2.5.6 shows the Sharples centrifuge and Fig. 2.5.7 shows the bowl of the Sharples centrifuge. The centrifuge is also driven by an electric motor through a belt, driving pulley (6), and rotating bowl (1). The revolution is

15,000 - 19,000 r.p.m., and the diameter of the bowl is 50 - 200 mm smaller than the diameter of the De Laval centrifuge.

(b) Self-cleaning centrifuge

(3) Gravitrol centrifuge

Fig. 2.5.8 shows the bowl of a gravitrol centrifuge.

This centrifuge has the following advantages:

(i) It can be used for a wide range of specific gravities of oils, and when the specific gravity is changed owing to changes in the temperature of the oil, it can be controlled by changing the temperature of the circulating water during operation without the need to stop it. It is called "gravitrol centrifuge" (gravity controlling centrifuge).

(ii) Purification and clarification are carried out more effectively than in other types owing to the effective use of separating plates.

(iii) The boundary line between the water and the oil is constant (Fig. 2.5.8) since the centrifuge is provided with a reject dam. The centrifuge is used for both purification and clarification, and driven by an electric motor through a worm gear.

Fig. 2.5.8 shows the bowl of the centrifuge and the water circulating system. The oil enters through the oil inlet, the sludge settles between the separating plates (5), and is discharged together with the water into the sludge tank; then the water is recirculated into the bowl by the pump (4). Since the quantity of circulating water is greater than the quantity of water mixed with sludge flowing from the nozzle (3), the surplus water flows out from the reject dam (1) to the sludge tank. Fig. 2.5.9 shows the reject dam and its adjusting plate in detail. In Fig. 2.5.10 during normal operation the level of the water in the sludge tank is at the level of the oil-collecting hopper (9). If the oil flows out from the sludge discharger port (2), some surplus oil will go to the controlling space (10) thus the float in the space (10) will be actuated by the oil to shut off the solenoid valve (11) electrically connected between them. Therefore the supply of oil from heater (8) to the centrifuge (1) stops. The pump (5) for purified oil and feed pump (6) are driven by an electric motor for the centrifuge. A centrifugal pump (4) is used to circulate the water. The deliver adjusting valve maintains the pressure and quantity of circulating water constant.

(4) Self-jector centrifuge

This centrifuge is an improvement over the manually cleaned De Laval centrifuge in that it is self-cleaning. Fig. 2.5.11 shows a centrifuge bowl capable of being programmed for periodic and regular dumping of all or part of the bowl contents to remove the sludge build-up. It has, moreover, the following advantages:

(i) Sludge discharge can simply be operated by a valve.

(ii) Since sludge discharge can be done in a shorter time than in other types, it saves time.

(iii) Since the operation of both the purifier and the clarifier are combined, the separation of the impurities and water in the oil is more efficient. Figs. 2.5.11 and 2.5.12 show the bowl and adjusting screw of the purifier and the clarifier, respectively. As shown in Fig. 2.5.11, the sludge discharge takes place through a number of slots in the bowl wall. Between discharges these slots are closed by the sliding bowl bottom, which constitutes an outer, sliding bottom (valve cylinder) (2) in the separating space. The sliding bowl bottom is forced downwards against a seal ring by the pressure of the operating water contained in the space below it, because the upper part of the sliding bowl bottom has a larger pressure surface than its lower part.

Fig. 2.5.13 shows the manual operation of discharge. First the flow of oil is stopped. Then the valve operating handle is moved to "Open". As the lower and upper pressure spaces of the bowl are filled with water through the larger nozzle (7), the sliding bowl (2) moves downwards, so that the sludge discharging ports open and discharge the sludge together with the water (Fig. 2.5.13 (1).

Secondly, the valve operating handle is moved to "Shut off" and is kept for several seconds in that position to discharge the water of the upper pressure space through the water discharge nozzle (Fig. 2.5.13 (2)).

Thirdly, the valve operating handle is moved to "Close" and kept in this position for ten to twenty seconds. The lower pressure space is filled with water through the small nozzle (8). Since the small nozzle is smaller than the water discharging nozzle in discharging capacity, the upper water pressure space is not filled up with water. As a result the sliding bowl is lifted and closes the sludge discharging ports (Fig. 2.5.13 (3)).

Finally, the valve operating handle is moved to "Shut off". Then the water valve opens. After the water has flowed out through the adjusting screw (6), the water valve is kept closed. Finally the oil valve is opened. In the case of automatic operation, sludge discharge as described above is done automatically.

2.6 Steering gears

A ship is provided with a steering gear to navigate a desired course. In most ships, except very small boats, a steering gear driven by a prime mover is used. A variety of different steering gears exist. All types, however, have the following four elements.

2.6.1 Elements

2.6.1.1 Controlling gear

Controlling gear is an equipment to transmit an operation from the steering wheel on the bridge (wheel house) to the rudder gear; it is divided into the mechanical type, the hydraulic type and the electric type. The mechanical type is mainly applied to small vessels, and medium and large ships using either the hydraulic or electric type.

2.6.1.2 Hanting gear or follow-up gear

Hanting gear is an equipment to stop and fix the rudder gear when the rudder has attained the required angle. It is divided into the mechanical type and the electric type.

2.6.1.3 Prime mover (steering engine)

A prime mover is a machine that operates the rudder in the required direction. The prime mover is divided into the steam prime mover and the electric prime mover. Most ships use the electric prime mover.

2.6.1.4 Rudder gear or transmission gear

Rudder gear is an equipment transmitting power from the prime mover to the rudder either through a shafting, gearing or chain, or hydraulically. That is, it moves the rudder against the water current and wave to give the ship a turning moment.

2.6.2 Structure of steering gear

2.6.2.1 Mechanical steering gear

A mechanical steering gear operates the rudder gear by working the extension of the steering wheel on the bridge to the steering shaft of the rudder gear through the medium of a transmission gear comprising a number of gears and universal joints as well as shaftings. In this type, accordingly, the steering speed is limited, and water sealing devices are necessary because the shaftings run through watertight bulkheads.

Fig. 2.6.1 shows a mechanical steering gear.

When a ship is navigating on a desired course, the steering system is halted, and the rudder is at the center position. When the steering wheel (1) is turned in the desired direction, its motion is transmitted to the shaft (2) through the gear and shaft, (4) is a control valve. When its stem is driven by the rotating motion of the shaft (2) and worm gear (3), the rudder is turned in a desired direction. That is, the drum on which the chains are wound is driven in the desired direction by means of the worm (5) and worm gear (6), winding up the chain on one side and winding it out on the other side in order to move the rudder tiller through a quadrant. On the other hand, the follow-up control valve (4) restores the control valve rod. Namely, the control valve starts turning back to the center position to keep the rudder at a desired angle.

Fig. 2.6.2 shows the construction of a steering wheel.

2.6.2.2 Hydraulic type steering gear (telemotor system)

A telemotor on the bridge is connected to a motor telemotor in the rudder gear room by a 10 to 16 mm copper or deoxidized copper tube. When the steering wheel is moved, the piston in the telemotor will move to develop a pressure. The pressure operates the piston in the motor telemotor to move the rudder gear. The piston in the telemotor is moved up and down through a gear mechanism when the steering wheel is moved. In addition, in the cylinder type, a telemotor of a rotary pump type is also used. The fluid used is required to be high in density, low in freezing point, and small in viscosity. Usually a glycerine solution or a special mineral oil is used. Charging of the fluid into the hydraulic system is carried out by means of the make-up tank, and a hand pump. Fig. 2.6.3 shows a hydraulic steering gear.

2.6.2.3 Electric steering gear

The system described here is called the duplex auto-pilot system. The auto-pilot combined with a gyrocompass keep the ship's course; namely, it is capable of piloting without the use of manpower. If, for any reason, the ship is deviated from its fixed course, the deviation angle appears on the gyrocompass and the ship is put back on its correct course. In this system, the power unit directly controls the rudder gear. The rudder gear is divided into the electric type and the hydraulic type. In the hydraulic type, a pump unit is required in addition. A system in which the power unit installed in the rudder gear room (steering engine room), is connected with an electric circuit between the power unit and the steering equipment in the wheel house (bridge), and between the power unit and rudder gear is a double system called "duplex pilot system".

2.6.2.4 Follow-up equipment

(a) Mechanical follow-up equipment

When the steering wheel in the wheel-house is moved to and stopped at a required angle, the follow-up mechanism comprising link mechanisms of rudder tiller, crosshead and ram will move the steering gear back to the central position. In the case of a hydraulic pump, the pump will be stopped so as to fix the rudder at the required angle.

(b) Electric follow-up equipment

In the case of an all-motor-driven steering system, the motor is electrically stopped by using the principles of the Wheatstone bridge, when the rudder angle has attained the required angle.

2.6.2.5 Prime mover (steering engine)

The prime mover should respond quickly and accurately to the motion of the steering wheel in the wheel-house; namely, at full-speed operating, its output should have power enough to move the rudder within 30 seconds from hard port to hard starboard and vice versa.

(a) Motor-driven hydraulic type

A variable delivery pump is driven by a motor to operate the rudder by hydraulic power. The motor always operates the oil pump, and the steering gear changes the direction of flow and quantity of oil to control the rudder. This type is now being applied in some medium-sized ships and most large-sized ships. It is common practice to install two sets of motor and pump, and to use them alternately.

(b) All-motor-driven steering system

The motor torque is directly transmitted to the rudder. The system is subdivided into two systems. One is the single-motor system for small vessels or as a standby for medium and large vessels. The other is the motor-generator system.

2.6.2.6 Transmission gear (rudder gear)

(a) Chain drum type rudder gear

This is the type that has been longest in use. Fig. 2.6.4 shows the chain drum type "transmission" gear. The rudder gear is installed in the astern steering engine room. As a chain is wound up on the chain drum and moved by the steering engine (prime mover), the rudder stock is operated to the required angle through the steering rod, buffer spring, steering chain and quadrant.

(b) Gear type rudder gear

This equipment is applied in all-motor-driven steering systems. An example is shown in Fig. 2.6.5. The worm attached to the motor shaft drives the worm gear, and the pinion on the worm gear shaft moves the quadrant. The quadrant is loosely fitted in the rudder stock, and not fixed. The rudder tiller is keyed to the rudder stock, and one end is connected without a key to the quadrant by two strong buffer springs. Since these springs are preloaded with the compression of the springs before installation, wave shocks are prevented from being communicated to the rudder gear; thus the rudder gear can work safely and effectively.

(c) Electro-hydraulic rudder gear

The electro-hydraulic rudder gear uses a variable hydraulic pump which is driven by an electric motor at a constant speed to generate oil pressure. That is, the hydraulic pump is controlled by means of a telemotor to operate the rudder stock.

The electro-hydraulic transmission gear is divided into "ram type" and "rotary vane type". The ram type, which has long been used, has two or four hydraulic cylinders arranged parallel to one another to operate their ram; they are connected to the crosshead on the rudder stock by pins or rapson slide shoes. Pressed oil from the hydraulic pump is led to the hydraulic cylinders to let the rams reciprocate, and the motion of the rams is converted into the rotating motion of the rudder stock through the crosshead.

The ram type is divided into the following according to the method of connecting the rudder tiller to the rams:

- (a) Rapson slide shoe type (Fig. 2.6.6, Fig. 2.6.7)
- (a-1) One-ram, two-cylinder system (Fig. 2.6.6)
- (a-2) Two-ram, four-cylinder system (Fig. 2.6.7)
- (b) Trunk piston type (Fig. 2.6.8)
- (c) Special type (Fig. 2.6.9)

Most medium and large-size vessels use the rapson slide type because it enables the most effective use of the oil pressure generated by the hydraulic pump.

In the trunk piston, one or two hydraulic cylinders are arranged parallel to one another and one or two pistons are worked alternately. The trunk piston type is simple in construction and light in weight compared with the rapson slide shoe types. Therefore, the trunk piston type is installed in small vessels with a narrow rudder gear room.

The special types are used for vessels that are equipped with a double rudder or a special rudder, or which have a very narrow stern space such as whale factory ships (which are provided with a skidway for the purpose of pulling up whales from the stern side).

The rotary vane type was developed in West Germany, recently. A stator with fixed vanes (hydraulic cylinder) and a rotor with rotating vanes are directly mounted on the rudder stock, and the fan-shaped pressure chamber made up of the stationary vanes and movable vanes (hydraulic motor) is supplied with a rudder shaft. Fig. 2.6.9 shows a rotary vane type transmission gear.

2.6.2.7 Typical rudder gear

(a) Hele Shaw type electro-hydraulic rudder gear

The principal components of this gear include; (a) rudder tiller (b) hydraulic cylinder, (c) ram, (d) Hele Shaw pump, and (e) motor. It is also provided with a manual oil pump and change-over cock, etc., as standby equipment.

In this system, the prime mover is driven by a shunt motor or a compound motor with a shunt characteristic for d.c. application and a cage-type induction motor for a.c. application.

Fig. 2.6.10 shows the arrangement of a Hele Shaw type electro-hydraulic rudder gear.

(i) Structure and function of the Hele Shaw pump

Figs. 2.6.11, 2.6.12, 2.6.13, and 2.6.14 show the structure and parts of a Hele Shaw pump. The tubular shaft (1) (Fig. 2.6.11) is equipped with ports (P) and (Q) (Fig. 2.6.14), and is fixed to the pipe connection side cover (14) (Fig. 2.6.12). The ports (P) have openings directed upwards at the center of the rotating cylinder, and the ports (Q) have openings directed downwards. These ports are connected to holes (A) and (B) (Fig. 2.6.12) at the stationary part, serving as the inlet and outlet of fluid.

The rotating cylinder (3) in Fig. 2.6.11 has a number of cylinders arranged radially (Fig. 2.6.14). These cylinders carrying pistons (7) are operated around the tubular shaft (1) by being driven by the motor. The piston (7) is connected with a piston pin to the slide metal (8), which is set in the groove in the inner wall of the slide ring (9). Thus, a circular motion takes place along the groove. The slide ring (9) is rotatably supported with ball bearings at both ends. The ball bearings are set in the eccentric head (11), and are horizontally driven by the eccentric rod in the horizontal direction along the guide shoe in the pump cover. Namely, the slide ring can be swung right and left from outside the pump by means of the eccentric rod to produce eccentricity. The common bed for the pump and motor serves as an oil tank in which two sets of a make-up oil valve and safety valve are immersed.

(ii) Operation of the Hele Shaw pump

a. Position at which eccentricity is zero

As illustrated in Fig. 2.6.14 (A), when the center of the slide ring is in line with the center of the tubular shaft, the piston cannot work due to there being no eccentric motion. This means that the pump is unable to work.

b. Eccentric leftwards

In Fig. 2.6.14 (B), if the center of the slide ring is shifted leftwards from the center of the tubular shaft by means of the eccentric rod, the right-hand piston will be pushed to the innermost position in the plunger of the pump, while the left-hand piston will be pulled out to the outermost position.

Namely, when the rotating cylinder makes a rotation, the piston reciprocates once. That is, the oil is sucked up from port (Q) on the lower half stroke of rotation, and is delivered from port (P) on the upper half stroke of rotation.

c. Eccentric rightwards

As illustrated in Fig. 2.6.14 (C), if the center of the slide ring is shifted rightwards from the center of the tubular shaft, the pump will suck up oil from port (P) on the upper half stroke, and deliver it from port (Q) on the lower half stroke of rotation.

In this way the flow direction and flow rate of oil can easily be controlled by regulating the center position of the slide ring from outside the pump provided that the pump speed and direction of rotation are fixed.

(iii) Operation of the Hele-Shaw electro-hydraulic rudder gear

This equipment is operated by the telemotor or gyro-pilot on the bridge or by the steering handle in the rudder gear room. Its operation can be switched from the bridge to the rudder gear room by means of a detachable pin.

Fig. 2.6.15 shows three variants of the eccentric arm (floating lever) arranged as a control and cut-off gear. The control movement is applied at point (A); point (B) is linked to the body whose movement is to be controlled; and point (0) is linked to the control mechanism of the power source.

a. Operation before the rudder starts

If the steering rod is driven in the arrow direction by working the steering wheel or telemotor, the eccentric arm of the pump will pivot about (B), shifting point (A) to point (A_1). Thus, the center of the eccentric arm is shifted from (0) to (0_1), giving an eccentricity to the pump which so far has been operated at neutral position. As a result, the oil starts flowing to move the rudder.

b. Operation from the start of rudder to the end of telemotor operation

The center (0) of the eccentric arm is limited by the maximum eccentric position (0_1) of the pump, and when point (A) passes (A_1) up to (A_2), the eccentric arm will pivot about (A_2).

Thus, (B) will be shifted to (B_1) while compressing the buffer spring of the follow-up equipment. A a result (0_1) turns bact to (0).

During this course, the pump will display its maximum capacity to operate the rudder hydraulically. Accordingly, the follow-up equipment is always acting to restore the eccentric arm to its neutral position (0).

c. Operation from the end of telemotor operation to the end of rudder motion

When the telemotor operation is completed as the eccentric arm attains position (A_2), the center of the eccentric arm (0_1) has still not turned back to point (0). Accordingly, the pump continues the operation to move the rudder. Point (B) shifts from (B_1) to (B_2), with (A_2) as a fulcrum when the rudder runs on; thus, the eccentricity of the pump diminishes and finally the neutral position is attained, and the flow of oil is stopped to keep the rudder at the required angle.

In this way, the rudder angle follows slightly later the angle of the steering wheel. When the steering wheel has been turned completely to the required position, the rudder attains its position.

b. William Janney type electro-hydraulic rudder gear (called "Janney")

Figs. 2.6.16 and 2.6.17 show the structure of a William Janney type electro-hydraulic rudder gear. It is usually operated by means of a telemotor from the bridge. In some specific cases, however, the control of the hydraulic unit can be done mechanically without using the telemotor if a mechanical stand is installed near the rudder gear room.

(i) Structure and operation of the Janney pump

By its structure, the Janney pump is a variable delivery type of the rotary plunger pump. As shown in Figs. 2.6.18 and 2.6.19, several plungers are provided in a square pump casing. These plungers rotate and reciprocate in the pump casing. The pump casing is shown in Fig. 2.6.18.

The reciprocating motion is done as follows:

The difference in distance from the pump casing between the socket ring at the top and that at the bottom functions as a base for the reciprocating motion. For example, when the pump is rotated clockwise, if the tilting box is inclined rightwards (Figs. 2.6.21 and 2.6.22) the plunger will be pulled away from the pump casing side due to its shifting its position from the lower half to the upper half of the left-hand half circle of the tilting box. In the right-hand cycle, the plunger is pushed towards the pump cylinder side due to its shifting its position from the upper half to the lower half of the circle of the tilting box.

As long as the pump continues to operate the afore-mentioned operations are repeated; namely, oil is sucked up on the left half stroke and is delivered out on the right half stroke.

If the right and left halves are connected to respective hydraulic cylinders through two holes in the valve plate as shown in Fig. 2.6.20, one hole will suck in oil, while the other will discharge oil. Fig. 2.6.22 shows a section of the pump assembly. The rotating elements are shown by cross lines.

(ii) Operation of Janney type electro-hydraulic rudder gear

Fig. 2.6.17 outlines the structure of the Janney type electro-hydraulic rudder gear. Motor (1) operates the Janney pump (2), the steering wheel rotates the shaft (3) connected to the mechanical pedestal in the bridge, the shaft (3) rotates clockwise or counterclockwise to rotate the shaft (4) forwards or backwards, through the medium of gear.

Thus, the levers (5) and (6) are inclined with point (a) as a fulcrum. Since the levers are connected to the shaft (7) of the tilting box of the Janney pump, the shaft (7) is turned clockwise or counterclockwise, and tilts the tilting box.

As a consequence, one of the hydraulic cylinders (10) and (11) is connected to the delivery side and the other to the suction side, through the pressure oil pipes (8) and (9), to drive two cylinder rams in the opposite direction to each other, whereby the rudder tiller (12) is driven to the helm right or left.

When the rudder tiller moves a required angle, the rod (13) of the follow-up equipment pushes the lever (5) at point (b) by the link (14). When the tilting box is turned back to its center (neutral position), the flow of oil is stopped as the pump will stop; the rudder also will stop at a required angle.

If the steering wheel is turned further, the above-mentioned operations will be repeated until a required helm angle is attained. When the steering wheel is turning, the tilting box will likewise turn steadily. The rudder starts moving as a result of delivery of the oil from the pump, and the follow-up equipment functions to restore the tilting box. Accordingly, the tilting box is brought to a halt at a point where the steering speed and follow-up speed are balanced with each other. The actual rudder angle follows slightly later the angle of the steering wheel during the operation. Only when the steering wheel has been stopped, can the rudder angle attain its required angle.

c. Electric steering gear

This gear uses a electric motor as a prime mover. Since an electric system is used for the steering gear and follow-up equipment, there is no idle travel and time lag. This gear is superior to all other types because of these advantages. The reversing and speed controlling of rudder motors are of the direct type and the Ward-Leonard type. The direct type is low in cost, and simple in construction. It is mostly applied for small vessels, while the latter is mostly used for large vessels. There are various types of electric steering gear as far as construction and manufactures' control schemes are concerned. An example is given below by way of explanation. Fig. 2.6.23 shows the wiring diagram of an electric steering gear and Fig. 2.6.24 the circuit connection. In the Ward-Leonard system, which comprises a motor-generator and two units of electric exciters, the direction of rotation and speed of the rudder motor are regulated by the variable voltage control method.

The difference between the two voltages generated by the two exciters controls the output current of the motor-generator, which is then applied to the rudder motor to control the power and direction of the rudder torque.

In this example, the equipment corresponding to the steering device is called "rudder setter" and the equipment corresponding to the follow-up equipment is called "rudder watcher".

In Fig. 2.6.24 is shown the rudder setter (A) having four resistors on either side, each with corresponding contacts. When the steering wheel is turned, the rudder setter is also turned with four resistors and contacts by means of the worm and worm gear. Around the rudder setter are nine stationary contacts which are connected to the respective stationary contacts of the rudder watcher (B).

The structural design of the rudder watcher is almost the same as that of the rudder setter, except for the shape of the contacts. The assembly of the rudder watcher is connected to the rudder head through the medium of a bevel gear to follow the motion of the rudder. Fig. 2.6.25 shows the circuit connection for the rudder setter and rudder watcher. When the rudder setter is moved to the required angle θ by turning of the steering wheel, the exciting circuit will close the circuit for the exciter (E_1), resulting in an unbalance in voltage between the two exciters (E_1, E_2). Thus, the generator (G) generates a voltage to drive the rudder motor (M) in the required direction.

When the rudder turns, the rudder watcher will be driven through the bevel gear (e) on the rudder head. If the rudder watcher rotates to the angle required by the rudder setter, the exciting circuit for the exciter (E_2) will be closed to stop its output voltage. Then the exciting circuit is balanced between the two exciters. The rudder motor stops, and the rudder keeps at a required rudder angle until the steering gear is driven again.

2.7 Deck Machinery

2.7.1 Winches

There are various types and structures of winches but all of these should meet the following requirements:

(a) to wind up a rating load at rating speed;

The rated horsepower of winches is determined as follows:

$$H = \frac{1,000\ W.V.}{4,500} f$$

where, H is rated horsepower (P.S.)
W is rated load (tons)
V is winding velocity (m/min) (30-40 m/min)
f is a factor (1.2 - 1.4)

(b) to be equipped with a reversing gear capable of reliably performing up and down motions;

(c) to be easily operated even by operators who are not familiar with the structure and equipment;

(d) to be equipped with reliable brakes which can stop the winch at any desired position easily and quickly;

(e) to allow easy control of the winding speed in relation to the weight of the load.

2.7.1.1 Classification of Winches

Winches are roughly divided into the electric type, the hydraulic type, and the steam type, according to the kind of prime mover used.

(1) Electric Type Winches

Direct current winches were widely used in the past, but they were very difficult to operate because they comprised many different parts. In view of this, the wide demand for automation of cargo handling work to increase working efficiency and minimize labour, and progress in electrification of engines have combined to replace the steam winches by electric winches which work more smoothely and easily than the steam type and can be operated by one man single-handed. Unlike the steam winch, the electric winch does not comprise a steam piping in the system, and its electric wiring can be arranged under the deck. Therefore, electric winches produce less noise.

However, the cost of electric winches is higher than that of steam winches.

Electric winches are divided into the direct current winch and the alternating current winch.

(a) Direct Current Winch (d.c. Winch)

Electric winches are required to deliver a large starting torque, rotate at a low speed for a large load, and at a high speed for a small load.

Since a winch hardly ever operates continuously under a heavy load, a series motor or a series characteristics cumulative compound motor of 30 minutes' duty is often used. Magnetic brakes are used for quick and reliable braking performance. For control of operation, drum controllers or magnetic controllers are used. In consideration of the fact that the winches are liable to be handled by persons who are not skilled in handling electric and mechanical equipments, an automatic start-up sequence is often incorporated in the control program. The winching speed at full load is usually set at about 40 m/min. Fig. 2.7.1 shows the external shape of a d.c. winch. Fig. 2.7.2 shows an example of the wiring diagram.

(b) Alternating Current Winches (a.c. Winch)

a.c. winches are classified according to the operating principles as follows:

(1-b-1) Ward-Leonard System

Each winch is provided with the Ward-Leonard set, namely, an a.c. motor is used to drive a d.c. generator whose output is applied to a d.c. motor.

The field current of a d.c. generator is regulated so as to control its output voltage to strictly regulate the d.c. winch motor.

This system is ideal but very expensive because of the large number of parts comprised in this equipment.

The Ward-Leonard type a.c. winch is available in two systems:-

(a) Separately installed M-G system (motor and generator system) in which two winches as a set are operated by two Ward-Leonard generators driven by a single induction motor.

(b) Built-in system in which each winch is equipped with a set consisting of a Ward-Leonard motor and a generator.

Fig. 2.7.3 shows the arrangement of the Ward-Leonard type a.c. winch.

(1-b-2) Pole-Change Type Squirrel Cage Induction Motor System

The pole-change type squirrel cage induction motor system easily permits the change of its starter pole arrangement to change synchronous speed by several steps for the speed control of the winch. Since the induction motor has shunt characteristics in itself, it is hard to realize series characteristics that attain a low speed for a heavy load and a high speed for a light load.

Moreover, this induction motor has an even worse defect in that the rush current at the time of starting and pole change are two to six times as large as the full load current.

(2) Hydraulic Winches

Hydraulic winches are easy to control, and simple in speed regulation. Besides, their braking performance excels that of the electric types. Also, the hydraulic type permits one-man control, and is smaller and lighter than the electric types.

Hydraulic winches comprise the low pressure type and the high pressure type.

(2-a) Low pressure Type

In the low pressure type, a hydraulic vane pump and a vane motor are used in combination. The delivery pressure of the vane pump is about 30 kg/cm^2.

On the same working basis, the low pressure type uses more working oil than the high pressure type because the pressure is low. As a result the size of piping is larger, so that it increases the total weight and installation space.

Fig. 2.7.4 shows a low pressure hydraulic type, and Fig. 2.7.5 shows the exterior aspect of a low-pressure type hydraulic winch.

(2-b) High Pressure Type

In the high pressure type, an axial type or gear type hydraulic pump is used, and hydraulic motors are used either of the radial plunger type or the axial plunger type.

The delivery pressure of the pumps is about 120 to 160 kg/cm^2.

High pressure hydraulic winches are classified, according to the rotation control of the winding drum, into the valve control type and the variable delivery axial plunger type.

Fig. 2.7.6 shows a high-pressure type hydraulic winch

Fig. 2.7.7 shows a high-pressure hydraulic pump.

Fig. 2.7.8 shows a high-pressure hydraulic motor.

2.7.2 Windlass

A windlass is a machine that lifts an anchor, and is mostly placed on the topmost deck on the bow. Windlasses are divided by type of prime mover into electric type, hydraulic type, and steam. As regards their structure and performance, these differ according to the manufacturer. However, any windlass should meet the following minimum requirements:

(1) be equipped with a reliable reversing gear;

(2) permit easy speed control to comply with load conditions;

(3) permit easy changes during lifting or casting of the anchor;

(4) provide an output capacity for lifting anchors with a chain of 55 meters from both sides at a rate of 9 meters per minute.

2.7.2.1 Electric Windlass

Electric windlasses are essentially of the same structure as the electric winches except that they are provided with a chain sheave instead of a winding drum. The chain sheave shaft is driven by a motor through a worm or spur gear to reduce its speed.

Electric windlasses comprise the direct current windlass and the alternating current windlass.

(1) Direct Current Windlass (d.c. Windlass)

A compound motor with a series characteristics is used.

For less than 70 P.S. or under, the speed can be regulated in 7 to 8 steps by the armature resistance control method with the ratio of no load speed to full load speed set at about 2:1.

For large output motors, the Ward-Leonard system, booster system, motor reducer system and other voltage control systems are applied.

Fig. 2.7.9 shows a d.c. windlass.

(2) Alternating Current Windlass (a.c. Windlass)

A wound motor type induction motor is used to drive the windlass.

When it is required to control speed over a wider range, a pole change motor is used in combination with an external winding resistance regulator for strict speed regulation. For a large output, the Ward-Leonard system is applied.

2.7.2.2 Hydraulic Windlass

A hydraulic windlass uses a hydraulic pump and a hydraulic motor to directly control the chain sheave shaft speed. Where a ship is equipped with a hydraulic winch, it is convenient to apply the hydraulic system to the windlass because the hydraulic pump used for the winch can also be used for the windlass, simplifying the overall installation.

Fig. 2.7.10 shows a hydraulic windlass.

2.7.2.3 Capstan

A capstan is an upright barrel winch which can be turned on a vertical shaft to heave mooring wires or ropes. It is driven by an electric motor or hydraulic motor. The capstan systems are the same as for winches and windlasses.

Fig. 2.7.11 shows a electric capstan, and Fig. 2.7.12 shows a hydraulic capstan.

2.8 Air Compressors

2.8.1 Type of Compressors

Air compressors are divided into two types: displacement and rotodynamic machines.

Rotodynamic machines comprise the axial flow type (axial flow compressor) and the centrifugal type (radial compressor, turbo-compressor), while displacement machines comprise the rotary type (sliding vane compressor, screw compressor, etc.) and the reciprocating-piston type. In marine engines, most air compressors are of the reciprocating-piston type, which are divided into single stage and multi-stage air compressor types.

2.8.1.1 Reciprocating-piston type Air Compressor

The reciprocating-piston type air compressor is a machine that compresses the air sucked from the atmosphere into a cylinder, and delivers it into an air tank or air machinery through a delivery valve and pipe. An engine-starting device is required to compress the air to 25 to 35 kg/cm^2. The multi-stage air compressor type is commonly used.

(a) The advantages of the multi-stage type are as follows:

(1) To reduce the power required for a given pressure.

(2) To prevent the lubricating oil from deteriorating, and extend valve service since the temperature is reduced at the end of gas compression.

(3) To increase the suction air volume since the volumetric efficiency is increased.

(4) To easily balance the torque by means of a suitable arrangement and combination of cylinders.

Fig. 2.8.1 shows the cylinder arrangement of air compressors.

(b) Requirements and structure

(b-1) Requirements

The main requirements of valves are the following:

(1) To move up and down in timing with the piston motion so that there is no time lag;

(2) To minimize wear of the valve seat by reducing the impact load when the valve closes;

(3) To ensure close contact with the valve seat for good airtightness;

(4) To be made of strong but light materials.

(b-2) Structure

(b-2-1) Valves

Valves are used for manual and automatic type compressor. The automatic type is most commonly used.

As valve materials, stainless steel, nickel-molybdenum steel, nickel-chromium steel, etc., are used.

Valves comprise the following:

(1) Ring valve (plate valve)

(2) Disc valve,

(3) Feather valve,

(4) Flapper valve,

(5) Channel valve,

(6) Poppet valve,

(7) Conical valve, etc.

Fig. 2.8.2 shows various kinds of valves

The ring (or plate) valve and feather valve are generally used for low-pressure service. The disc valve is used for high-pressure service. The other kinds are not commonly used.

Various springs are fitted to valves to relieve the opening and closing impact load.

(b-2-2) Pistons and piston rings

(1) Pistons

Pistons are usually made of high-grade cast iron. However, for high speed pistons a light alloy is used.

(2) Piston rings

Piston rings are made of cast iron, chromium-plated cast iron, a bronze-lead alloy, etc.

Pistons operating below 7 kg/cm^2 have 2 to 3 rings; 4 to 6 rings are used for below 15 kg/cm^2; 8 to 10 rings for below 50 kg/cm^2.

(c) Lubrication

(c-1) Lubricating oil

Compressor-piston lubricants serve to (1) prevent wear by providing a low-frictional supporting film between rubbing surfaces, (2) seal clearances, (3) protect against corrosion, and (4) carry away heat generated by friction and (5) wash away minute wear particles from points of contact.

(c-2) Lubricating oil system

For force-feeding lubricants to crankshaft and bearing surfaces the following are used: a gear or plunger pump driven by the crankshaft, or a spray or drop lubricator. For cylinder-surface lubrication are used the drop type lubricators placed in the suction chamber or pipe, or other types of lubricators driven by the crankshaft and located near the suction ports to suck in oil together with air, or force-feed lubricators of the Bosch type. Fig. 2.8.3 shows a drop type lubricator.

(d) Cooling system

When a gas is cooled, the power required for a given pressure is reduced and the lubricants are prevented from deteriorating since suction and delivery temperatures are reduced.

For this reason, air compressors are usually equipped with a cooling system.

(d-1) Cylinder jacket

Small-sized compressors and low-pressure ratio compressors use natural convection air cooling, fins being placed on the cylinder head or round the cylinder jacket, or by driving a pulley which is used as a fan, or by the force convection air cooling method using the pully arms, or by a fan driven by the crankshaft.

(d-2) Inter-cooler and After-cooler

A cooler between cylinders is called an inter-cooler. A cooler placed between the last stage of the cylinder and the air tank cools the delivery gas. It is called an after-cooler. The after-cooler is utilized to separate the water and the air, and to reduce the delivery gas temperature.

Fig. 2.8.4 shows a cylindrical multiple pipe type cooler, and Fig. 2.8.5 shows a coil type cooler.

Fig. 2.8.6 shows a vertical two-stage air compressor.

Fig. 2.8.7 shows the piping of an air compressor.

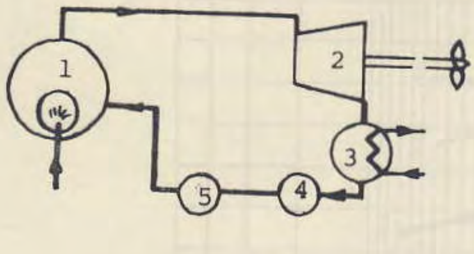
(e) No-load starting method

In starting a reciprocating air compressor driven by an electric motor, the no-load starting method is used to avoid an overload by minimizing the starting current. The no-load starting method consists in (1) opening all suction valves, (2) purging air through the check valve placed on the discharge pipe from the compressor to the air tank, and (3) closing the air suction valve.

Fig. 2.8.8 shows the no-load starting device for (2) above. When the motor connected to the air compressor starts, the air in the space above the discharge valve (1) starts discharging through the discharging path (5) because the pilot valve (2) is opened by the spring (3). As the discharge valve (1) is pushed up by high-pressure air from the drain separator (10), the air flows out, as shown by the arrows in Fig. 2.8.8.

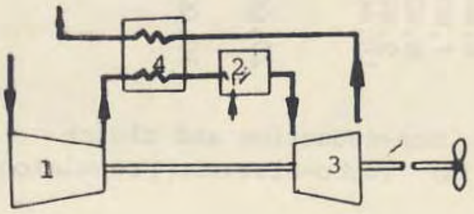
When the motor speed is increased, the magnet (6) operates to pull the lever (7) up. As a result the spring-loaded pilot valve (2) and discharge valve (1) are automatically closed by the spring (4), since the pressure between the top and bottom of the discharge valve (1) is balanced. The air compressor then starts compressing the air.

FIGURES



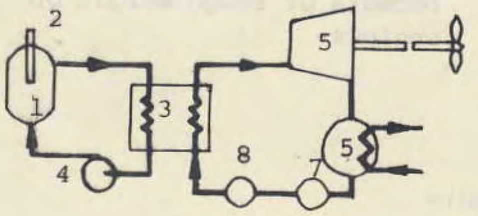
(1) Boiler (2) Steam reciprocating engine (3) Water condenser (4) Condenser pump (5) Feed water pump

(a) Steam engine



(1) Air compressor (2) Combustion chamber (3) Gas turbine (4) Regenerator (heat exchanger)

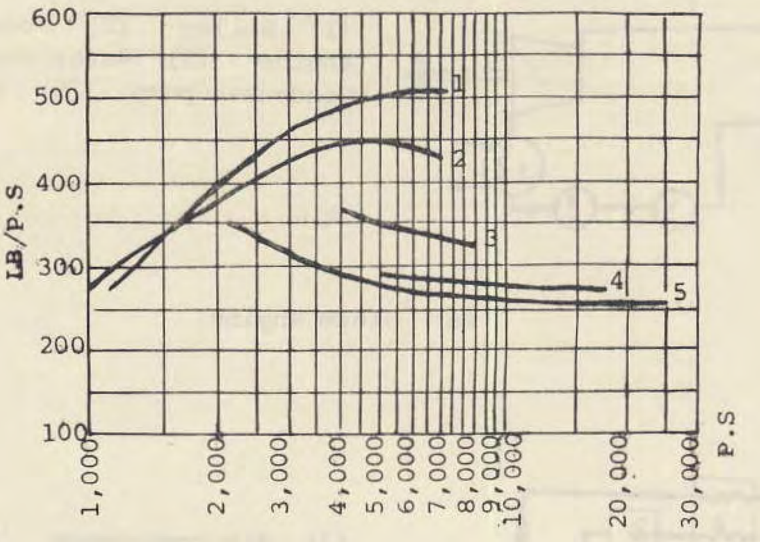
(b) Gas turbine



(1) Nuclear reactor (2) Control shaft (3) Heat exchanger (4) Circulating water pump (5) Steam turbine (6) Water condenser (7) Condenser pump (8) Feed water pump

(c) Nuclear power (atomic)

Fig. 1.1 Kinds of main engines



(1) Steam reciprocating engine (2) Non-reduction and clutch engine (3) Geared diesel engine (4) Turbo-electric propulsion engine (5) Geared steam engine

Diesel E.	(BHP + 1000)/15~21
Steam R.	$(IHP_{max} + 1000)/30\sim50$
Steam C.	$(IHP_{max} + 1000)/45\sim50$
Turbine	(SHP + 1000)/60~70

Formula of rough weight on engines

E..Engine
R..Reciprocating engine
C..Steam compound engine

Fig. 1.2 Weight and P.S. of main engines

	1	2	3
Large size	0.40~0.50	0.10~0.15	0.50~0.35
Small size	0.37~0.45	0.10~0.13	0.53~0.42
High speed	0.28~0.33	0.07~0.10	0.65~0.57
Large common	21~0.25	0.01~0.05	0.75~0.70
W.S. size	0.25~0.27	0.05~0.08	0.70~0.65

Rough weight of hull, engine and cargo

Large size..Large size cargo ship
Small size..Small size cargo ship
High speed..Large size high speed cargo ship
Large common..Large size common cargo ship
M.S. size..Medium and small size cargo ship

1..Hull weight, 2..Engine weight, 3..Cargo weight

Type	1 BHP (weight)
4S.......	90~140 kg
2S.......	70~100 "
2D.......	50~90 "
2SS......	40~60 "
SH.......	10~20 "

Weight on diesel engines per BHP
4S..Four-cycle single-acting engine, 2S..Two-cycle single-acting engine, 2D..Two-cycle double-acting engine, 2SS..Two-cycle single-acting engine with supercharger, SH..Special high-speed engine.

Fig. 1.2 Weight and P.S. of main engines (cont.)

Type	P.S.	N x D x S	rpm	W(kg)	W/P.S.
Four-cycle single-acting diesel engine	1000	4 x 640 x 900	150	115	112
	1500	6 x 640 x 900	150	163	104
	1750	6 x 600 x 700	215	166	95
	3000	10 x 530 x 530	390	95	30
	1800	6 x 740 x 1500	90	424	231
	1850	6 x 750 x 1200	105	277	149
	2250	8 x 750 x 1150	115	368	161
	1760	7 x 740 x 1140	112	272	151
Four-cycle double-acting diesel engine	1200	4 x 590 x 800	150	133	110
	2000	4 x 740 x 1000	125	222	110
	6750	6 x 840 x 1500	125	520	77
	10000	8 x 840 x 1500	115	869	86
Two-cycle single-acting diesel engine	1700	4 x 680 x 1100	80	193	111
	3250	6 x 700 x 920	127	297	91
	4000	6 x 680 x 1200	95	414	102
	1600	4 x 675 x 920	105	174	109
	1890	4 x 700 x 1200	107	238	125
Two-cycle double-acting diesel engine	4000	6 x 710 x 1200	76	439	109
	4400	6 x 700 x 1200	84	414	93
	15000	9 x 860 x 1500	94	1132	76

P.S..metric horsepower, N x D x S..Number of cylinder x Bore x Stroke, rpm..Revolution per minute, W..Weight of engine, W/P.S..Weight per P.S.

Name of part	3 cyl.	6 cyl.
Crankshaft	11	10
Enginebed	12	11
Cyl. jacket	10	9.5
Main bearing	2.5	2.0
Cylinder	13	12
Cylinder Liner	6	5.5
Head cover	6	5.7
Piston	5	4
Connecting Rod	5	4.7

Weight of each engine part (%)

Remark: Flywheel, strainer, cooler, etc., are not included.

Fig. 1.3 Comparison of weight of marine engines

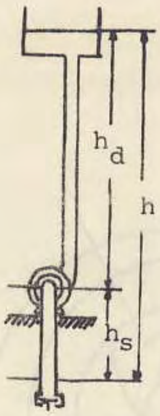
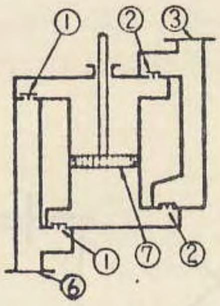


Fig. 2.1 Pump head



1. Suction valve
2. Delivery valve
3. Delivery pipe
4. Bucket valve
5. Bucket
6. Suction pipe
7. Piston

Fig. 2.2 Piston pump

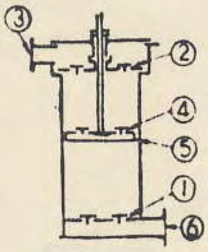
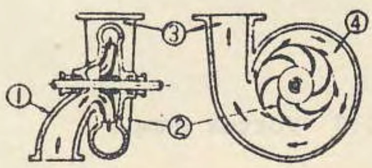


Fig. 2.3 Bucket pump



1. Suction pipe
2. Impeller
3. Delivery pipe
4. Volute chamber

Fig. 2.5 Volute pump

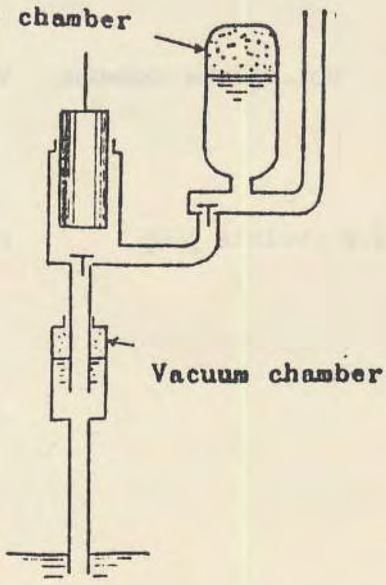
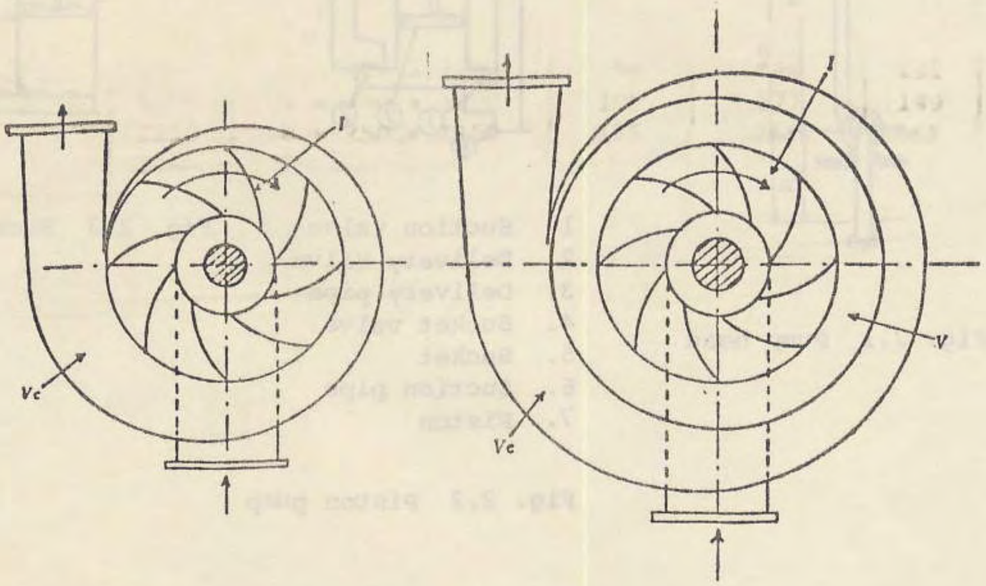
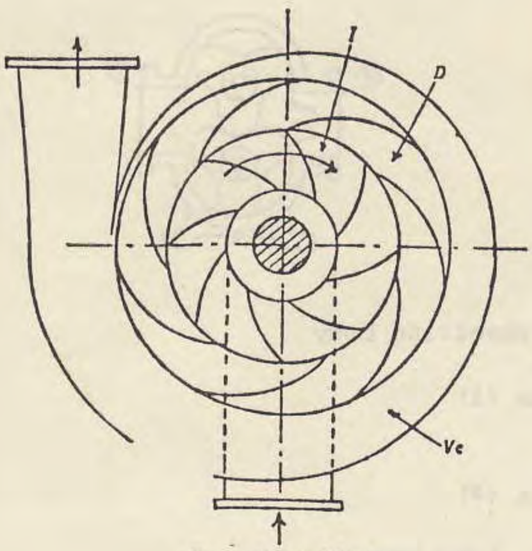


Fig. 2.4 Plunger pump



Vc..Volute chamber   V..Vortex chamber

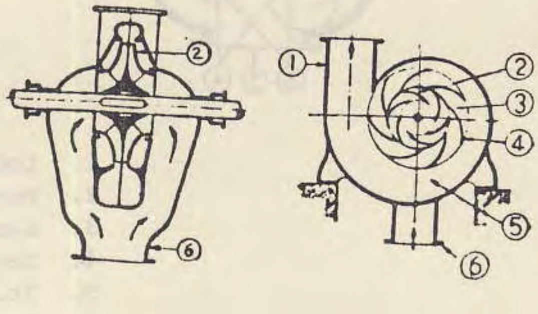
Fig. 2.6 Volute pump   Fig. 2.7 Vortex pump



I. Impeller

D..Guide vane
Vc..Volute chamber

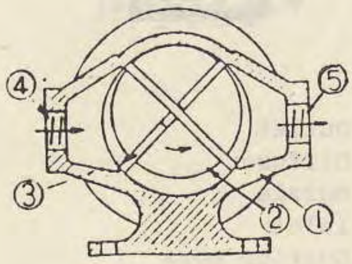
Fig. 2.8 Turbine pump



I. Impeller

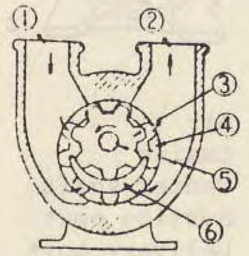
1. Delivery pipe
2. Impeller
3. Vortex chamber
4. Guide blade
5. Volute chamber
6. Suction pipe

Fig. 2.9 Double-suction pump



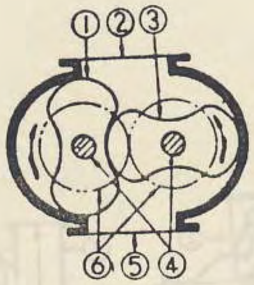
1. Casing
2. Rotor
3. Sliding vane
4. Suction port
5. Delivery port

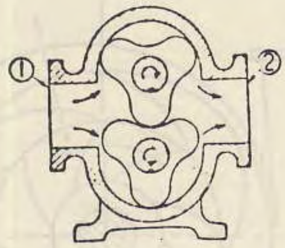
Fig. 2.10 Sliding vane pump



1. Suction port
2. Delivery port
3. Idle gear
4. Working gear
5. Driving shaft
6. Cover

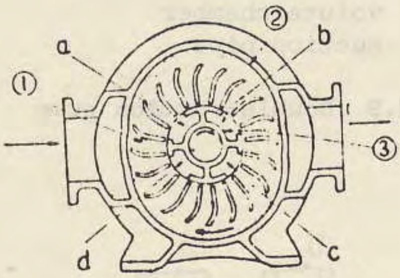
Fig. 2.11 Viking pump





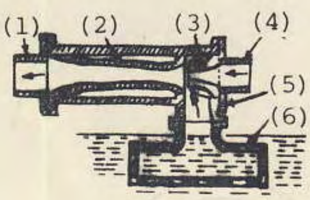
1. Lobar revolving body
2. Outlet
3. Same as (1)
4. Gear
5. Inlet
6. Same as (4)

Fig. 2.12 Lobe pump



1. Air
2. Casing
3. Center shaft
a. Suction port
b. Delivery port
c. Same as (a)
d. Same as (b)

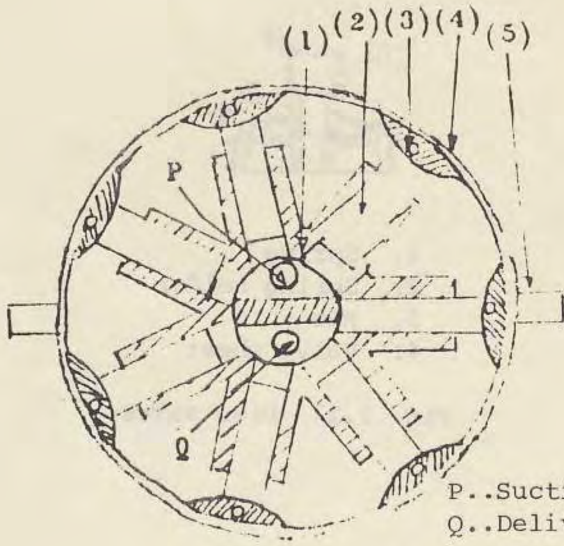
Fig. 2.13 Nash pump

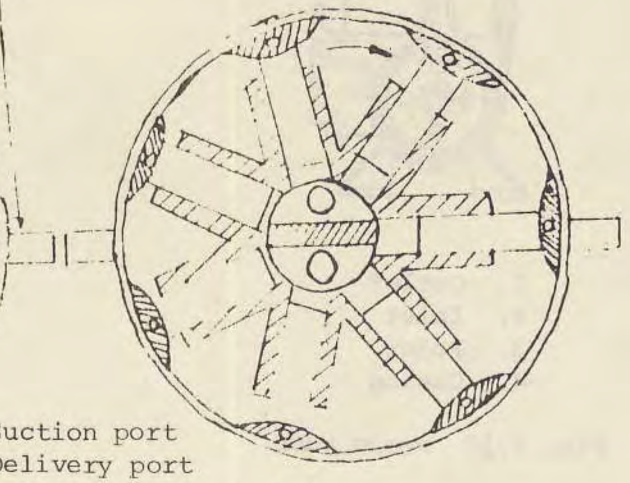


1. Outlet
2. Diffuser
3. Nozzle
4. Inlet
5. Suction port
6. Filter

Fig. 2.14 Steam jet pump

Hele Shaw pump



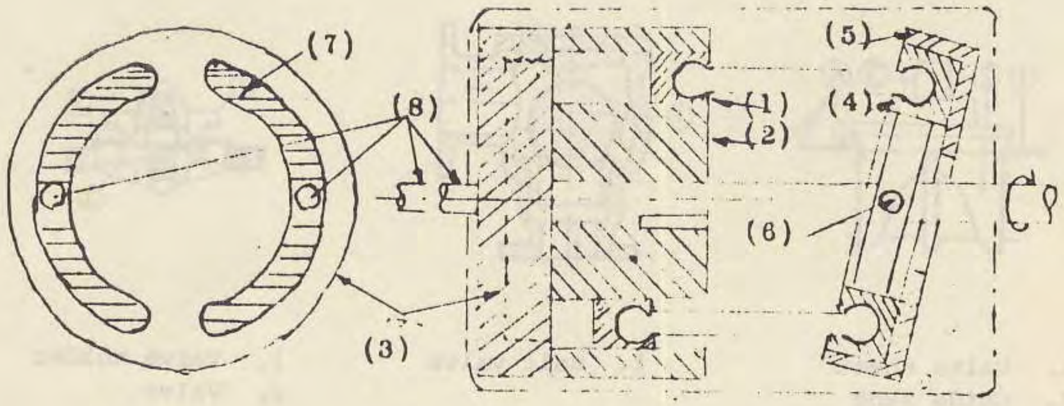


P..Suction port
Q..Delivery port

(1) (2)

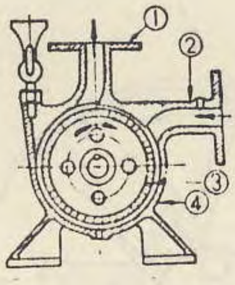
1. Cylinder
2. Plunger
3. Slipper
4. Floating ring
5. Control rod

William Janney pump



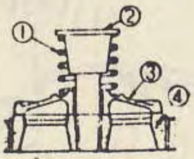
1. Plunger
2. Cylinder
3. Valve plate
4. Socket ring
5. Tilting box
6. Universal joint
7. Oil groove
8. Suction and delivery pipe

Fig. 2.15 Hele Shaw and William Janney pumps



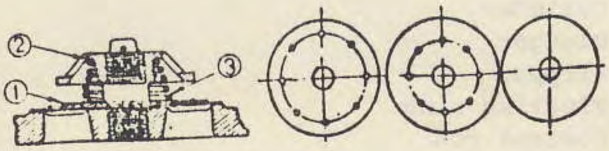
1. Outlet
2. Inlet
3. Rotor
4. Casing

Fig. 2.16 Wesco pump



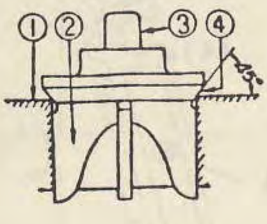
1. Spring
2. Spring holder
3. Rib
4. Valve sheet

Fig. 2.17 Disc valve



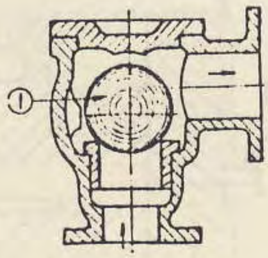
1. Sheet valve
2. Spring holder
3. Spring

Fig. 2.18 Kinghorn valve



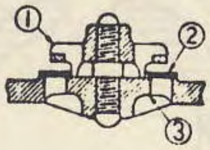
1. Valve sheet
2. Guide vane
3. Valve head
4. Valve sheet angle

Fig. 2.19 Conical valve



1. Ball valve

Fig. 2.20 Ball valve



1. Valve holder
2. Valve
3. Ring hole

Fig. 2.21 Ring valve

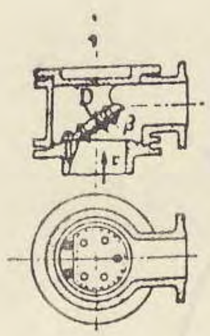
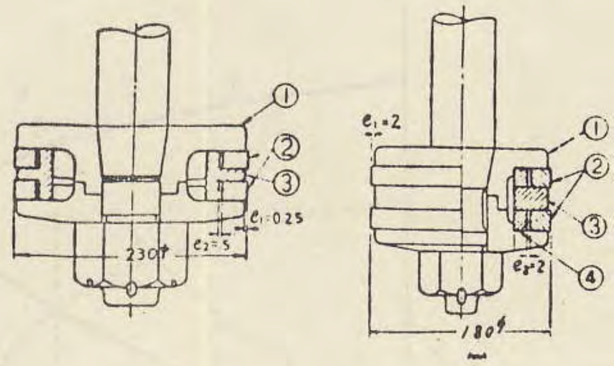


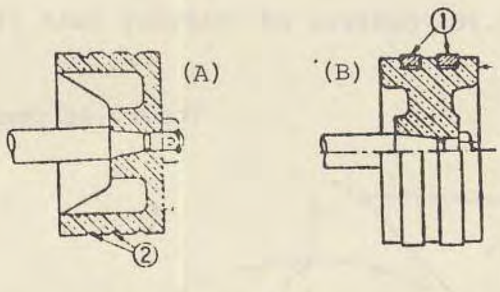
Fig. 2.22 Flap valve



1. Piston 2. Ring
3. T-type carrier frame
4. Idle ring

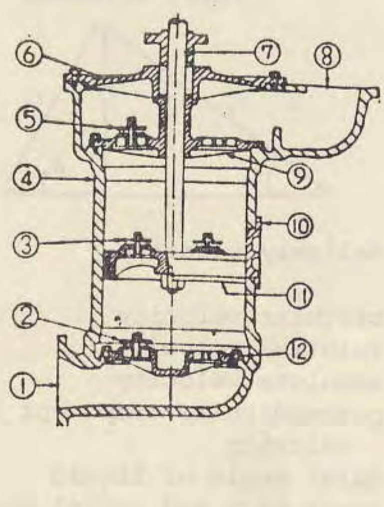
Fig. 2.25 (a) Piston

Fig. 2.26 Plunger



1. Piston ring 2. Groove

Fig. 2.25 (b) Piston



1. Suction port 2. Suction valve
3. Bucket valve 4. Cylinder
5. Delivery valve 6. Cover
7. Bucket rod 8. Delivery valve
9. Delivery valve sheet
10. Cover for inspection
11. Bucket
12. Suction valve sheet

Fig. 2.27 Bucket type air pump

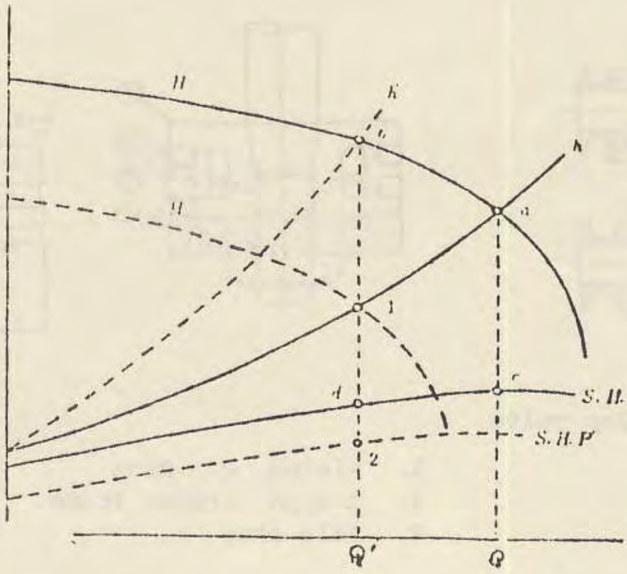
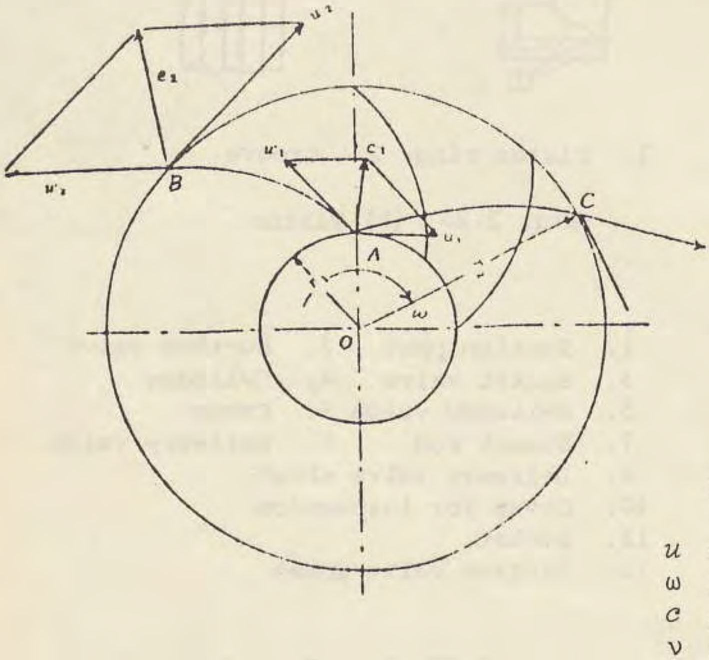
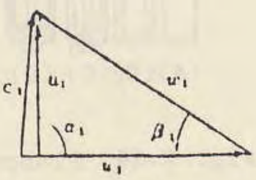


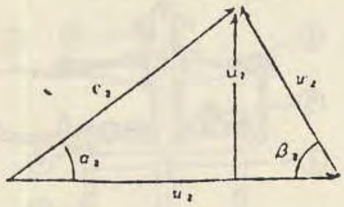
Fig. 2.28 Control of delivery rate of centrifugal pump

Theory of centrifugal pump





inlet velocity



delivery velocity

u circular velocity
ω relative velocity
c absolute velocity
ν pertendicular component of velocity
α inlet angle of liquid
β angle of *u* and radial direction

Fig. 2.29 Liquid flow velocity of centrifugal pump

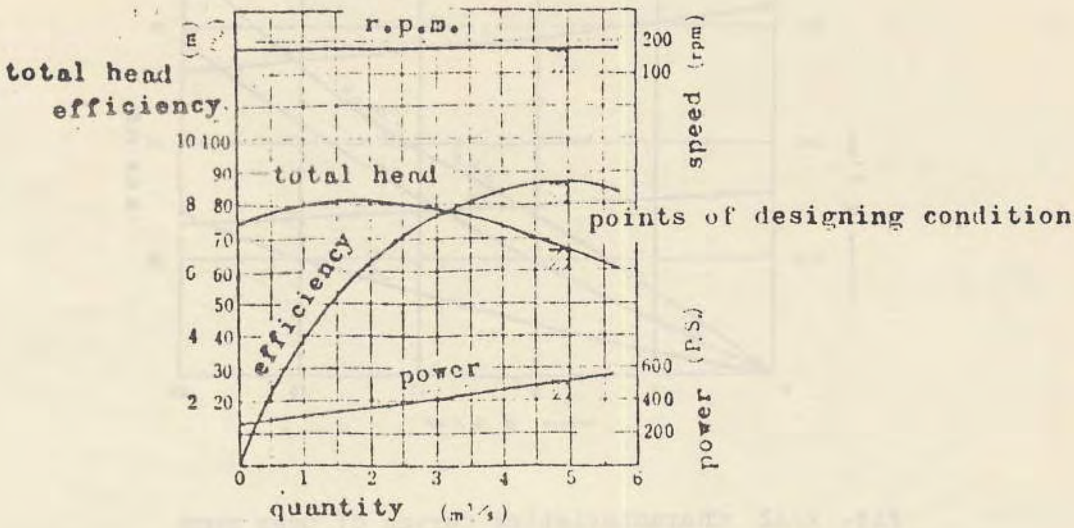


Fig. 2.30 Characteristics curves of centrifugal pump

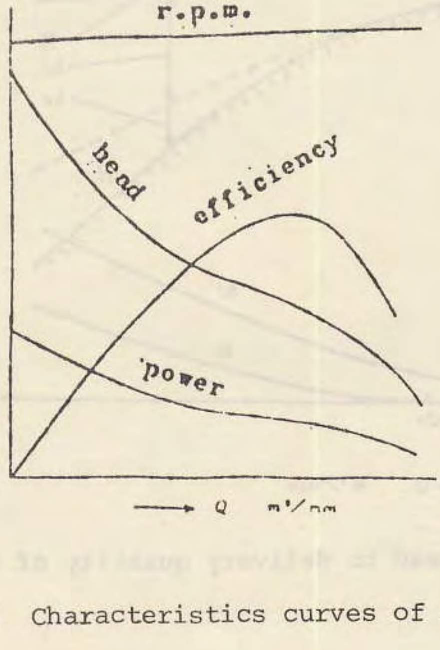


Fig. 2.31 Characteristics curves of axial pump

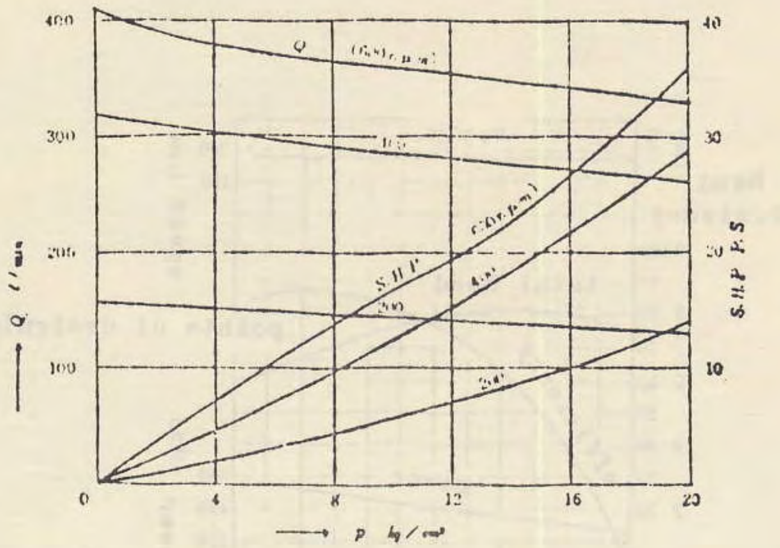
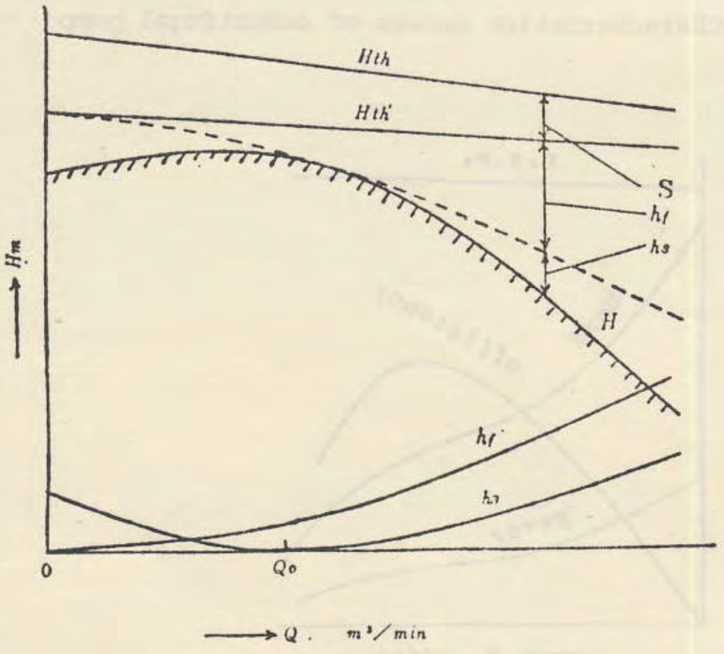
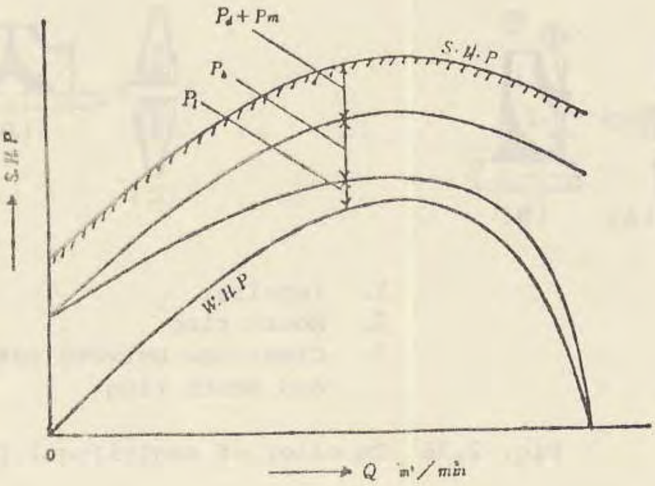


Fig. 2.32 Characteristics curves of gear pump



hf..Friction loss by liquid
hs..Suction loss
Qo..Rated flow quantity
S...Slip (leakage loss between blade and casing)

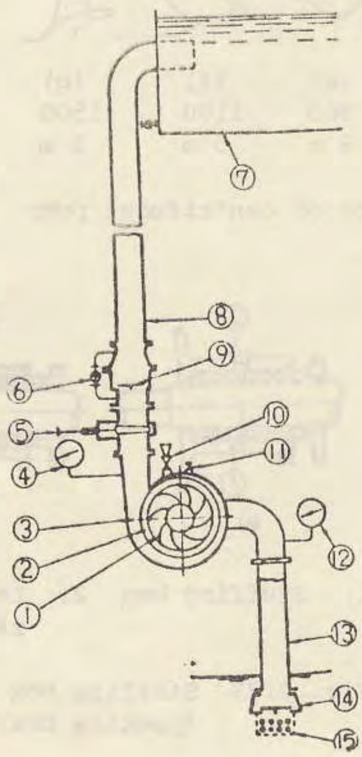
Fig. 2.33 Head to delivery quantity of centrifugal pump



pd..Friction loss = 0.02 - 0.10
pl..Leakage loss = 0.03 - 0.15
pm..Mechanical loss = 0.01 - 0.05
ph..Fluid loss = 0.08 - 0.20

$$\eta = \frac{WHP}{shp} = \frac{pd + pl + pm + ph}{shp}$$

Fig. 2.34 Delivery flow quantity of centrifugal pump to S.H.P.

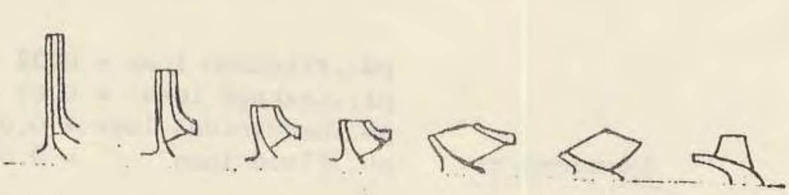


1. Impeller
2. Vortex chamber
3. Volute chamber
4. Pressure gauge
5. Stop valve
6. Bypass valve
7. Water tank
8. Delivery pipe
9. Check valve
10. Priming valve
11. Air cock
12. Vacuum gauge
13. Suction pipe
14. Check valve
15. Filter.

Fig. 2.35 Pumping equipment of centrifugal pump

1. Impeller
2. Mouth ring
3. Clearance between casing and mouth ring

Fig. 2.36 Impeller of centrifugal pump



	(a)	(b)	(c)	(d)	(e)	(f)	(g)
rpm	100	100	330	550	860	1100	1500
head	30 m	20 m	12 m	10 m	8 m	5 m	3 m

Fig. 2.37 Shape of impellers of centrifugal pump

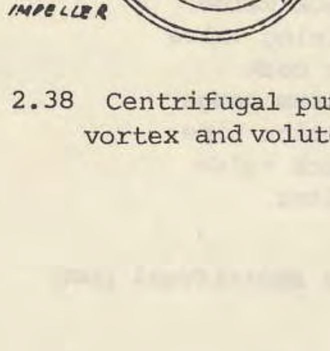
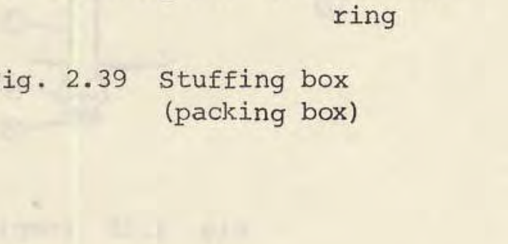
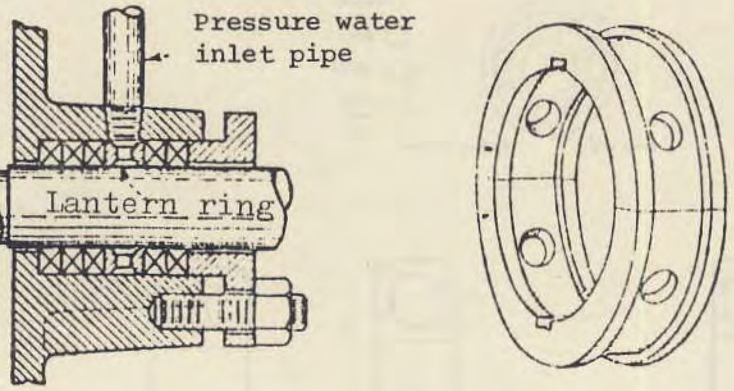


Fig. 2.38 Centrifugal pump with vortex and volute casings

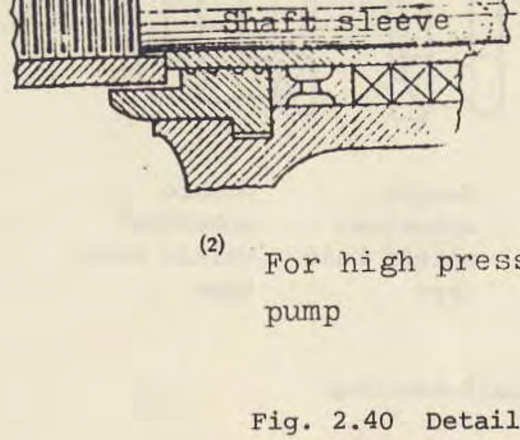


1. Stuffing box 2. Lantern ring

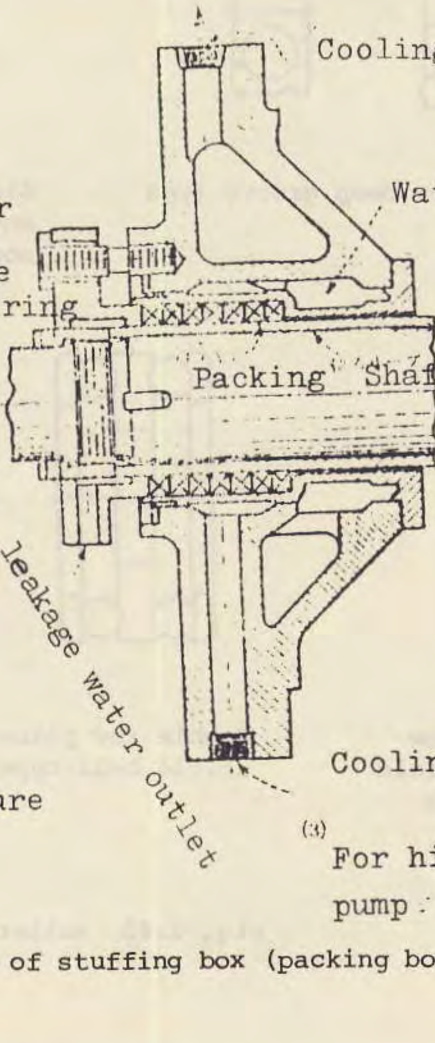
Fig. 2.39 Stuffing box (packing box)



(1) For low pressure pump

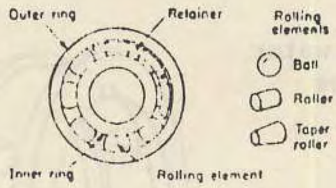


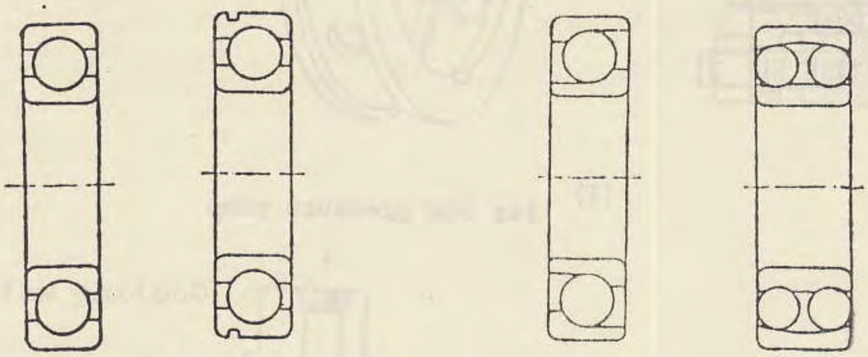
(2) For high pressure pump



(3) For high temperature pump

Fig. 2.40 Details of stuffing box (packing box)

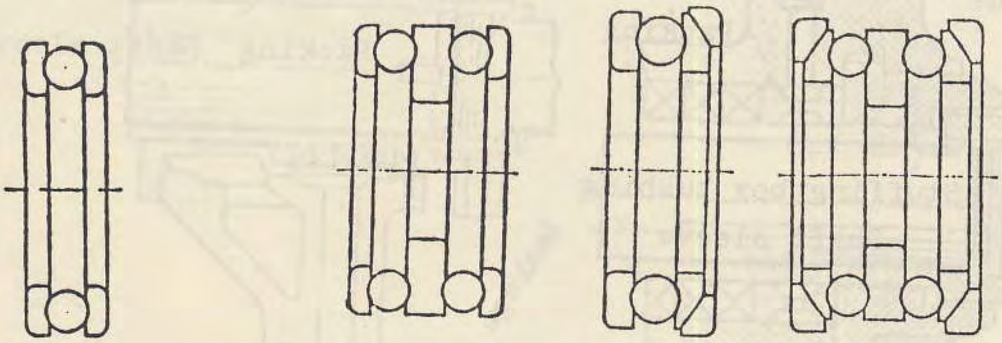




Single row deep groove type

Single row angular-contact type

Double row self-aligning ball type



Single row plane shield ball type

Double row plane shield ball type

Single spherical shield ball type

Double spherical shield ball type

Fig. 2.42 Roller ball bearings

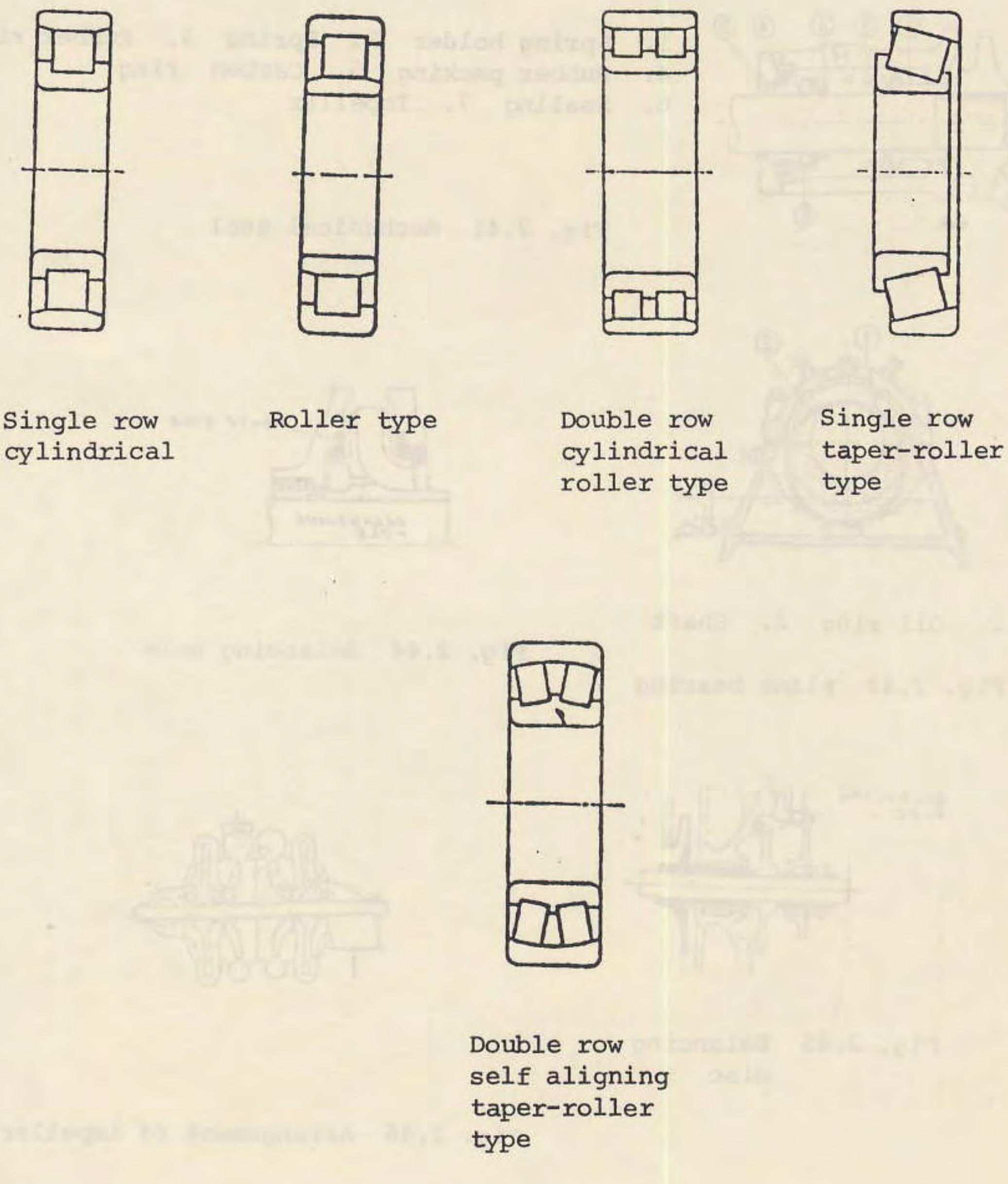
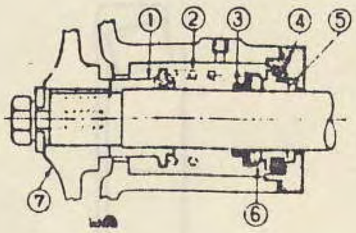
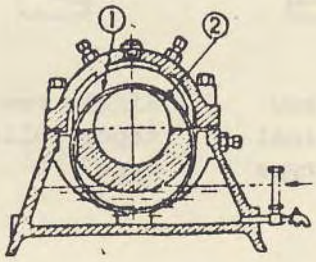


Fig. 2.42 Roller ball bearings (cont.)



1. Spring holder 2. Spring 3. Rubber ring
4. Rubber packing 5. Carbon ring
6. Sealing 7. Impeller

Fig. 2.41 Mechanical seal



1. Oil ring 2. Shaft

Fig. 2.43 Plane bearing

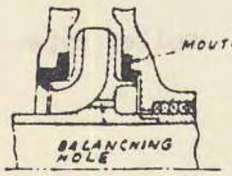


Fig. 2.44 Balancing hole

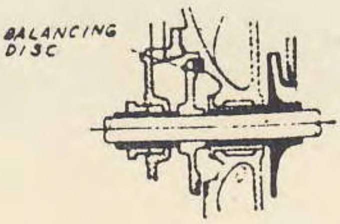


Fig. 2.45 Balancing disc

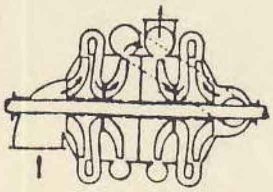
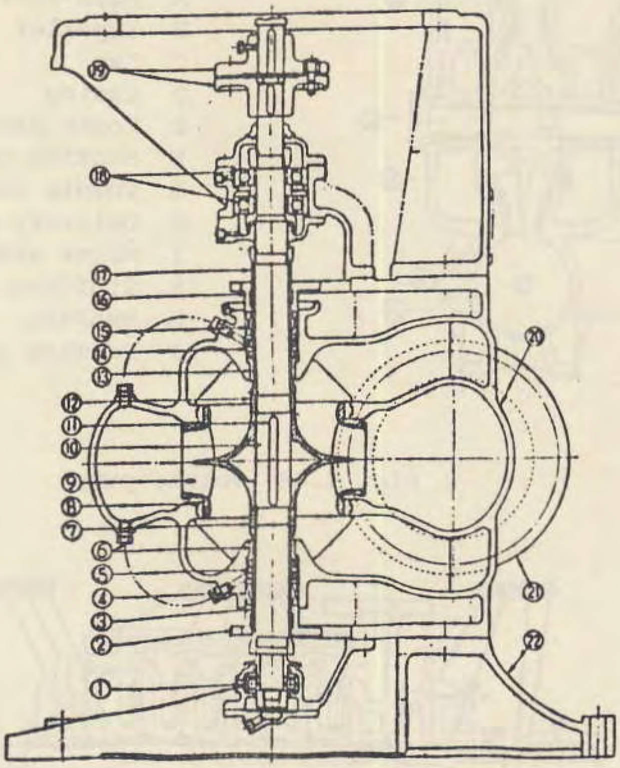
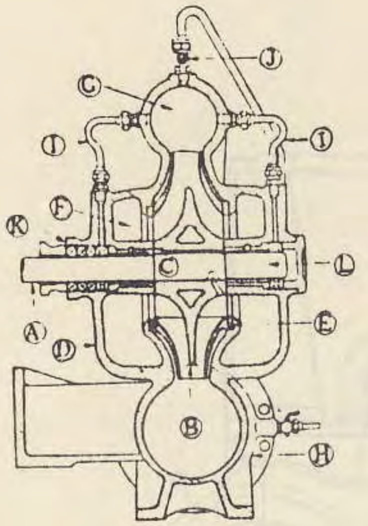


Fig. 2.46 Arrangement of impeller



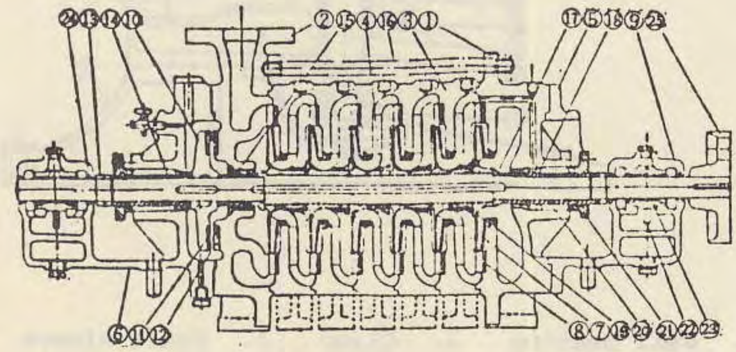
1. Ball bearing 2. Gland 3. Shaft sleeve 4. Packing 5. Stuffing box 6. Neck bush 7. Nut 8. Mouth ring 9. Impeller 10. Shaft 11. Key 12. Nut 13. Neck bush 14. Stuffing box 15. Packing 16. Gland 17. Shaft sleeve 18. Ball bearing 19. Coupling 20. Volute chamber 21. Suction pipe 22. Bedplate

Fig. 2.47 Water circulating pump



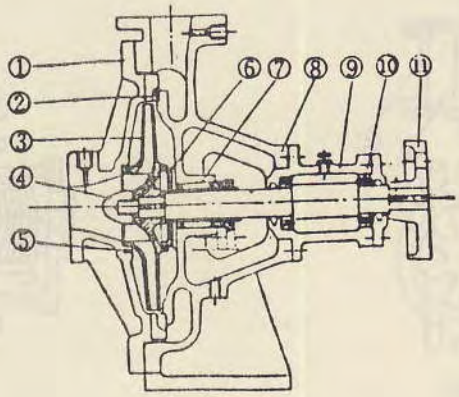
A Main shaft
B Impeller
C Key
D Casing
E Mouth ring
F Suction port
G Volute casing
H Delivery pipe
I Water sealing pipe
K Stuffing box
L Bearing
J Priming cock

Fig. 2.48 Volute pump



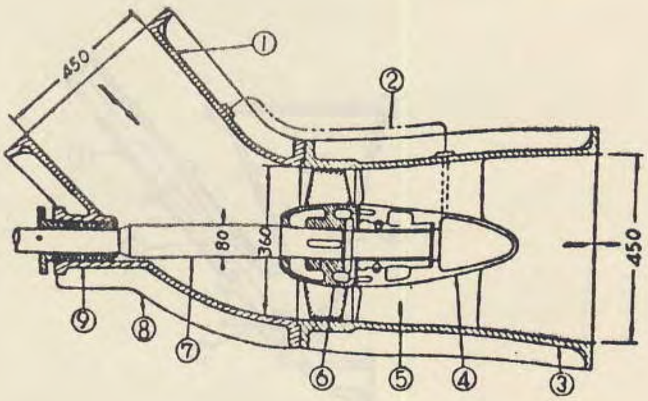
1. Suction side cover 2. Delivery 3. Flange 3. Casing
4. Impeller blade 5. Shaft bracket 6. Same as (5) 7. Impeller
8. Guide blade 9. Ball bearing case 10. Balance disc 11. Balance sheet 12. Balance sheet 13. Sleeve nut 14. Sleeve
15. Bush 16. Stay bolt 17. Shaft sleeve 18. Lantern ring
19. Mouth ring 20. Gland packing 21. Gland 22. Oil ring
23. Bearing 24. Packing 25. Coupling

Fig. 2.49 Six-stage turbine pump



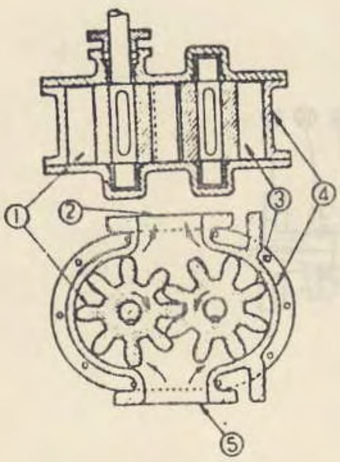
1. Cover 2. Guide blade 3. Impeller 4. Impeller nut
5. Impeller mouth ring 6. Mouth ring 7. Packing
8. Casing 9. Bearing case 10. Ball bearing 11. Coupling

Fig. 2.50 Single-stage centrifugal pump



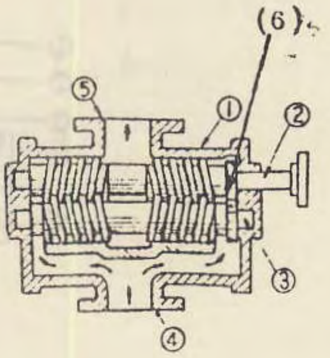
1. Suction pipe 2. Return pipe
3. Delivery pipe 4. Bearing casing
5. Guide blade 6. Impeller 7. Shaft
8. Pump casing 9. Stuffing box

Fig. 2.51 Axial flow pump



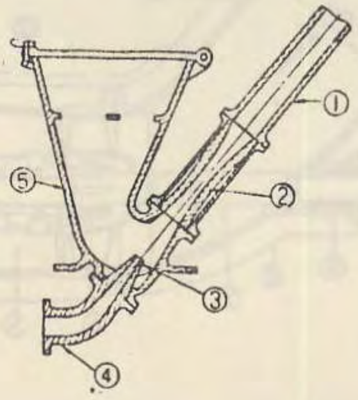
1. Drive gear
2. Delivery port
3. Driven gear
4. Casing
5. Suction port

Fig. 2.52 Gear pump



1. Casing 2. Driving shaft
3. Idle shaft 4. Suction port
5. Delivery port 6. Timing gear

Fig. 2.53 Screw pump



1. Delivery pipe 2. Diffuser
3. Nozzle 4. Inlet pipe
5. Ash hopper

Fig. 2.54 Water jet pump

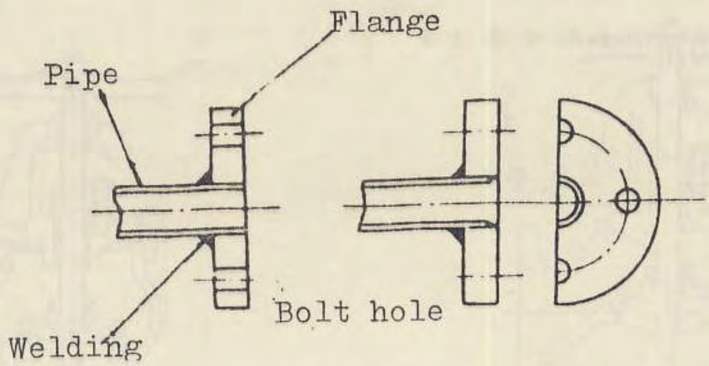


Fig. 2.2.1 Welded flange joint

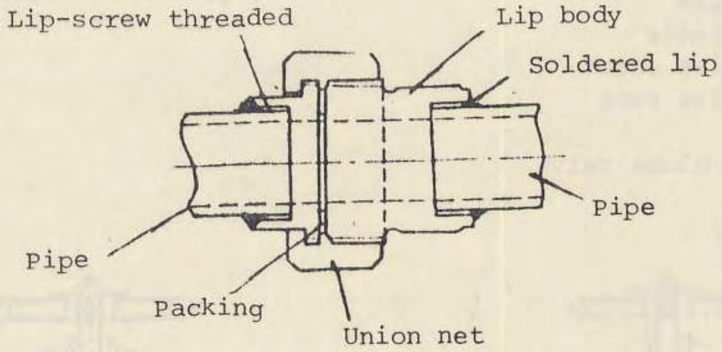


Fig. 2.2.2 Union joint

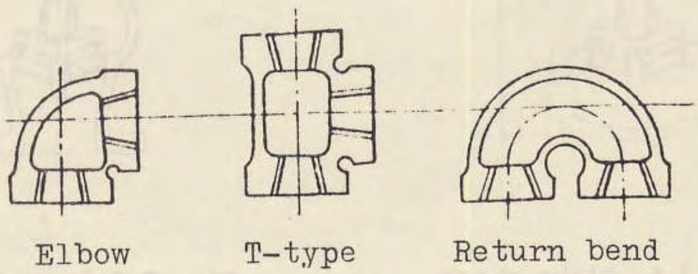
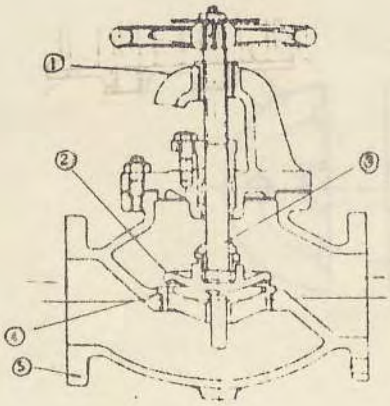


Fig. 2.2.3 Screw-threaded joint



1. Spindle guide
2. Valve
3. Spindle
4. Valve sheet
5. Valve case

Fig. 2.2.4 Globe valve

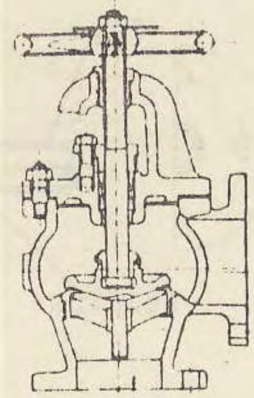


Fig. 2.2.5 Angle valve

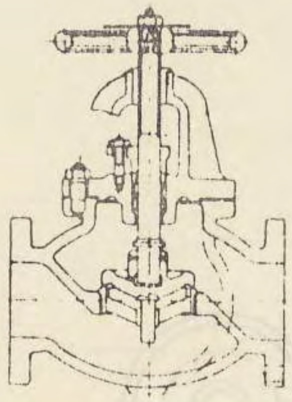


Fig. 2.2.6 Globe check valve

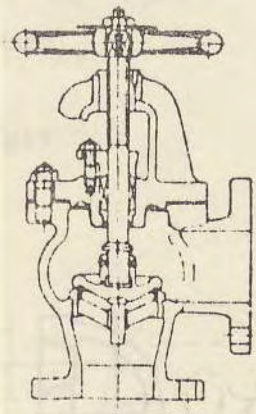


Fig. 2.2.7 Angle check valve

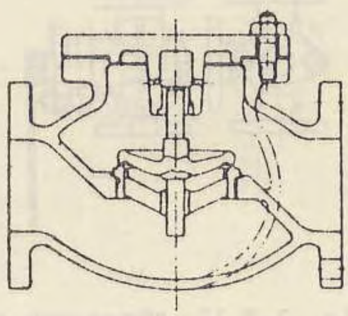


Fig. 2.2.8 Lift-type check valve

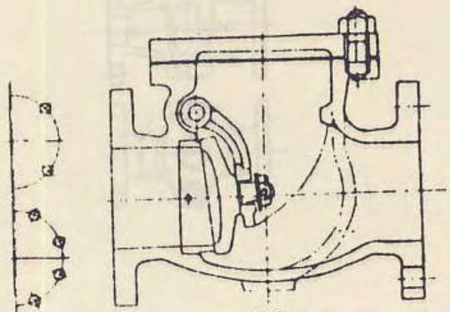


Fig. 2.2.9 Swing-type check valve

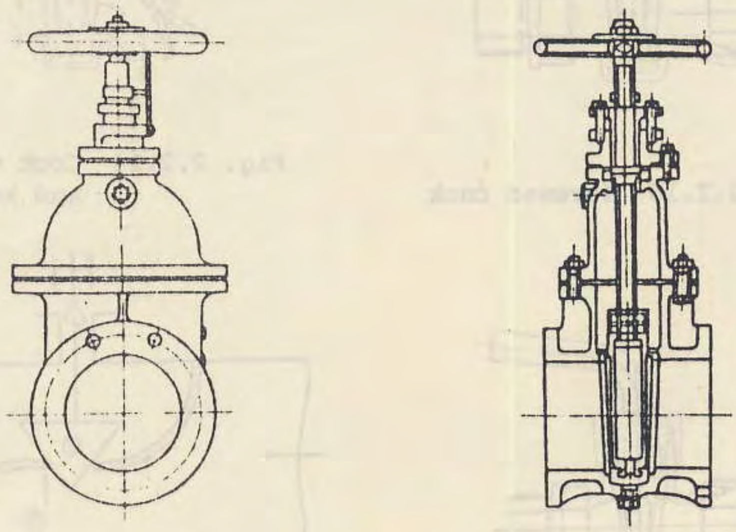


Fig. 2.2.10 Wedge gate or sluice valve

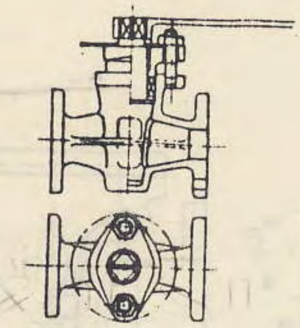


Fig. 2.2.11 Two-way cock

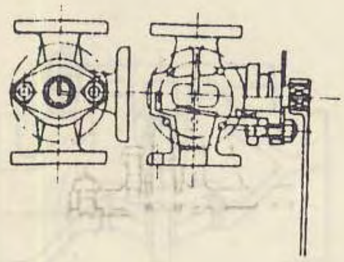


Fig. 2.2.12 Three-way cock

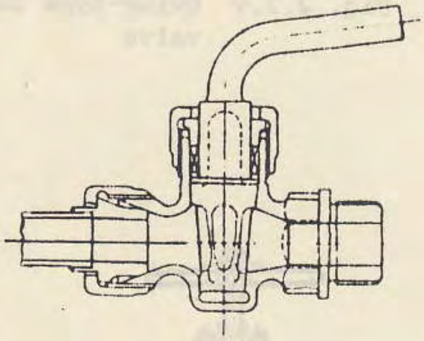


Fig. 2.2.13 Screwed cock

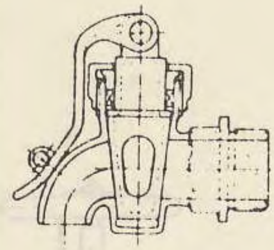


Fig. 2.2.14 Cock with lock and key

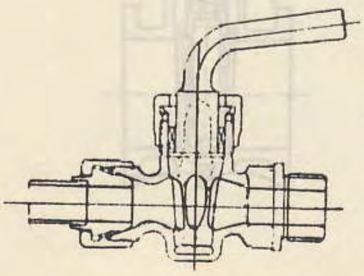
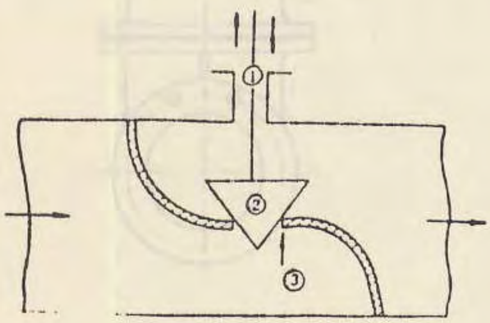
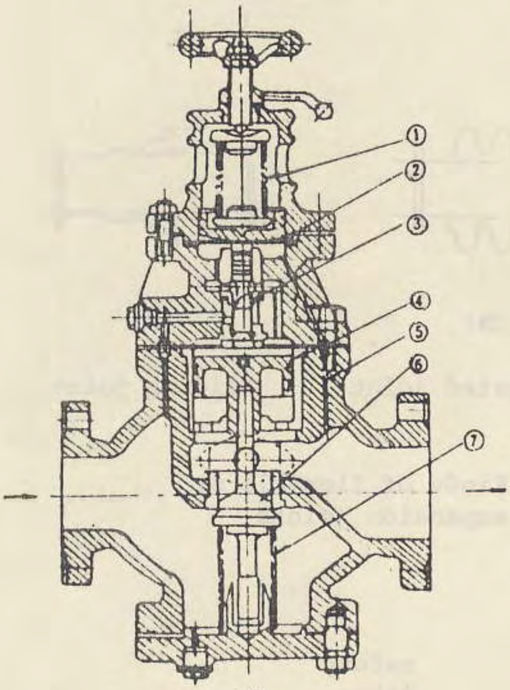


Fig. 2.2.15 Cock for pressure gauge



1. Valve spindle
2. Valve (body)
3. Valve sheet

Fig. 2.2.16 Diagramm of valve



(A)

1. Adjusting valve
2. Diaphram
3. Pilot valve
4. Piston
5. Secondary air hole
6. Main valve
7. Spring for main valve
8. Handle for pressure adjusting
9. Diaphram

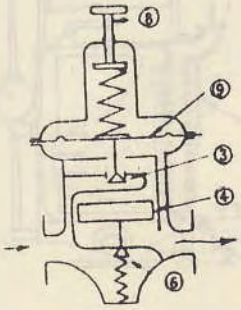
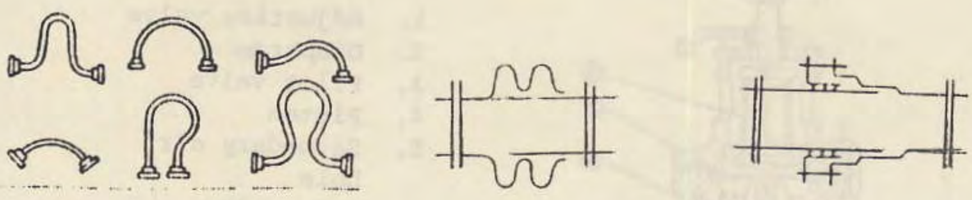


Fig. 2.2.17 Pressure-reducing valve



(A) Bend pipe joint
(B) Corrugated joint
(C) Sliding joint

Fig. 2.2.18 Kinds of flexible or expansion joints

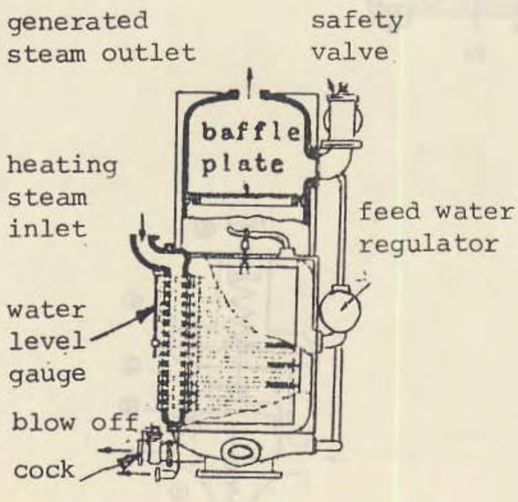
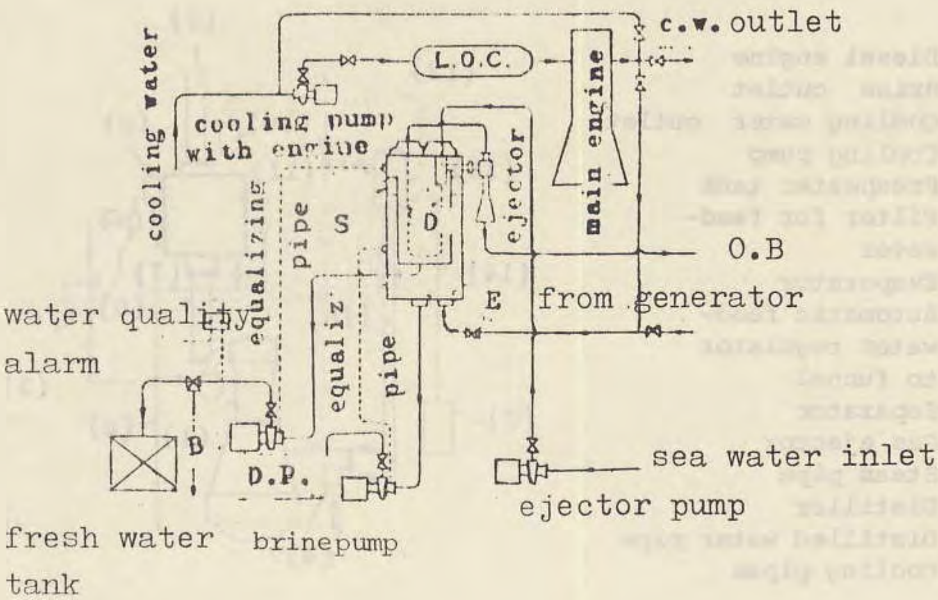


Fig. 2.3.1 Evaporator



D....Distiller
E....Evaporator
S....Separater

B...to ship bottom D.P...Distilling water pump
O.B...to overboard

Fig. 2.3.2 Low-pressure type distilling plant using diesel engine cooling water

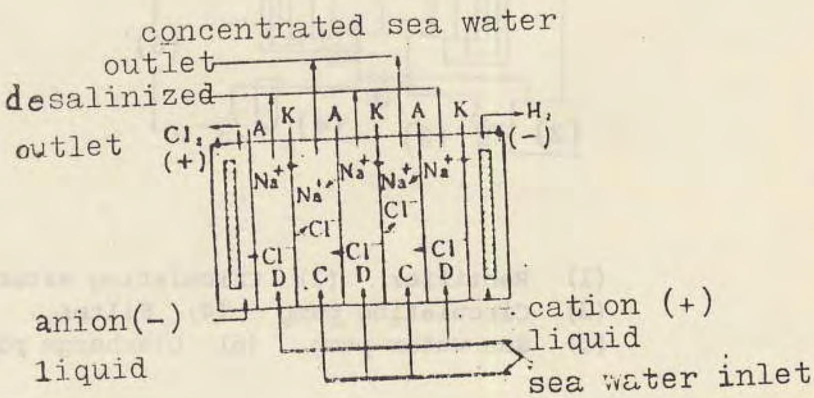


Fig. 2.3.4 Principle of ion-exchange type water desalinization

1. Diesel engine
2. Brine outlet
3. Cooling water outlet
4. Cooling pump
5. Freshwater tank
6. Filter for feed-water
7. Evaporator
8. Automatic feed-water regulator
9. to funnel
10. Separator
11. Gas ejector
12. Steam pipe
13. Distiller
14. Distilled water pipe
15. Cooling pipes

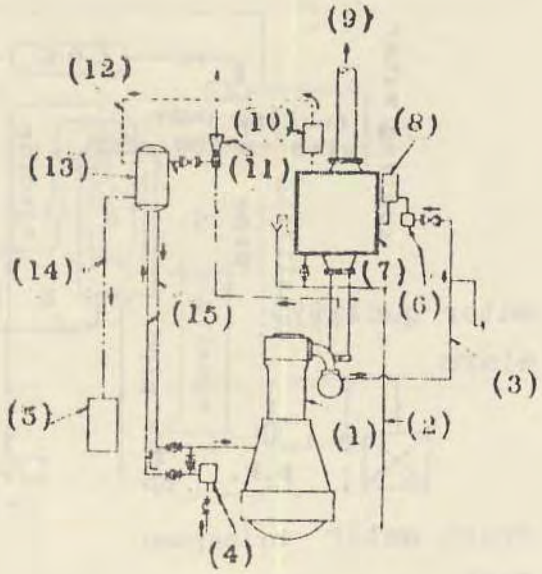
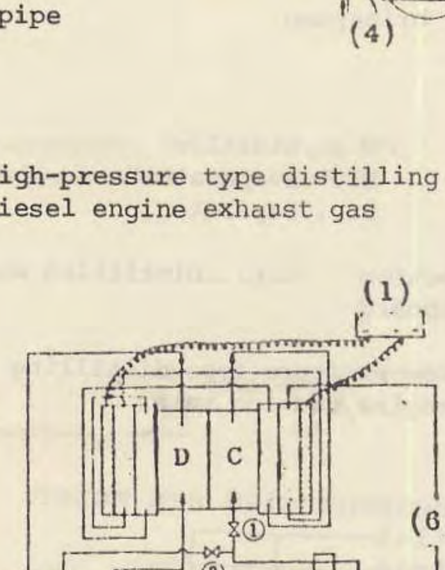
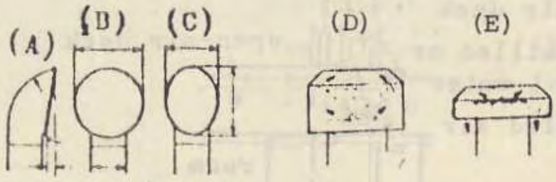


Fig. 2.3.3 High-pressure type distilling plant using diesel engine exhaust gas



(1) Rectifier (2) Circulating water tank
(3) Circulating pump (4) Filter
(5) Sea water pump (6) Discharge pipe

Fig. 2.3.5 Actual system of ion-exchange type



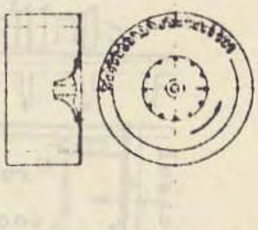


Fig. 2.4.2 Sirocco fan

(A)..cowl head type
(B)..circular head type
(C)..ellipitical type
(D)..splash-proof type
(E)..rain-proof type

Fig. 2.4.1 Cowl head type and mushroom head type ventilators

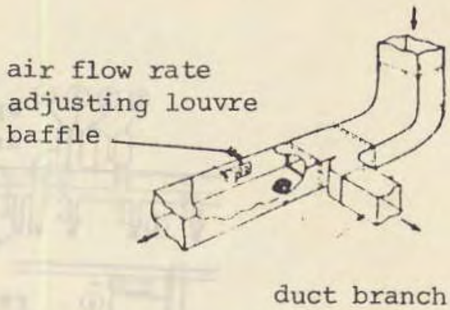


Fig. 2.4.4 Duct

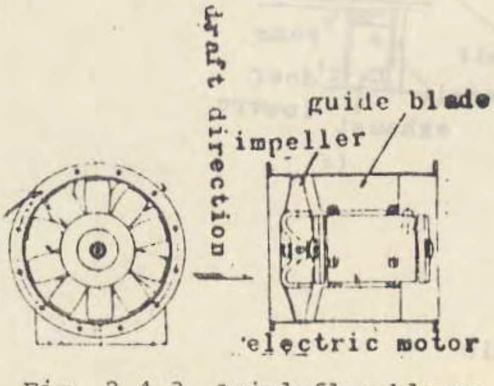


Fig. 2.4.3 Axial-flow blower

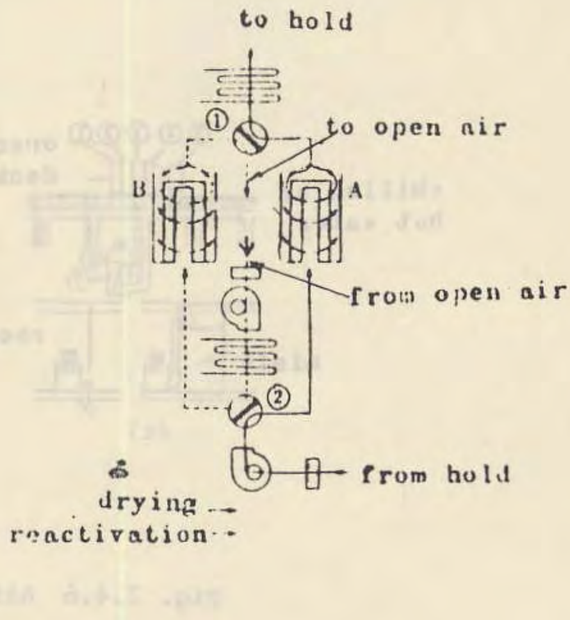
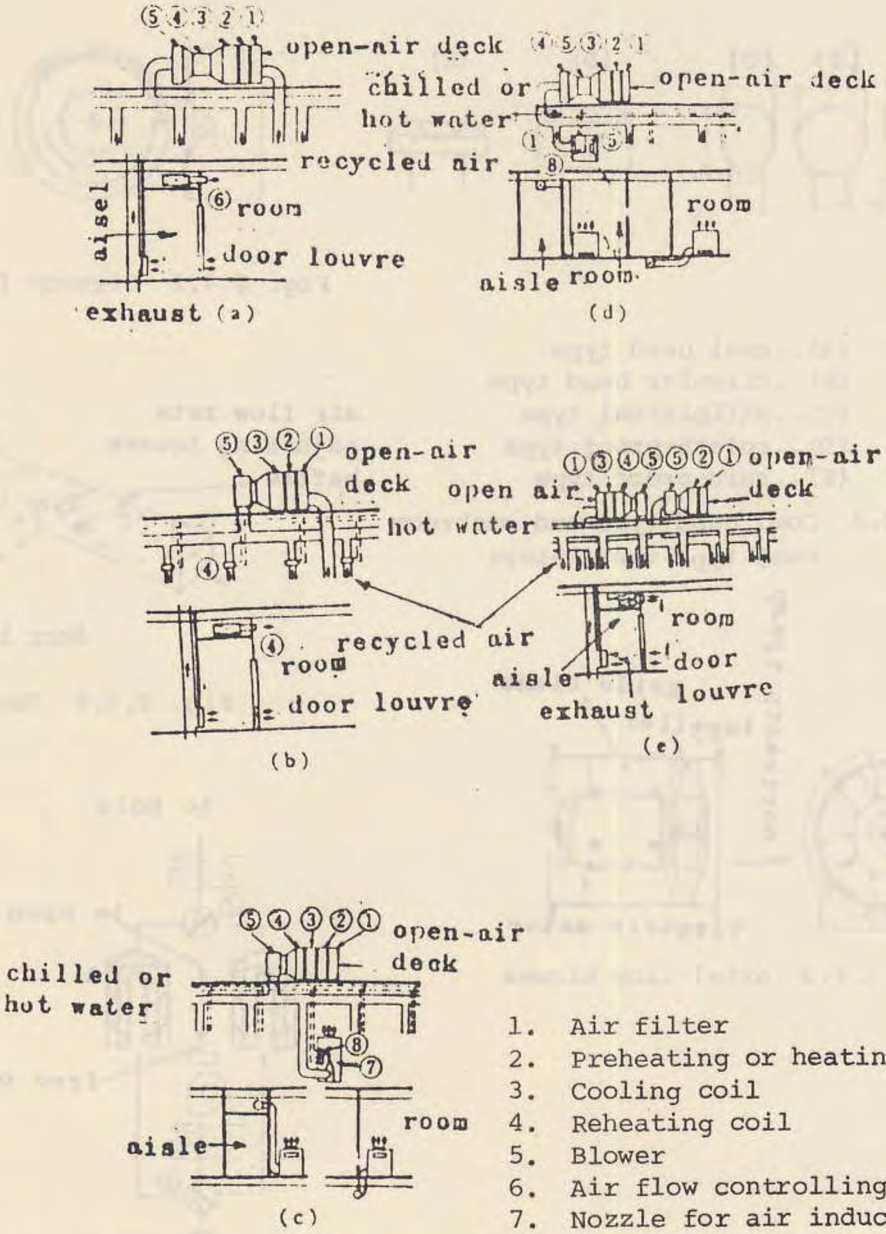


Fig. 2.4.5 Cargo Care



1. Air filter
2. Preheating or heating coil
3. Cooling coil
4. Reheating coil
5. Blower
6. Air flow controlling damper
7. Nozzle for air induced and recycled

Fig. 2.4.6 Air-conditioning systems

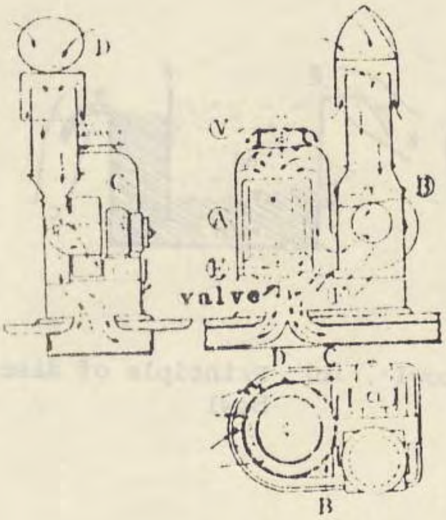
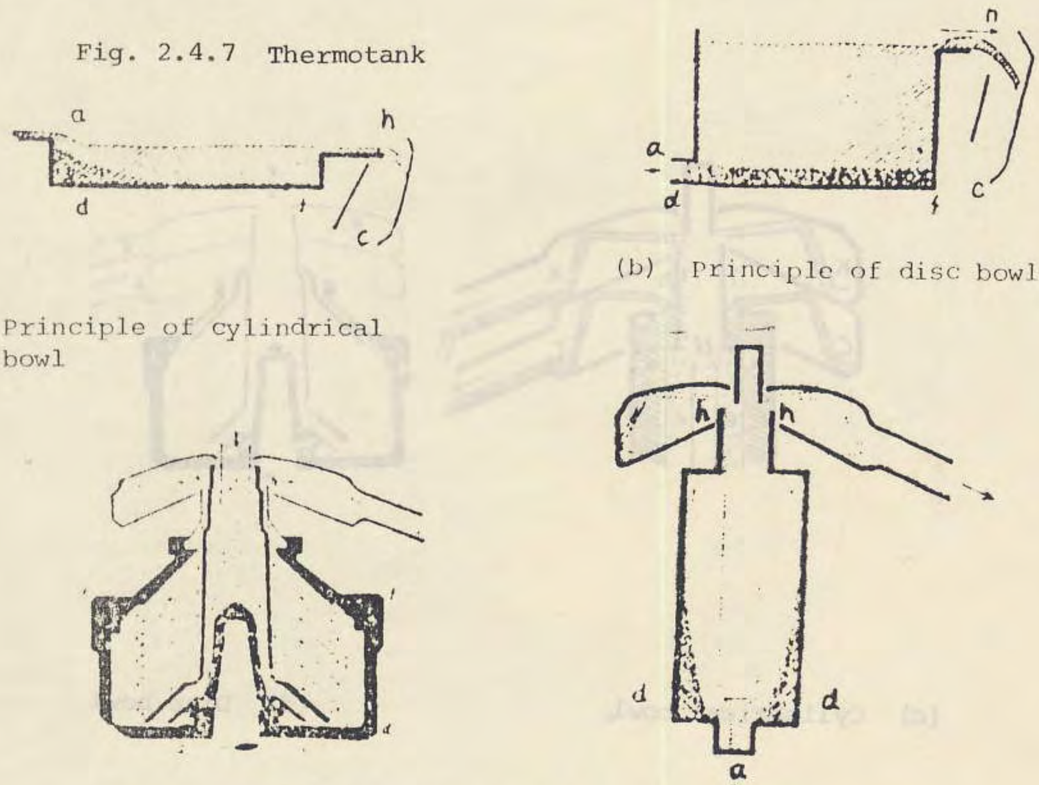


Fig. 2.4.7 Thermotank



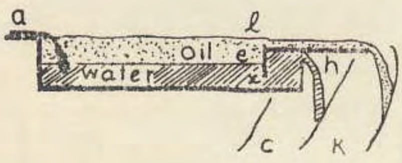
(a) Principle of cylindrical bowl

(b) Principle of disc bowl

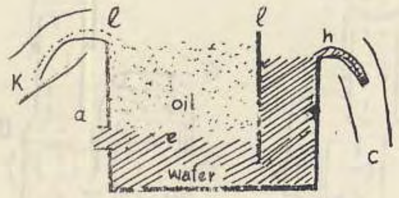
(c) Cylindrical bowl

(d) Disc bowl

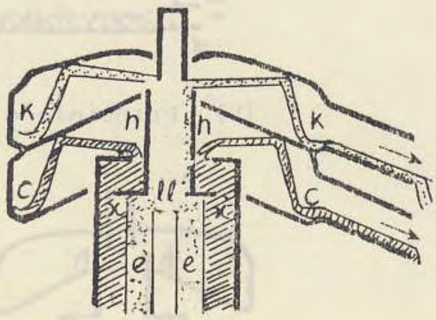
Fig. 2.5.1 Principle of clarification



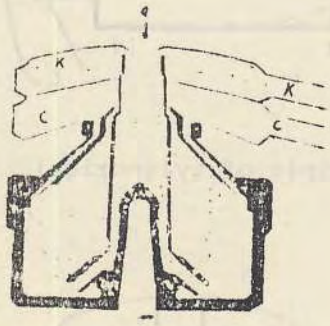
(a) Principle of cylindrical bowl



(b) Principle of disc bowl

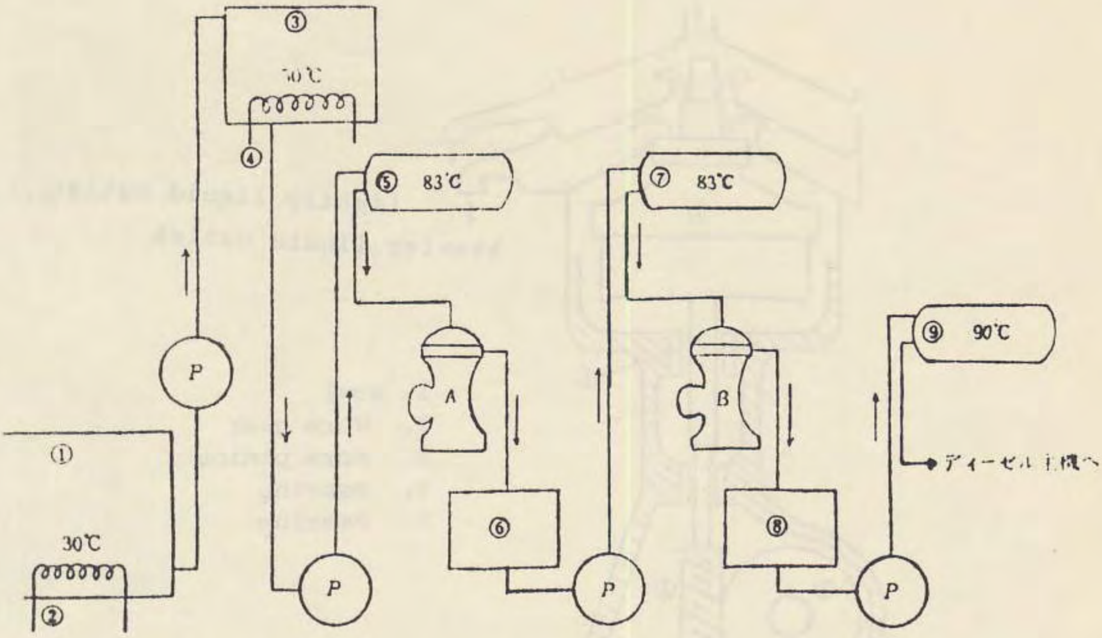


(c) Cylindrical bowl



(d) Disc bowl

Fig. 2.5.2 Principle of purification



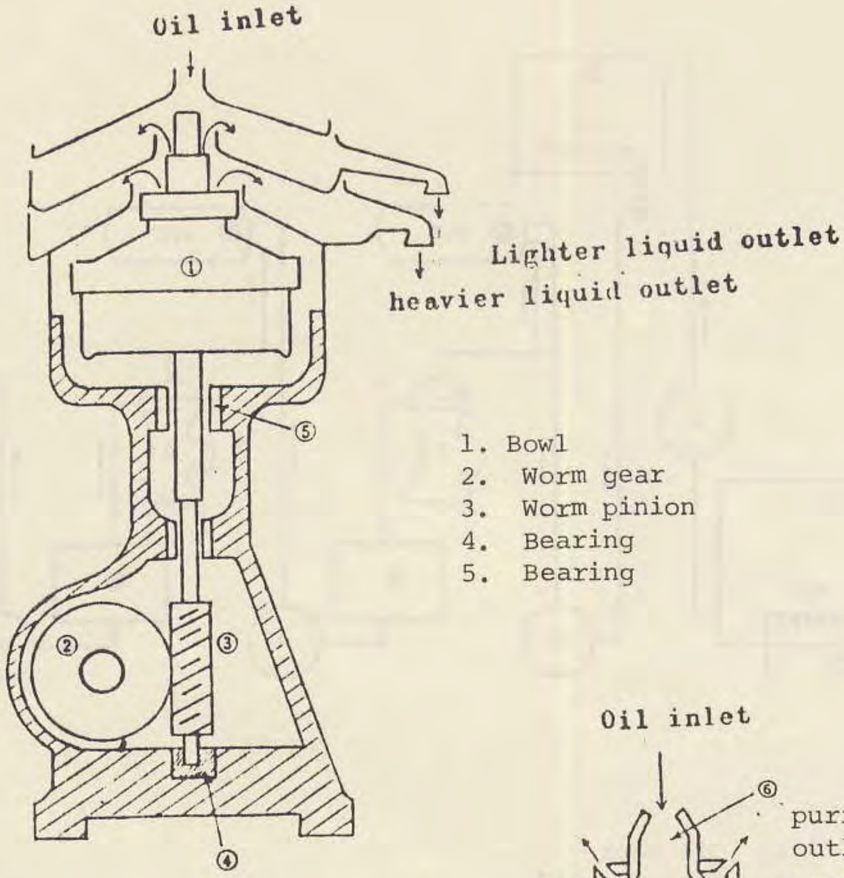
1. Oil tank
2. Heating coil
3. Settling tank
4. Heating coil
5. Heating coil for centrifuge
6. Purified oil tank
7. Heating coil for clarifier
8. Clarified oil tank
9. Heater for fuel oil

P. Oil pump

A. Purifier

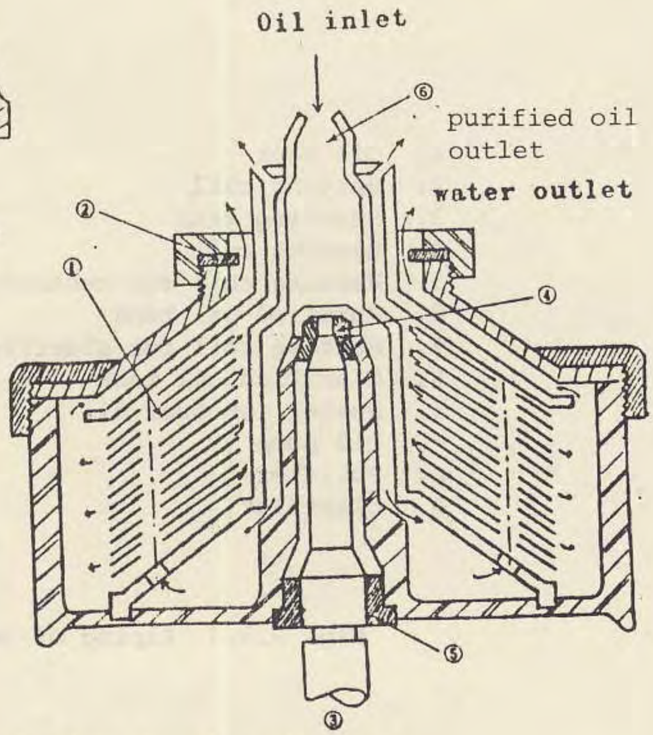
B. Clarifier

Fig. 2.5.3 Piping of large-sized diesel engine



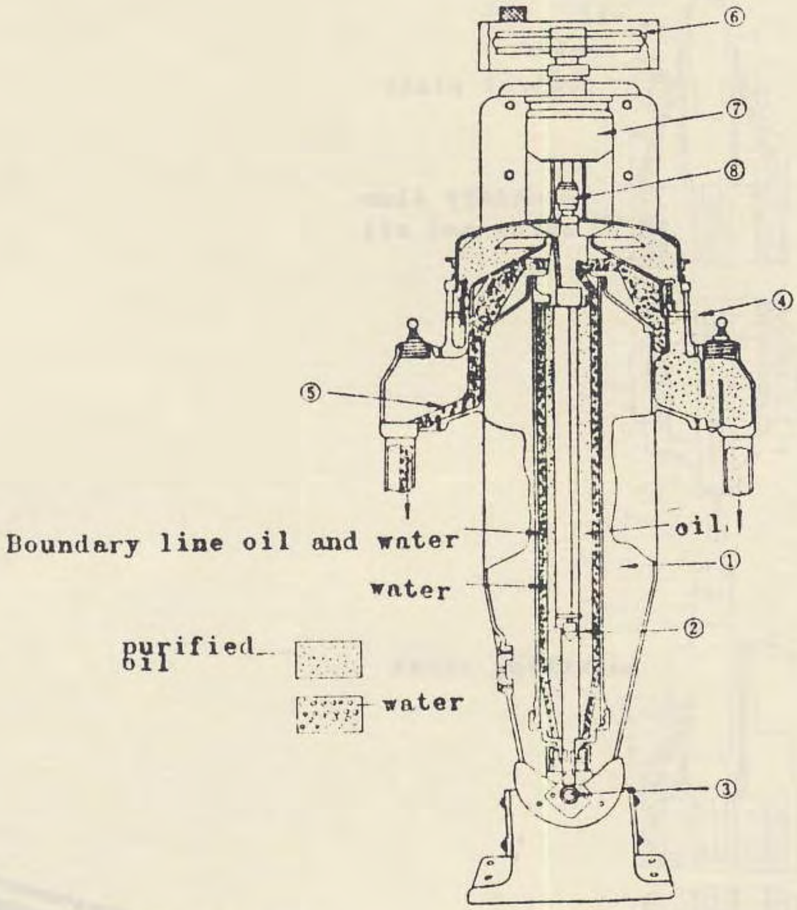
1. Bowl
2. Worm gear
3. Worm pinion
4. Bearing
5. Bearing

Fig. 2.5.4 De Laval centrifuge



1. Separating plate
2. Control plate
3. Bowl shaft
4. Cone metal
5. Bottom bush
6. Guide cylinder

Fig. 2.5.5 Bowl of De Laval centrifuge



1. Bowl
2. Three wing
3. Feed oil, water inlet
4. Purified oil outlet
5. Water outlet
6. Pulley
7. Bearing
8. Jointing nut

Fig. 2.5.6 Sharples centrifuge

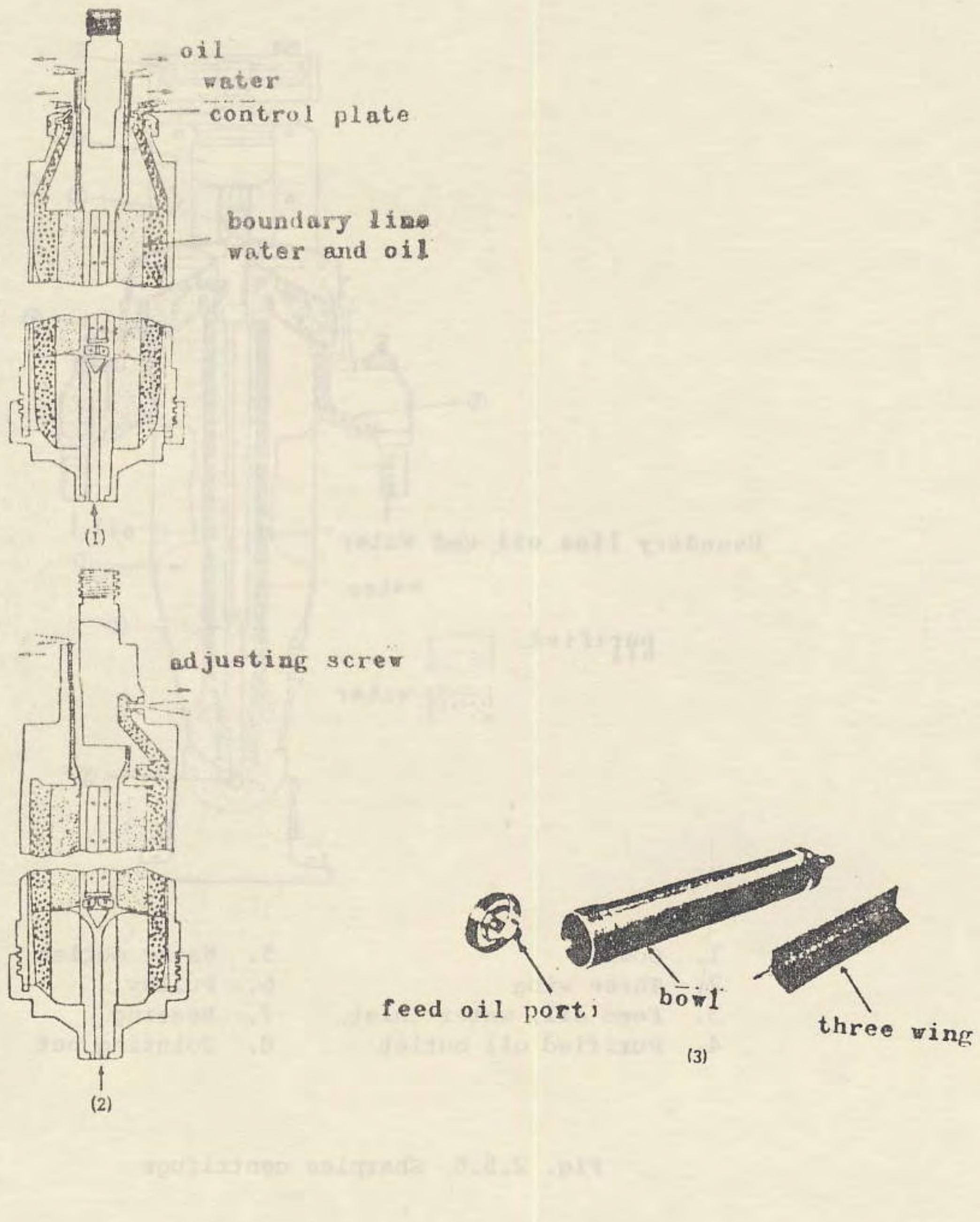
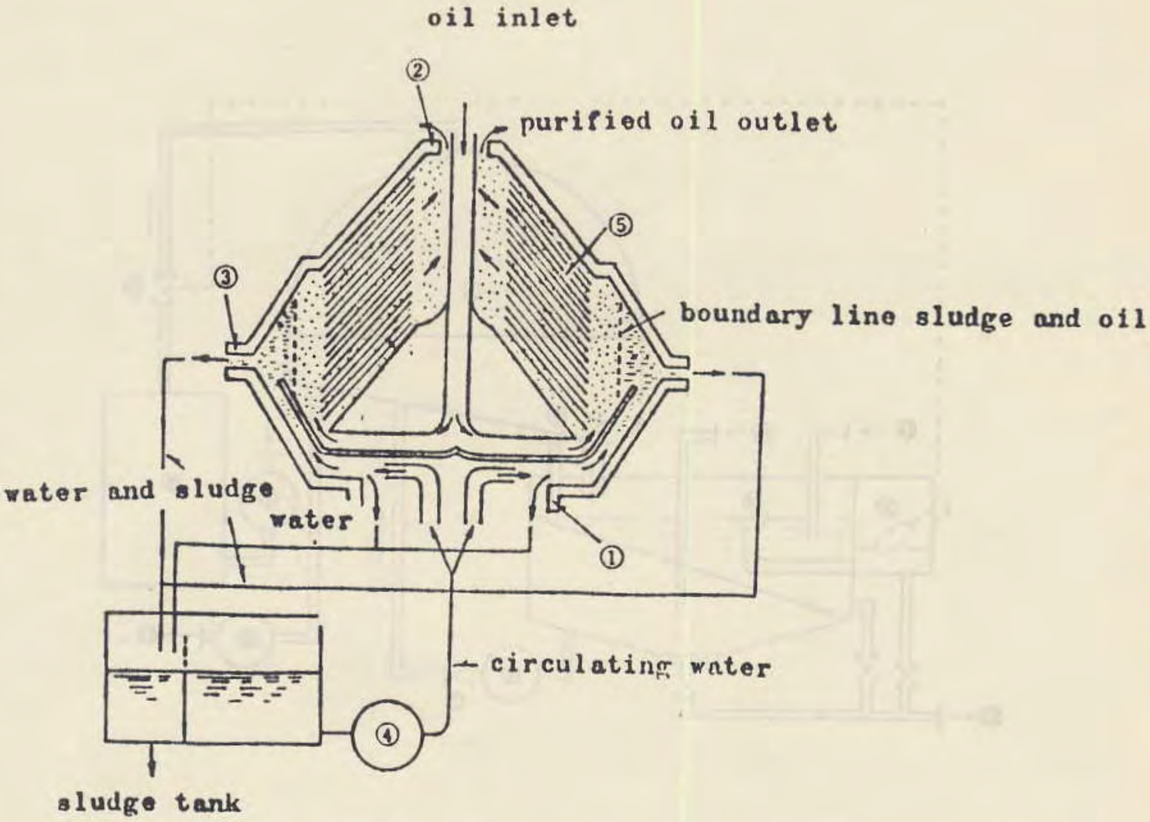


Fig. 2.5.7 Bowl of Sharples centrifuge



1. Reject dam
2. Control plate
3. Nozzle x 8
4. Circulating water pump
5. Separating plate

Fig. 2.5.8 Bowl of gravitrol centrifuge

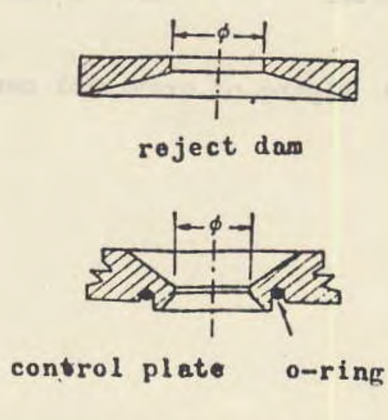
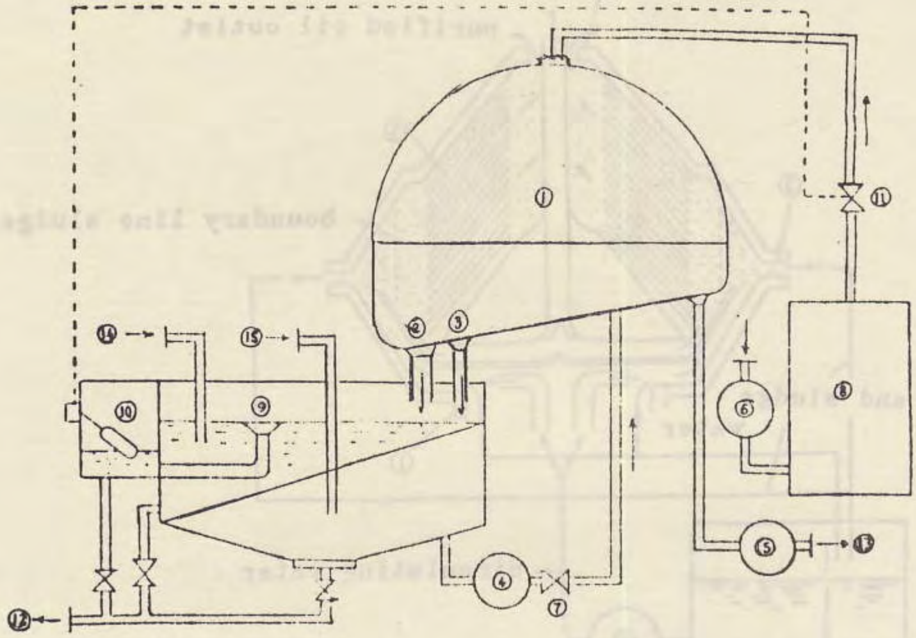
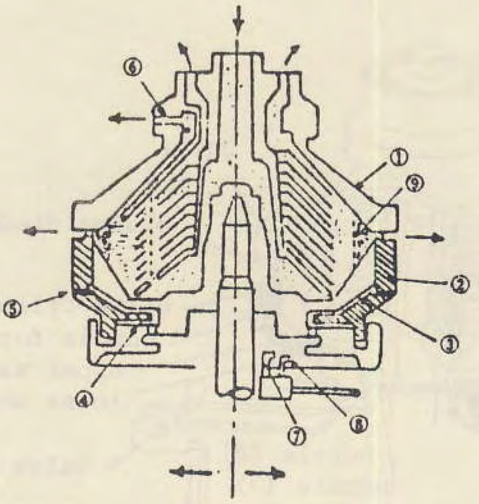


Fig. 2.5.9 Reject dam and control plate



1. Centrifuge
2. Sludge discharge port
3. Water discharge port
4. Water circulating pump
5. Pump for purified oil
6. Oil feed pump
7. Control valve for circulating water
8. Heater
9. Oil hopper
10. Alarming space
11. Solenoid valve
12. Sludge drain
13. Purified oil
14. Water pipe
15. Steam pipe for heating

Fig. 2.5.10 Piping of gravitrol centrifuge



1. Cover
2. Valve cylinder
3. Upper water pressure space
4. Lower water pressure space
5. Nozzle for water
6. Adjusting screw
7. Nozzle
8. Nozzle
9. Boundary line

Fig. 2.5.11 Bowl of Self-jector centrifuge

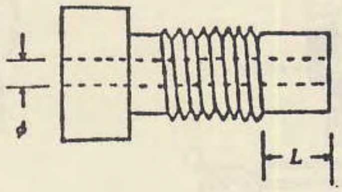


Fig. 2.5.12 Adjusting screw

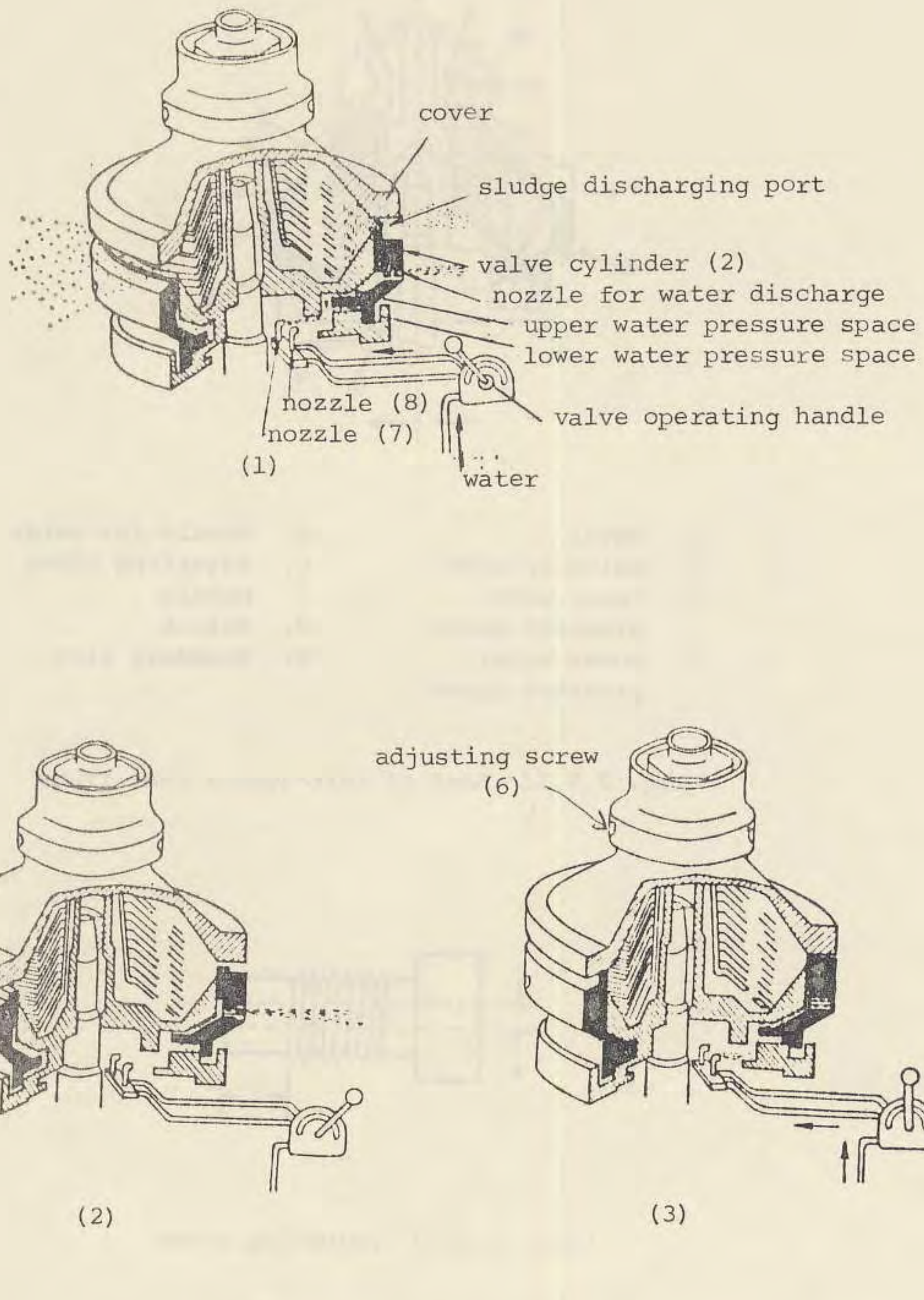
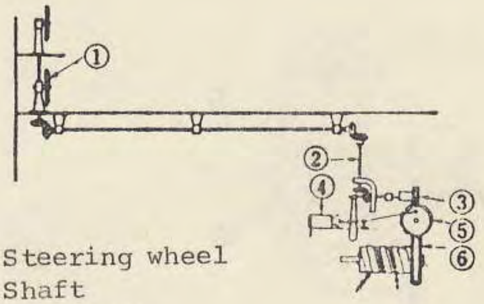
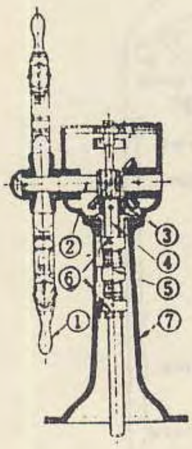


Fig. 2.5.13 Sludge discharging of
self-jector centrifuge



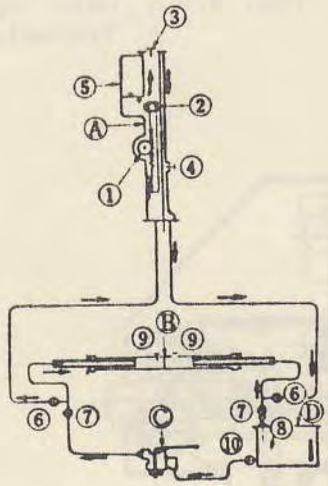
1. Steering wheel
2. Shaft
3. Worm gear
4. Control valve
5. Worm
6. Worm gear

Fig. 2.6.1 Mechanical type steering gear



1. Steering wheel
2. Shaft
3. Bevel gear
4. Shaft
5. Nut
6. Stopper
7. Casing

Fig. 2.6.2 Steering wheel



1. Piston
2. Pinion
3. Air purge plug
4. Manual bypass valve
5. Make-up tank
6. Connecting valve
7. Priming valve
8. Back-pressure valve
9. Air purge plug
10. Connecting valve
A. Starting cylinder
B. Driven cylinder
C. Injection pump
D. Injection tank

Fig. 2.6.3 Hydraulic steering gear

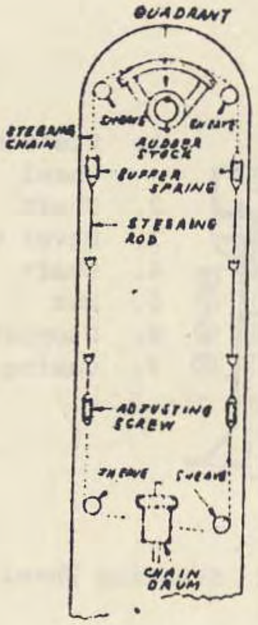
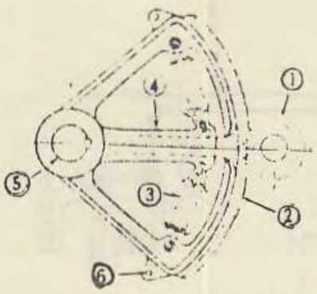


Fig. 2.6.4 Chain drum type transmission gear



1. Pinion
2. Rudder quadrant
3. Buffer spring
4. Rudder tiller
5. Rudder stock
6. Manual shackle hole

Fig. 2.6.5 Gear type transmission gear

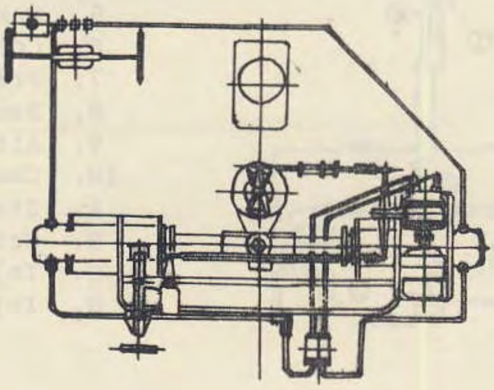


Fig. 2.6.6 Rapson slide shoe type 1-ram, 2-cylinder system

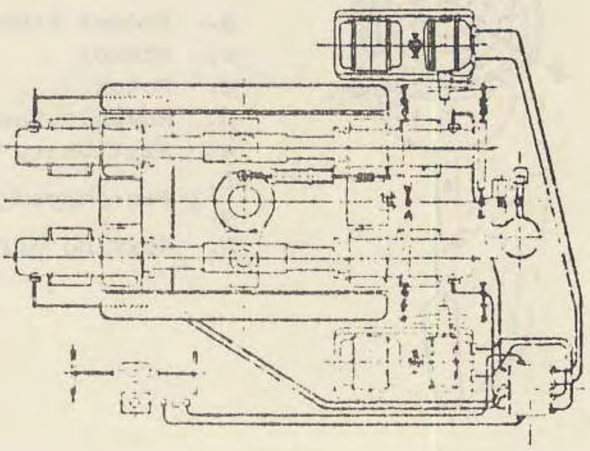


Fig. 2.6.7 Rapson slide shoe type 2-ram, 4-cylinder system

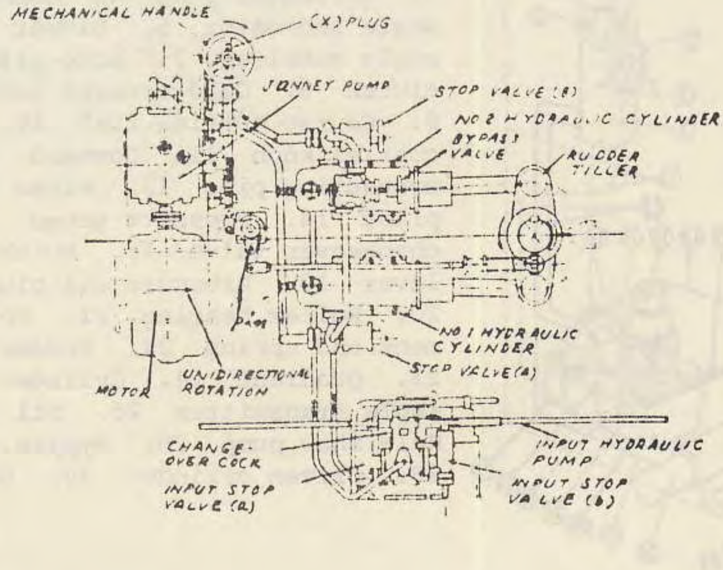
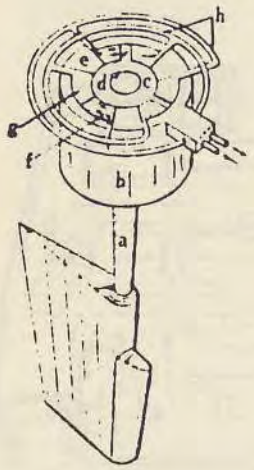
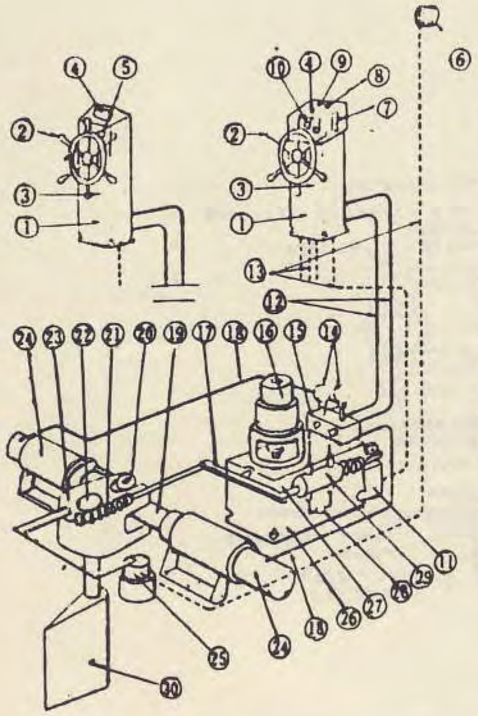


Fig. 2.6.8 Trunk piston type transmission gear



a. Rudder stock
b. Stator
c. Rotor
d. Movable vane
e. Stationary vane
f.
g. } Fan-shaped pressure chamber
h. Working oil manifold

Fig. 2.6.9 Rotary vane type transmission gear



1. Telemotor stand 2. Telemotor stand 3. Telemotor pump 4. Command rudder angle indicator 5. Dimmer 6. Rudder angle receiver 7. Auto-pilot changeover clutch 8. Card (course indicator) 9. Course setting knob 10. Weather control knob 11. Command 12. Telemotor connecting pipe 13. Wires for helm and pilot 14. Pressure gauge 15. Automatic changeover valve 16. Motor 17. Floating lever 18. Pressure oil pipe 19. Ram 20. Roller bearing 21. Follow-up equipment and spring 22. Rudder stock 23. Quadrant 24. Cylinder 25. Rudder angle transmitter 26. Oil tank 27. Hele Shaw pump 28. Bypass valve 29. Driven cylinder 30. Rudder

Fig. 2.6.10 Arrangement of Hele Shaw type electro-hydraulic rudder gear

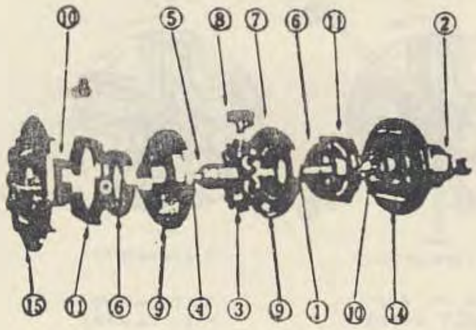


Fig. 2.6.11 Hele Shaw pump disassembly

1. Tubular shaft
2. Washer for tubular shaft
3. Rotating cylinder
4. Transmission shaft
5. Nut for transmission shaft
6. Ball bearing for slide ring
7. Piston
8. Slide metal
9. Slide ring
10. Ball bearing for rotating cylinder
11. Eccentric slide head
14. Cover on the pipe connection side
15. Motor side cover

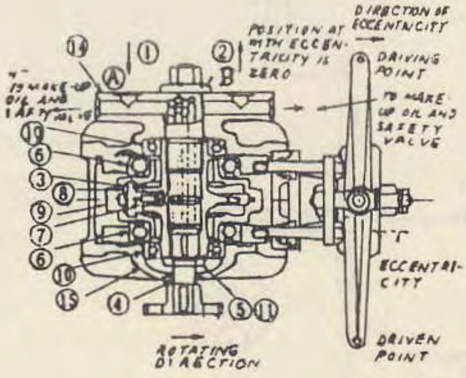


Fig. 2.6.12 Sectional view of Hele Shaw pump assembly

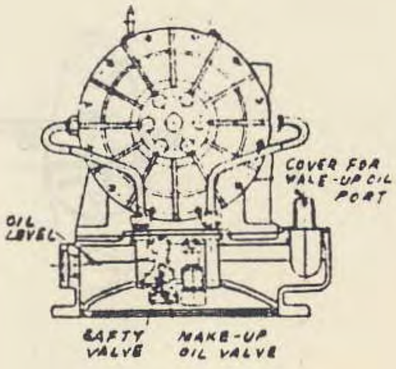


Fig. 2.6.13 Outward form of Hele Shaw pump

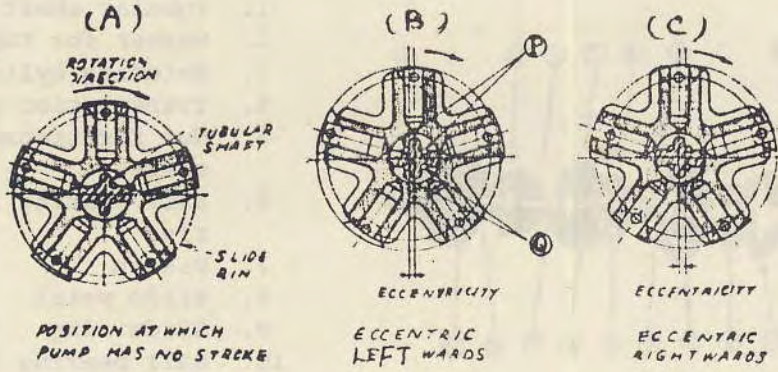


Fig. 2.6.14 Operation of Hele Shaw pump

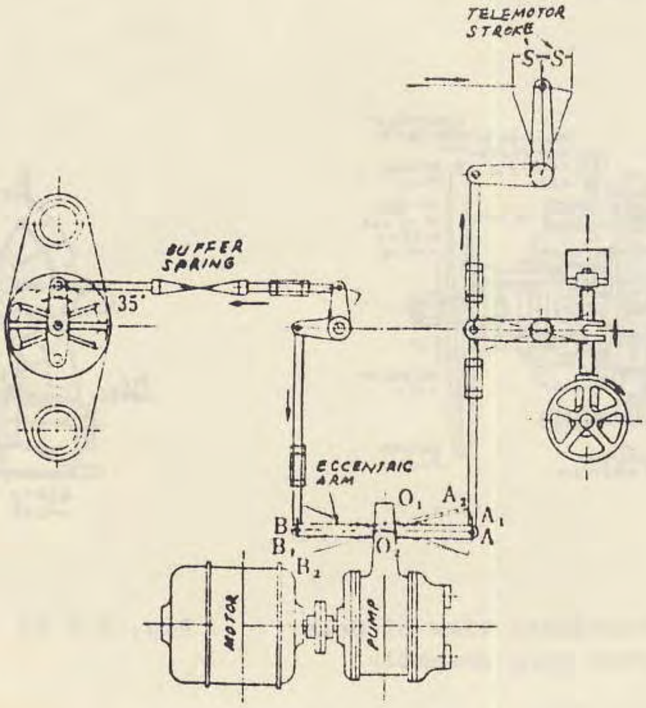


Fig. 2.6.15 Illustrative view of the function of Hele Shaw electro-hydraulic rudder gear

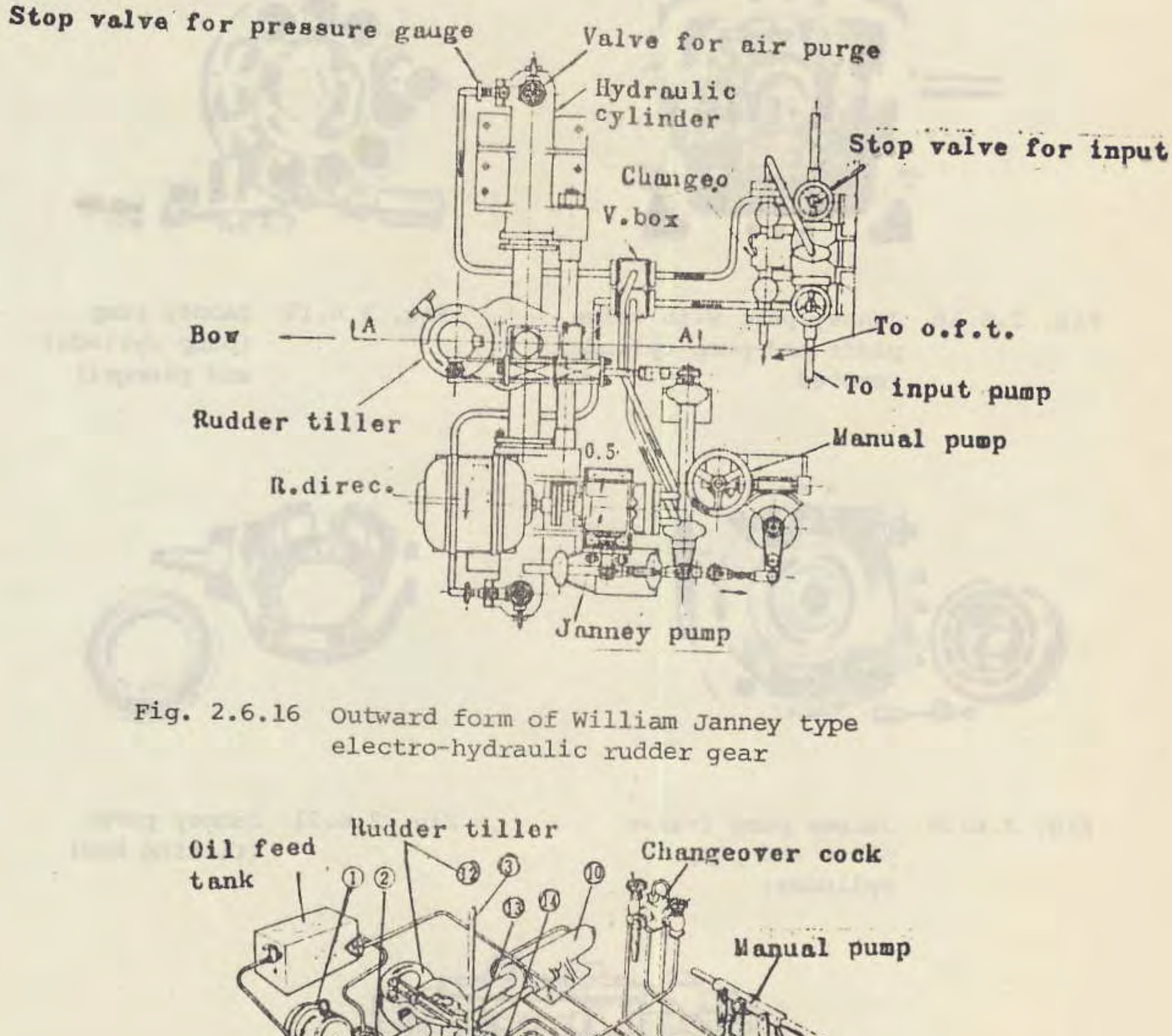


Fig. 2.6.16 Outward form of William Janney type electro-hydraulic rudder gear

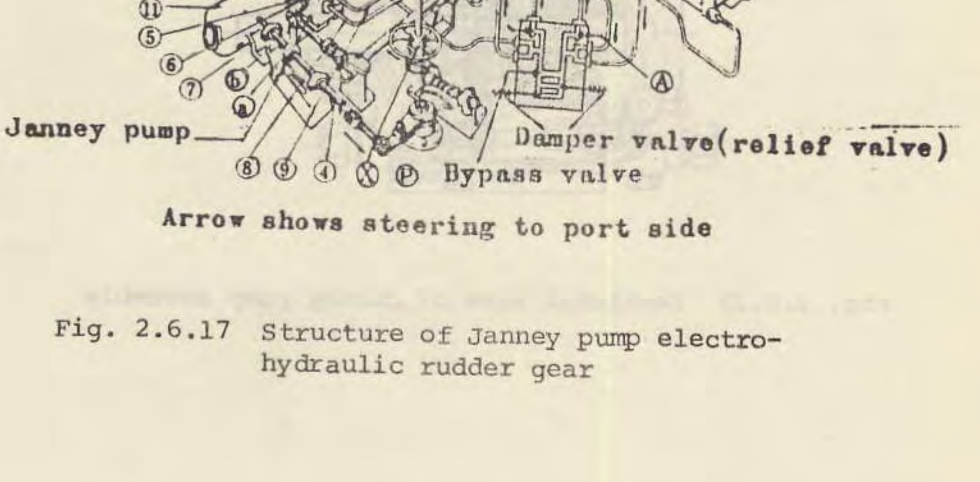


Fig. 2.6.17 Structure of Janney pump electro-hydraulic rudder gear

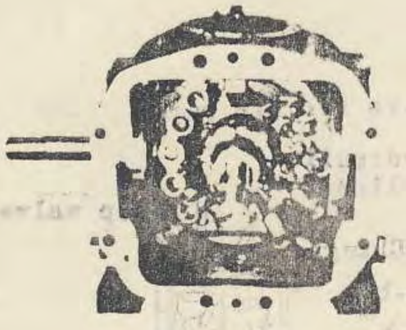


Fig. 2.6.18 Janney pump with valve plate and pump cylinder removed

Fig. 2.6.19 Janney pump (pump cylinder and plunger)

Fig. 2.6.20 Janney pump (valve plate and pump cylinder)

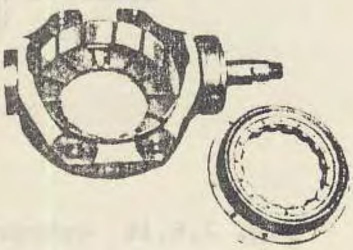


Fig. 2.6.21 Janney pump (tilting box)

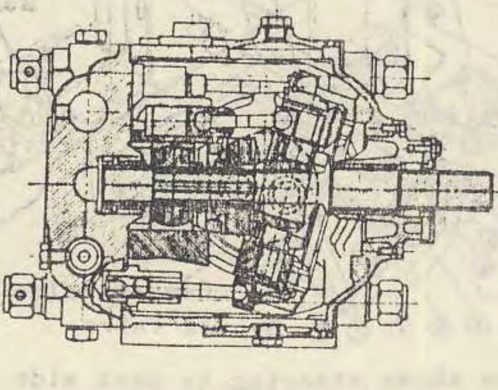
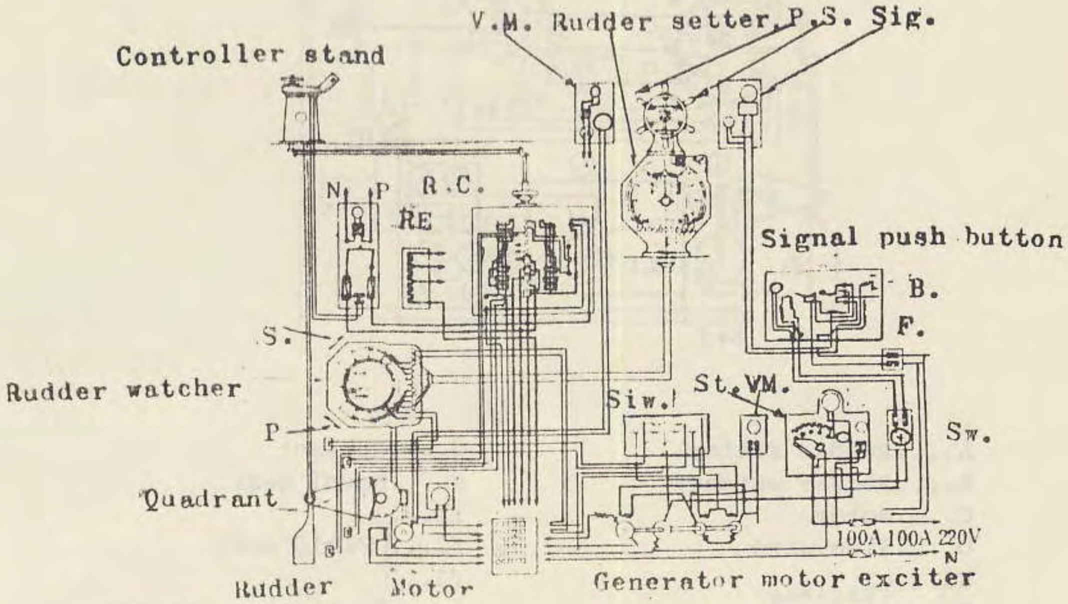
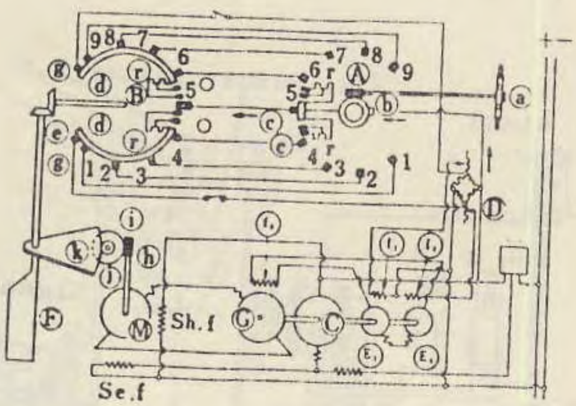


Fig. 2.6.22 Sectional view of Janney pump assembly



V.M....Volt meter
Sig....Signal
B......Buzzer
Sw.....Switch
Re.....Resistor
P......Port
S......Starboard
R.C....Reversible controller
F......Fuse
St.....Starter
Siw....Side wire for balancing resistor

Fig. 2.6.23 Wiring diagram of electric steering gear



A....Rudder setter
B....Rudder watcher
C....Motor
D....Side wire
E1...} Exciter
E2...}
F....Rudder
G....Generator
M....Rudder motor
a....Steering wheel
b....Worm gear
c....Contact piece
d....Contact
e....Bevel gear
f1...}
f2...} Field coil
f3...}
g....Stationary contact
h....Worm
i....Worm gear
j....Pinion
k....Quadrant
r....Resistor
Se.f.Series field coil

Fig. 2.6.24 Circuit connection of electric steering gear

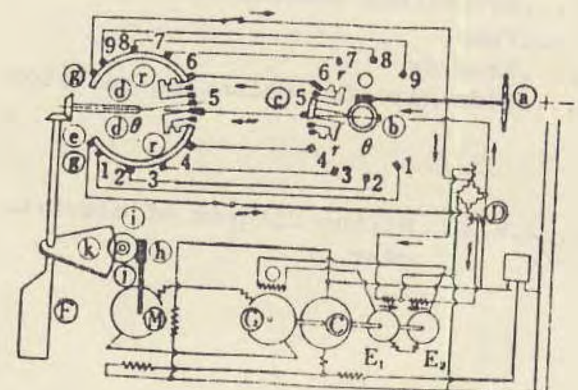


Fig. 2.6.25 Circuit connection for rudder setter and rudder watcher

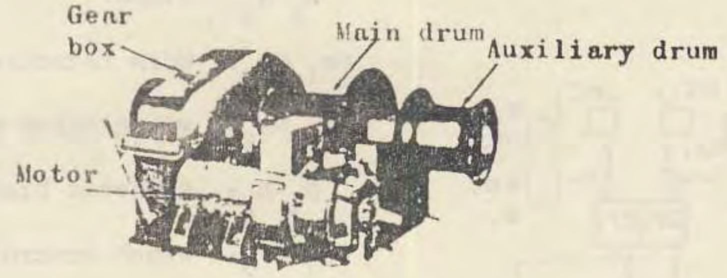
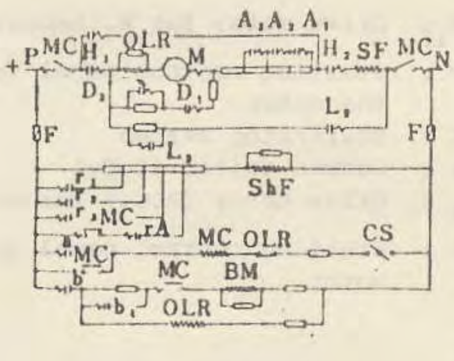


Fig. 2.7.1 Direct current winch

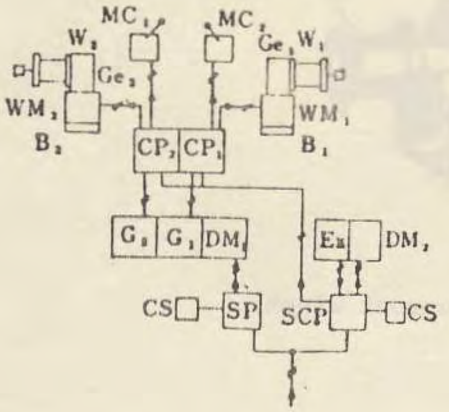


	Casting						Lifting				
	5	4	3	2	1	0	1	2	3	4	5
H_1							O	O	O	O	O
H_2							O	O	O	O	O
L_1	O	O	O	O	O						
L_2	O	O	O	O	O						
L_3	O	O	O	O							
A_1	O	O	O						O	O	O
A_2										O	O
A_3	O	O									O
D_1				O	O		O				
D_2					O						
r_1	O	O	O	O	O	O	O	O			
r_2	O	O	O	O	O						
r_3		O	O	O	O						
r_4			O	O	O						
a						O					
b	O	O	O	O	O		O	O	O	O	O
b_1					O	O	O				

Sequence diagram for the operation of controller contact

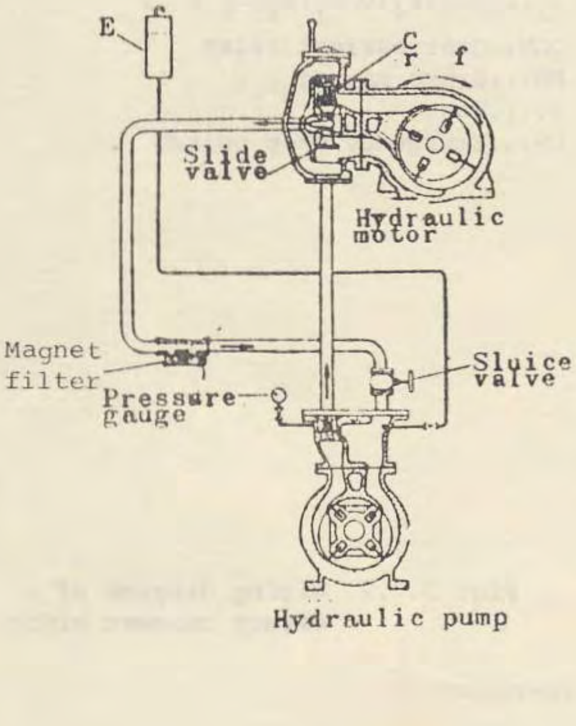
M....Motor
ShF..Shunt coil of motor
SF...Series coil of motor
MC...Magnetic contactor
$H_1, H_2, A_1, A_2, A_3, L_1, L_2, L_3$, $r_1, r_2, r_3, r_4, b, b_1, D_1, D_2$ ..Cam controller
OLR..Over current relay
BM...Brake magnet
F....Fuse
CS...Emergency stop switch

Fig. 2.7.2 Wiring diagram of direct current winch



W_1 W_2: Winch
Ge_1 Ge_2: Worm reduction gear
WM_1 WM_2: Winch drive motor (D.C.)
B_1 B_2: Magnetic brake
CP_1 CP_2: Winch control board
MC_1 MC_2: Winch control panel
G_1 G_2: Ward-Leonard generator (D.C.)
DM_1: Drive motor for W. Leonard (A.C.)
SP : Starting control panel for the motor
CS : Start/stop switch
Ex : Common exiter (D.C.)
DM_2 : Drive motor (A.C.) for exiter
SCP : Starting control panel for motor

Fig. 2.7.3 Arrangement of Ward-Leonard alternating current winch



E...Expansion tank
C...Check valve
r...Reverse
f...Forward

Fig. 2.7.4 Hydraulic drive system of low-pressure type winch

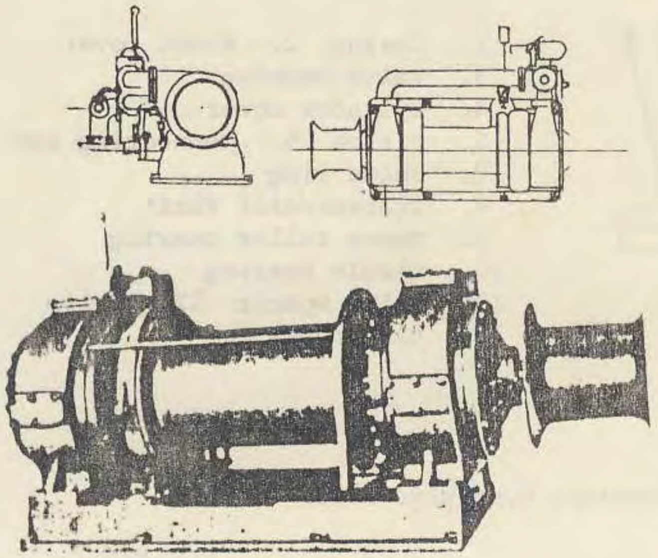


Fig. 2.7.5 Low-pressure type hydraulic winch

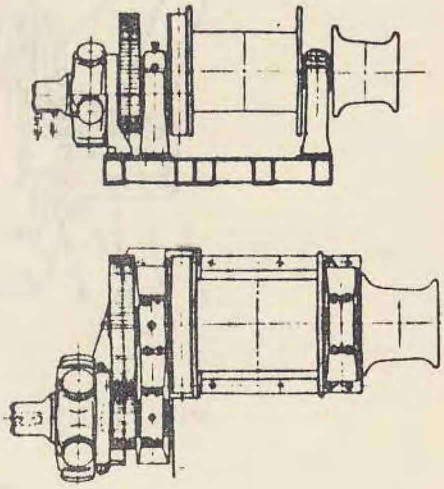
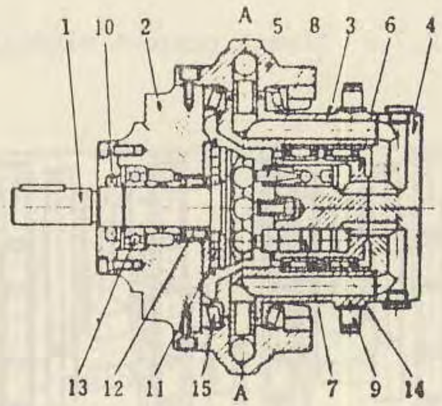


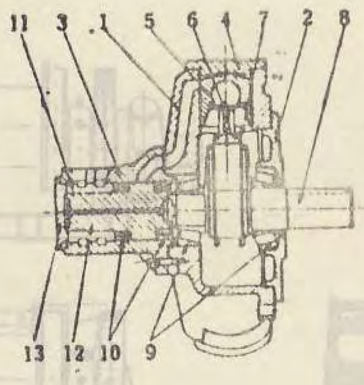
Fig. 2.7.6 High-pressure type hydraulic winch



1. Drive shaft
2. Bearing casing
3. Cylinder casing
4. Valve block
5. Pipe flange
6. Cylinder
7. Piston
8. Connecting rod
9. Taper pin
10. Oil seal
11. Radial bearing
12. Radial bearing
13. Ball bearing
14. Needle bearing
15. Taper roller bearing

A-A. Center line

Fig. 2.7.7 High-pressure hydraulic pump



1. Casing 2. Front cover
3. Valve housing
4. Cylinder cover
5. Piston 6. Connecting rod
7. Guide ring
8. Transmission shaft
9. Taper roller bearing
10. Needle bearing
11. Valve spacer 12. Valve
13. Rear cover

Fig. 2.7.8 High-pressure hydraulic motor

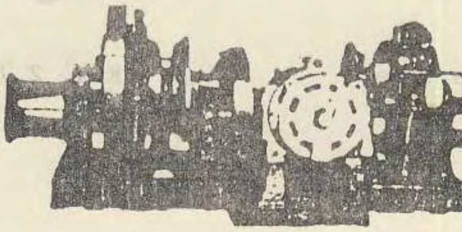


Fig. 2.7.9 Direct current windlass

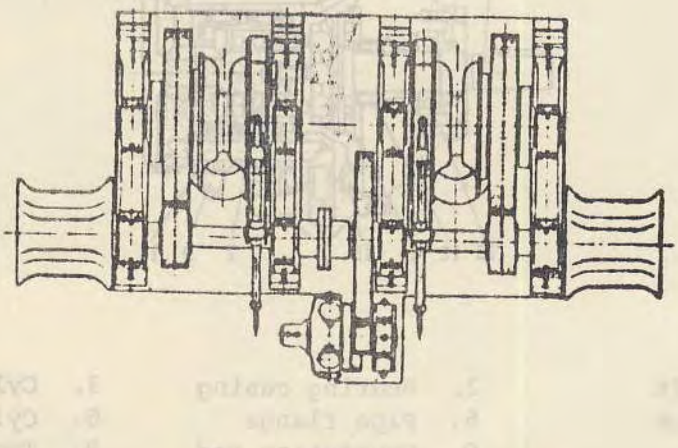


Fig. 2.7.10 Hydraulic windlass

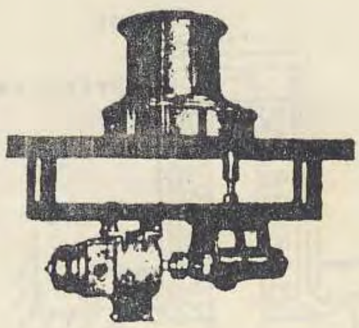


Fig. 2.7.11 Electric capstan

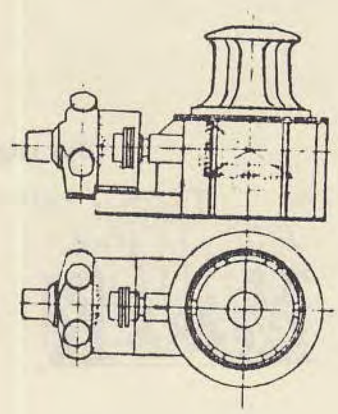
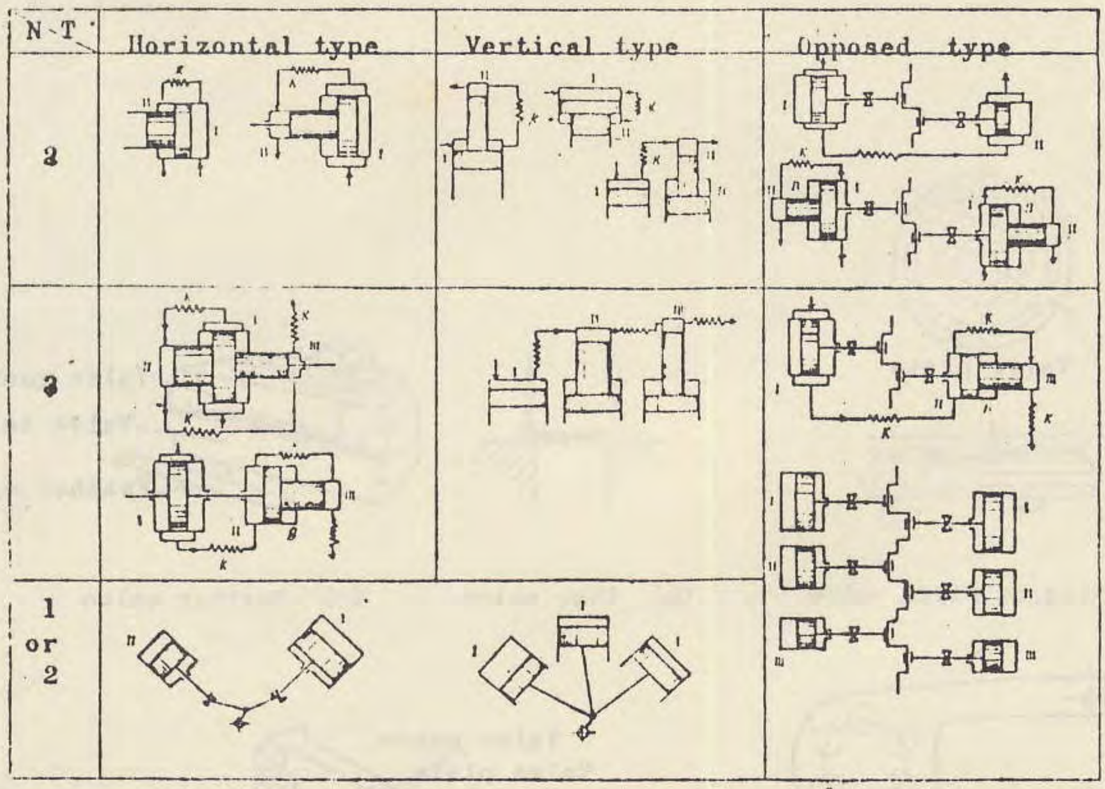
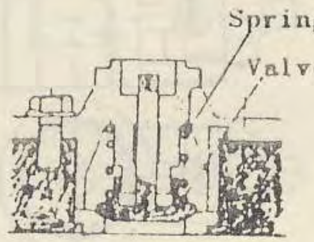


Fig. 2.7.12 Hydraulic capstan

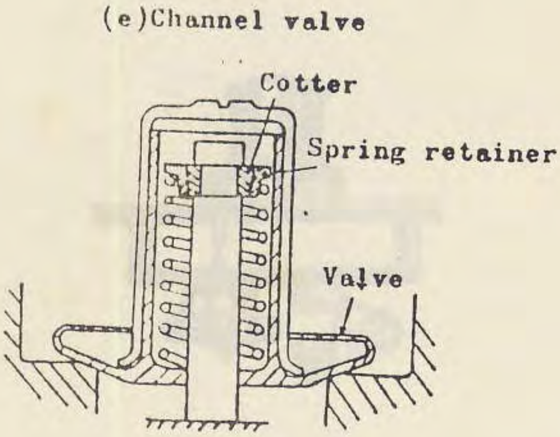


K...Inter- or After-cooler B...Torque balancing chamber T...Type
N...Number of stage

Fig. 2.8.1 Cylinder arrangement of air compressors

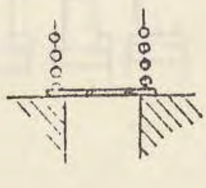


(f) Poppet valve

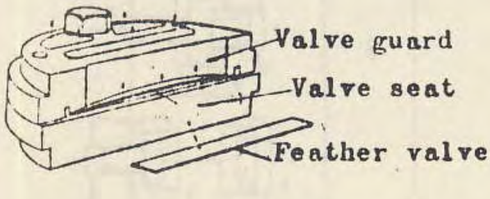


(g) Conical valve

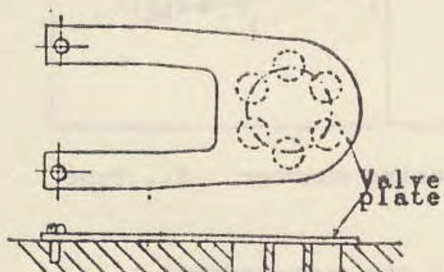
(a) Ring or Plate valve



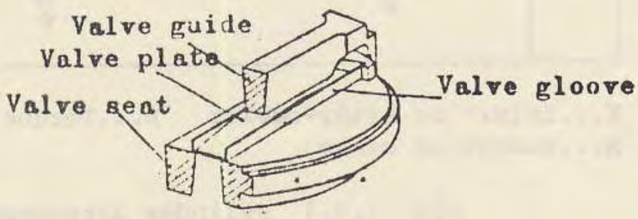
(b) Disc valve



(c) Feather valve

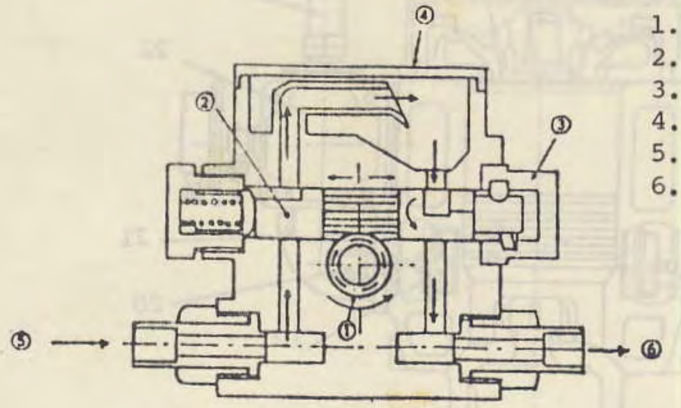


(d) Flapper valve



(e) Channel valve

Fig. 2.8.2 Kinds of valves for air compressor



1. Worm gear for driving shaft
2. Plunger
3. Flow rate controlling cam
4. Glass for oil check
5. Oil inlet
6. Oil outlet

Fig. 2.8.3 Drop type lubricator

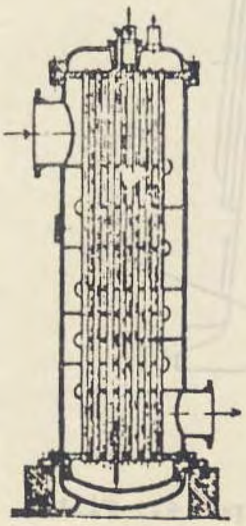


Fig. 2.8.4 Cylindrical multiple pipe type cooler

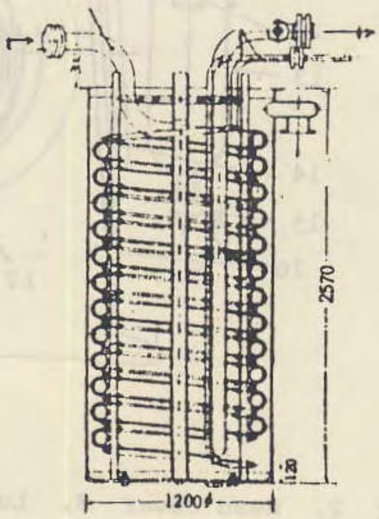
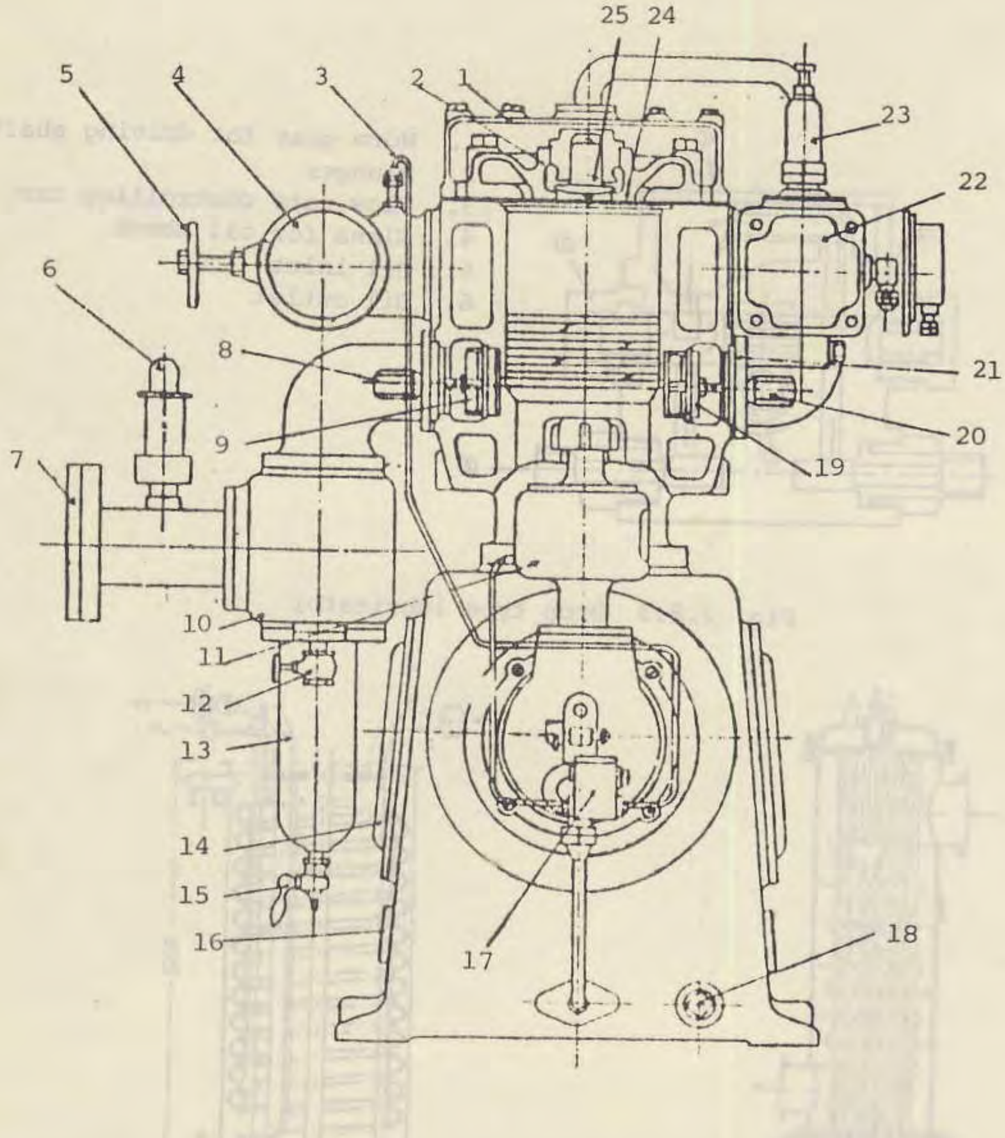
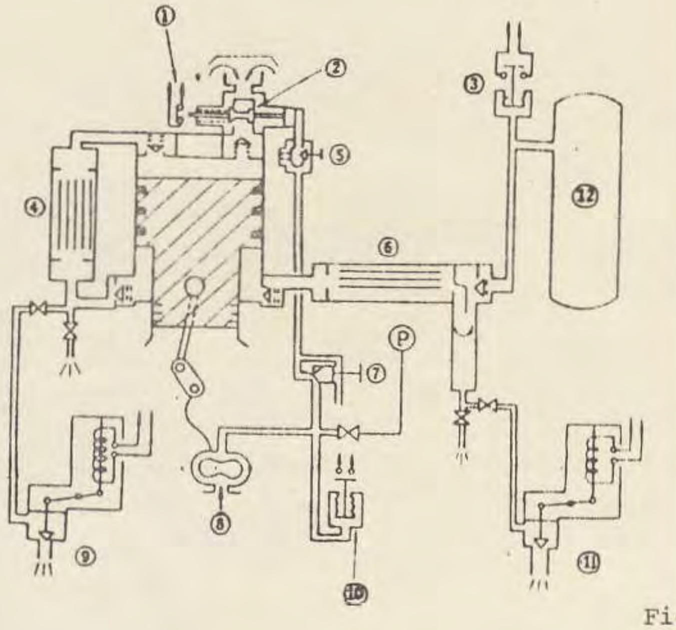


Fig. 2.8.5 Coil type cooler



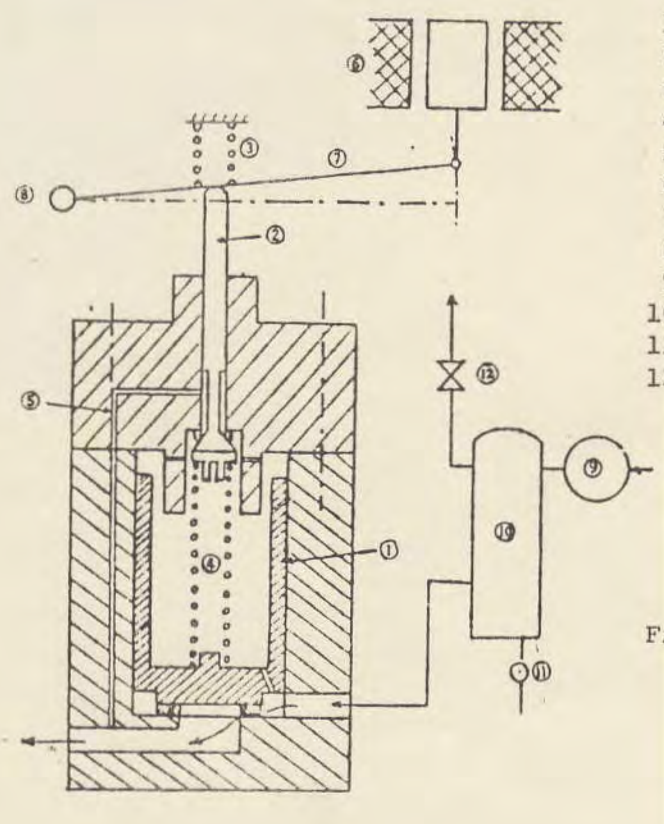
1. Cover 2. Head cover 3. Lubricating oil pipe 4. Filter 5. Throttle valve 6. Safety valve 7. Flange for delivery side 8. Cap nut for high-pressure delivery valve 9. High-pressure delivery valve 10. After-cooler 11. Oil box 12. Drain cock 13. Oil separator 14. Cover for crank chamber 15. Drain cock 16. Oil gauge 17. Lubricator 18. Drain plug for oil chamber 19. High-pressure suction valve 20. Cap for high-pressure suction valve 21. Flange for high-pressure suction valve 22. Inter-cooler 23. Safety valve for low-pressure 24. Low-pressure suction valve 25. Low-pressure delivery valve

Fig. 2.8.6 Vertical two-stage air compressor



1. Limit switch for alarm
2. Unloader for start
3. On-off switch (on at 25, off at 30 kg/cm^2)
4. Inter-cooler
5. Control valve for flow rate
6. After-cooler
7. Manual change valve
8. Lubricating oil pump
9. Solenoid valve for drain
10. Pressure switch for alarm
12. Air reservoir (Tank)

Fig. 2.8.7 Piping of air compressor



1. Air discharge valve
2. Pilot valve
3. Spring for lever
4. Spring for discharge valve
5. Discharge path
6. Solenoid for lever
7. Lever
8. Fulcrum for lever
9. After-cooler
10. Drain separator
11. Drain valve
12. Check valve

Fig. 2.8.8 No-load starting device