7 WATER TURBINES AND PUMPS

7.1 INTRODUCTION

The hydraulic machines which convert the hydraulic energy into mechanical energy are called turbines whereas the hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps. In this chapter, we shall study the various types of hydraulic turbines such as Pelton turbine, Francis turbine, Kaplan turbine etc. and various types of hydraulic pumps such as reciprocating pump, centrifugal pump etc.

7.2 TURBINE

A turbine is a hydraulic machine which converts the hydraulic energy into mechanical energy. The mechanical energy may further be converted into electrical energy. The electric power obtained from hydraulic energy is called hydro-electric power which, at present, is cheapest as compared to power generated by other sources such as coal, oil etc.

7.3 CLASSIFICATION OF HYDRAULIC TURBINES

Hydraulic turbines may be classified as follow :

1. *According to type of energy at inlet :*
   (*i*) Impulse turbine,
   (*ii*) Reaction turbine.
2. *According to direction of flow through runner :*
   (*i*) Axial flow turbine,
   (*ii*) Radial flow turbine,
   (*iii*) Tangential flow turbine,
   (*iv*) Mixed flow turbine.
3. *According to head available at the inlet of turbine :*
   (*i*) High head turbine,
   (*ii*) Medium head turbine,
   (*iii*) Low head turbine.
4. *According to specific speed of turbine :*
   (*i*) Low specific speed turbine,
   (*ii*) Medium specific speed turbine,
   (*iii*) High specific speed turbine.

7.4 IMPULSE TURBINE AND REACTION TURBINE

In an impulse turbine, the available head of water is first converted into velocity head or kinetic energy by passing it through a nozzle. Water leaves the nozzle in the form of very high velocity jet which strikes a series of buckets mounted on the periphery of a wheel and thus imparts energy to it. The wheel then revolves freely in the air. The pressure of water leaving the nozzle is atmospheric which remains constant while the water moves over the buckets *i.e.* an impulse turbine works under atmospheric pressure. Pelton wheel is an example of impulse turbine. Fig. 7.1 shows the principle of an impulse turbine.

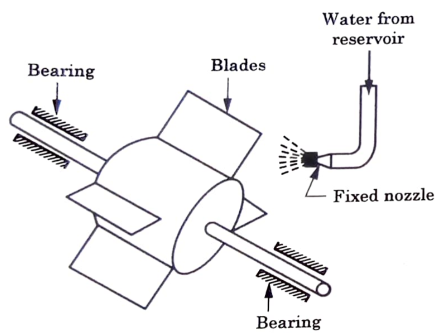

Fig. 7.1 : Impulse Turbine

In a reaction turbine, there is no separate nozzle to expand water before it enters the turbine. In this turbine, the shape of blades or vanes is such that when the water enters the wheel under pressure, it expands and thus pressure head is converted into velocity head till the pressure becomes atmospheric before leaving the wheel. Francis turbine and Kaplan turbine are the examples of reaction turbine. Fig. 7.2 shows the principle of pure reaction turbine.

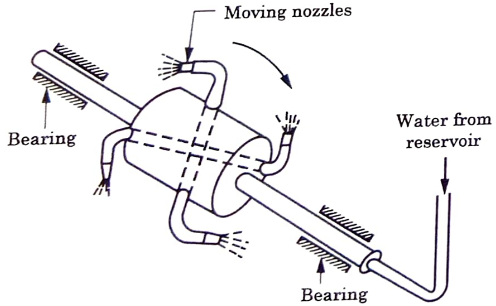

Fig. 7.2 : Reaction Turbine

7.5 DIFFERENCE BETWEEN IMPULSE TURBINE AND REACTION TURBINE

	Impulse Turbine	Reaction Turbine
1.	The head of water available is first converted into kinetic energy by a nozzle.	Only a portion of head available is converted into kinetic energy and there is no separate nozzle.
2.	The pressure of water remains constant and equal to atmospheric as the water passes through the wheel.	Both pressure and velocity of water vary as it passes through the wheel.
3.	The wheel does not run full so that the air has free access between the vanes.	The wheels always run full.
4.	Casing only prevents the splashing of water and guides the water to the tail race.	Casing is absolutely essential to seal the turbine.
5.	It does not require any draft tube.	Draft tube is needed to discharge water from the exit of turbine to the tail race.
6.	It is possible to regulate the flow without loss.	It is not possible to regulate the flow without loss.
7.	It is placed above the tail race.	It is kept entirely submerged in water.
8.	**Example :** Pelton wheel.	**Example :** Francis turbine, Kaplan turbine.

7.6 PELTON WHEEL OR PELTON TURBINE

Pelton wheel shown in fig. 7.3 (*a*) is a tangential flow, high head, low specific speed impulse turbine designed by L.A. Pelton, an American engineer. In this turbine, water from the reservoir flows through the penstock at the outlet of which a nozzle is fitted. The available head of water converts into velocity head or kinetic energy after passing through the nozzle. Water leaves the nozzle in the form of very high velocity jet which strikes the series of buckets (vanes) mounted on the periphery of the runner. The runner then revolves freely in the air. The important parts of pelton wheel are as follow :

1. Nozzle and spear,
2. Runner with buckets,
3. Casing,
4. Brake nozzle.

1. Nozzle and Spear : The quantity of water striking the buckets of the runner is controlled by providing a spear in the nozzle. The spear is of conical shape which is operated automatically or by a hand wheel in the axial direction. When the spear is pushed forward in the nozzle, the quantity of water striking the buckets is reduced, whereas, when the spear is pushed backward, the quantity of water striking the buckets increases.

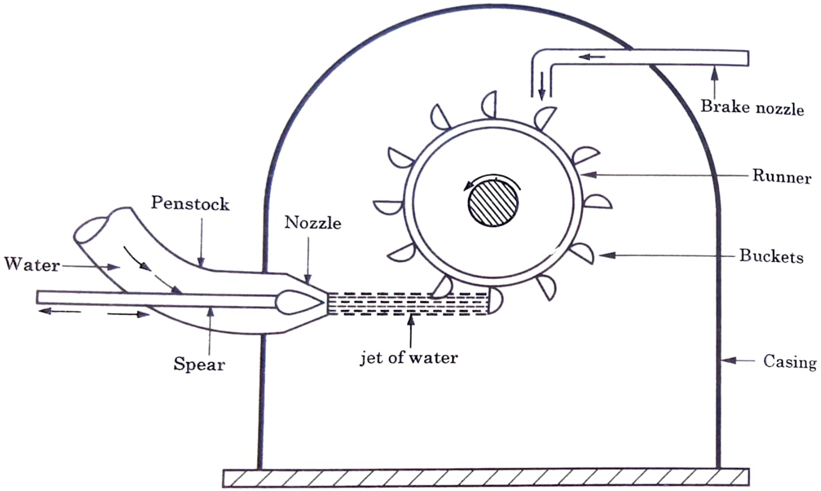

Fig. 7.3 (*a*) : Pelton Wheel

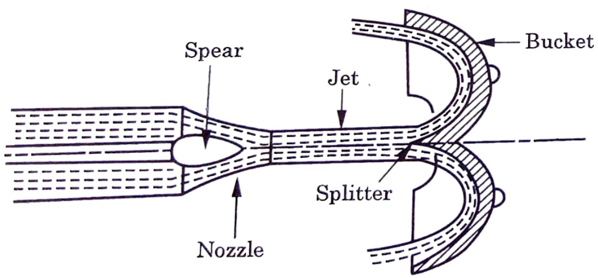

Fig. 7.3 (*b*)

2. Runner with Buckets : Runner of Pelton wheel consists of a circular disc having a number of equally spaced buckets on its periphery. The shape of buckets is of double hemi-spherical cup. Each bucket is divided into two symmetrical parts by a dividing wall called splitter.

The high velocity jet of water strikes the splitter. The splitter divides the jet into two equal parts and each part comes out at the outer edge of the bucket after deflecting through 160° to 170°. The buckets are generally made of cast iron, cast steel or stainless steel.

3. Casing : The casing of Pelton wheel prevents the splashing of water and guides the water to the tail race. It is made of cast iron or fabricated steel plates and acts as a safeguard against accidents. There is no hydraulic function of the casing of the Pelton wheel.

4. Brake Nozzle : When the nozzle is completely closed by pushing the spear in the forward direction, the quantity of water striking the runner becomes zero, but the runner keeps on revolving for a long time due to inertia. To stop the runner in a short time, a small nozzle known as brake nozzle is provided which directs the jet of water on the back of the buckets.

Working : The water under high head flows through the penstock and comes out of the nozzle in the form of very high velocity jet which strikes the sharp central edge known as splitter of the bucket. The buckets are so shaped that the jet is deflected through 160° to 170° after dividing into two parts. Due to the momentum of striking jet at the central edge of the buckets and rate of change of momentum due to deflection of flowing water, a tangential force acts on the runner which causes the rotation of the runner at high speed.

7.7 FRANCIS TURBINE

Francis turbine as shown in fig. 7.4 is an inward flow, medium head, medium specific speed reaction turbine designed by J.B. Francis, an American engineer. The important parts of Francis turbine are as follow :

1. Penstock,
2. Spiral/Scroll casing,
3. Guide mechanism,
4. Runner,
5. Draft tube.

1. Penstock : *It is a closed pipe which carries water from the reservoir to the spiral casing of the turbine.* To prevent the entry of debris or any other floating material in the casing, trashracks are provided at the inlet of penstock.

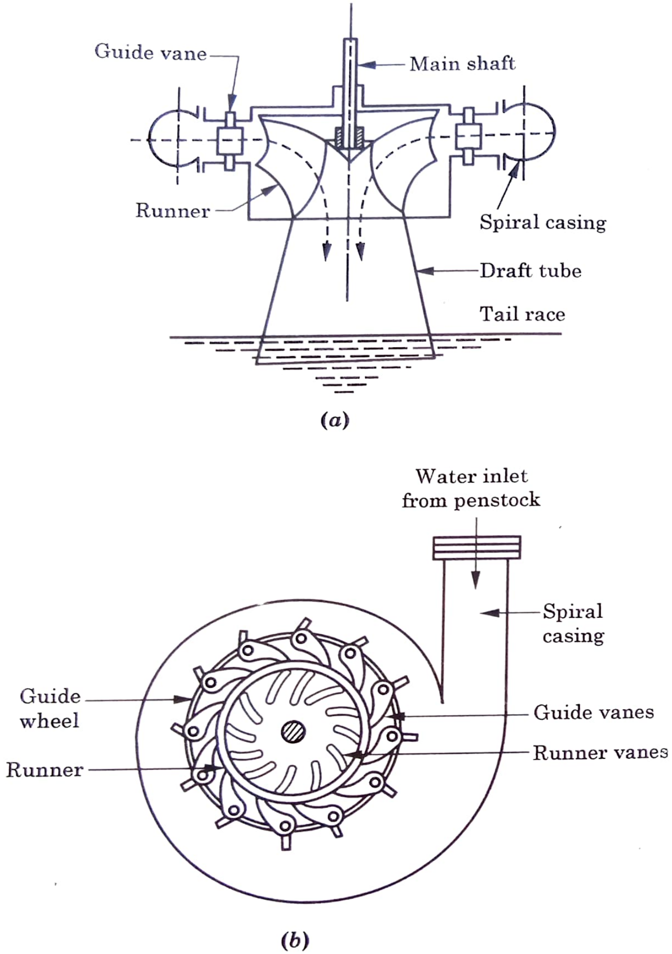

Fig. 7.4 : Francis Turbine

2. **Spiral/Scroll Casing :** *Water from penstock enters the spiral casing whose cross-sectional area goes on reducing along the direction of flow.* Spiral shape of casing is provided so

that water enters the runner at constant velocity throughout the circumference of the runner. The casing completely surrounds the runner of the turbine. It is made of concrete, cast steel etc.

3. **Guide Mechanism :** *Guide mechanism regulates the supply of water from casing to the runner vanes.* It consists of a guide wheel and guide vanes with links and levers. Guide wheel is a stationary circular wheel provided round the runner. Guide vanes are fixed to it. Guide vanes allow the water to strike the runner vanes without shock. The width between two adjacent guide vanes can be altered so that the amount of water striking the runner can be varied.

4. **Runner :** *It is a circular wheel on which a series of radial curved vanes is fixed.* The surface of these vanes is very smooth. The shape of radial curved vanes is such that the water enters and leaves the runner without shock. The runners are keyed to the shaft and are made of cast iron, cast steel, stainless steel etc.

5. **Draft Tube :** The pressure of water at the exit of runner is generally less than atmospheric pressure. Therefore, the water at exit cannot be directly discharged to tail race. Hence, *a tube of gradually increasing area called draft tube is used to discharge water from exit of turbine to the tail race.*

Working : Water enters the turbine radially and leaves axially. Water from penstock is allowed to enter spiral casing so that no eddies are formed and there is no loss of head due to eddy formation. Water from the casing enters the guide wheel which surrounds the runner. To regulate the entry of water through guide wheel into runner, a guide mechanism is provided. The water entering the runner possesses both pressure head and velocity head. As the water leaves the runner, both of these heads decrease. Due to the difference of heads at the entry and exit, the runner rotates. The water at the exit of runner is discharged with the help of draft tube below the tail race water level to increase the efficiency of turbine.

7.8 KAPLAN TURBINE

Kaplan turbine as shown in fig. 7.5 is an axial flow, low head and high specific speed reaction turbine. In Kaplan turbine, water flows parallel to the axis of the shaft. The rotating shaft is in vertical position. The lower end of the shaft is of larger diameter than the diameter of the shaft and, therefore, is called hub or boss of the shaft. Vanes are attached to the hub which are adjustable. The important parts of Kaplan turbine are as follow :

1. Spiral/Scroll casing,
2. Guide mechanism,
3. Runner (or hub with vanes),
4. Draft tube.

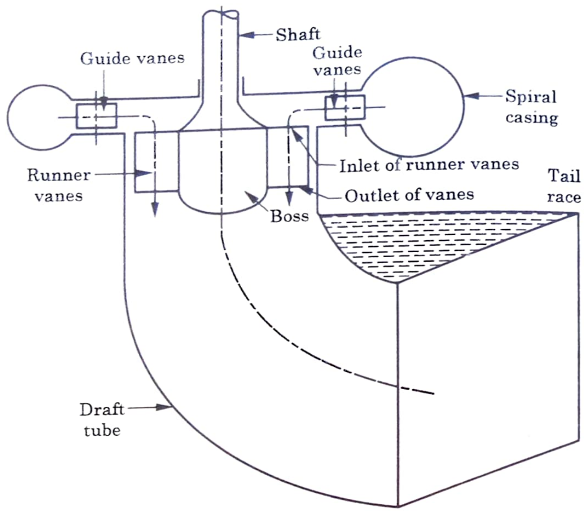

Fig. 7.5 : Kaplan Turbine

1. **Spiral Casing :** Water from penstock enters the spiral casing whose cross-sectional area goes on reducing along the direction of flow. Spiral shape of the casing is provided so that water enters the runner at constant velocity throughout the circumference of the runner. The casing completely surrounds the runner of the turbine. It is made of concrete, cast steel etc.

2. **Guide Mechanism :** Guide mechanism regulates the supply of water from casing to the runner. It consists of a guide wheel and guide vanes with links and levers. Guide wheel is a stationary circular wheel provided round the runner. Guide vanes are fixed to it. From the guide vanes, water turns through 90° and flows axially through the runner. The number of guide vanes depends upon the diameter of guide wheel. The number of guide vanes varies from 8 to 24 for 300 mm to more than 4000 mm diameter guide wheel.

3. **Runner :** Runner of the turbine is enlarged end of the vertical shaft called hub or boss fitted with vanes which can be adjusted. The adjustment of vanes means varying the passage between two vanes. This can be done by using a servo motor mechanism. The flow of water at inlet and outlet is axial. The space between guide vanes outlet and runner inlet is called wheel chamber. Fig. 7.6 shows the runner of Kaplan turbine.

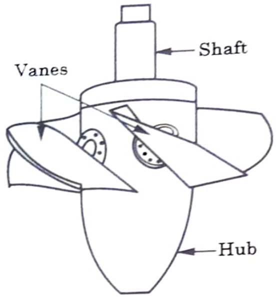

Fig. 7.6 : Runner of Kaplan Turbine

4. **Draft Tube :** The pressure of water at the exit of runner is generally less than atmospheric pressure. Therefore, the water at exit cannot be directly discharged to tail race. Hence, tube of generally increasing area called draft tube is used to discharge water from the exit of turbine to the tail race.

Working : The working of Kaplan turbine is similar to Francis turbine. In this turbine, water enters the spiral casing through the penstock. From spiral casing, the water enters the guide vanes and from guide vanes, water is turned through 90° and flows axially through the runner into the draft tube.

7.9 PROPELLER TURBINE

The propeller turbine is exactly similar to the Kaplan turbine with the difference that the vanes are fixed to the hub and they are not adjustable.

7.10 UNIT QUANTITIES

The following are the three important unit quantities :

1. Unit speed,
2. Unit discharge,
3. Unit power.

7.10.1 Unit Speed

Unit speed of turbine may be defined as *the speed of turbine working under unit head i.e. under a head of 1m*. It is generally denoted by N_u.

Let
N = Speed of turbine under a head H,
H = Actual head under which turbine is working,
u = Tangential velocity,
v = Absolute velocity of water.

The tangential velocity, absolute velocity of water and head of turbine are related on under :

$$u \propto V$$

and $$V \propto \sqrt{H}$$

$\therefore$ $$u \propto \sqrt{H} \quad \ldots(i)$$

Also $$u = \frac{\pi DN}{60}$$ where D = Diameter of turbine.

For a given turbine, diameter is constant.

$\therefore$ $$u \propto N$$

or $$N \propto u$$

or $$N \propto \sqrt{H} \quad [\because u \propto \sqrt{H} \text{ from equation } (i)]$$

or $$N = K_1 \sqrt{H} \quad \ldots(ii)$$

where K_1 = Constant of proportionality.

Now, if head on the turbine is unity, then the speed will become unit speed *i.e.*

If $H = 1$, then $N = N_u$

Putting these values in equation (*ii*), we get

$$N_u = K_1 \sqrt{1} = K_1$$

Putting the value of K_1 in equation (*ii*), we get

$$N = N_u \sqrt{H}$$

or $$N_u = \frac{N}{\sqrt{H}}$$

7.10.2 Unit Discharge

Unit discharge of turbine may be defined as *the discharge passing through turbine working under unit head i.e. under a head of 1m*. It is generally denoted by Q_u.

Let Q = Discharge passing through turbine under a head H,
H = Actual head under which turbine is working,
A = Area of flow of water.

We know that

$$Q = \text{Area of flow} \times \text{Velocity} = A \times V$$

But for a turbine, area of flow is constant and velocity is proportional to $\sqrt{H}$.

$\therefore$ $$Q \propto V$$

or $$Q \propto \sqrt{H}$$

or $$Q = K_2 \sqrt{H} \quad \ldots(i)$$

where K_2 = Constant of proportionality.

Now, if $H = 1$, then $Q = Q_u$

Putting these values in equation (*i*), we get

$$Q_u = K_2 \sqrt{1} = K_2$$

Putting the value of K_2 in equation (*i*), we get

$$Q = Q_u \sqrt{H}$$

or $$Q_u = \frac{Q}{\sqrt{H}}$$

7.10.3 Unit Power

Unit power of turbine may be defined as *the power developed by the turbine working under a unit head i.e. under a head of 1m.*

Let P = Power developed by the turbine under a head H,
H = Actual head under which turbine is working,
Q = Discharge passing through the turbine under a head H.

Overall efficiency of turbine,

$$\eta_o = \frac{\text{Power developed}}{\text{Water power}} = \frac{P}{wQH}$$

where w = Specific weight of water.

$\therefore$ $$P = \eta_o \times w\,Q\,H$$

or $$P \propto Q\,H$$

or $$P \propto \sqrt{H} \times H \quad (\because Q \propto \sqrt{H})$$

or $$P \propto H^{3/2}$$

or $$P = K_3 H^{3/2} \quad \ldots(i)$$

where K_3 = Constant of proportionality.

Now, if $H = 1$, then $P = P_u$.

Putting these values in equation (*i*), we get

$$P_u = K_3 \times (H)^{2/3}$$

or $$P_u = K_3$$

Putting the value of K_3 in equation (*i*), we get

$$P = P_u H^{3/2}$$

or $$P_u = \frac{P}{H^{3/2}}$$

7.11 SIGNIFICANCE OF UNIT QUANTITIES (N_u, Q_u and P_u)

If a turbine is working under different heads, then the behaviour of turbine can be easily predicted from the values of unit quantities *i.e.* N_u, Q_u and P_u.

Let $H_1, H_2, \ldots$ are the heads under which a turbine is working.

$N_1, N_2, \ldots$ are the corresponding speeds.

$Q_1, Q_2, \ldots$ are the corresponding discharges.

$P_1, P_2, \ldots$ are the corresponding powers developed by turbine.

Now, using the equations derived for N_u, Q_u and P_u, we get

$$N_u = \frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$Q_u = \frac{Q_1}{\sqrt{H_1}} = \frac{Q_2}{\sqrt{H_2}}$$

$$P_u = \frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

Hence, if the speed, discharge and power developed by a turbine under a head are known, then by using the above equations, speed, discharge and power developed by the same turbine working under a different head can be calculated.

7.12 SPECIFIC SPEED OF TURBINE

Specific speed of a turbine may be defined *as the speed of a geometrically similar turbine i.e. a turbine similar to dimensions, shape, blade angles, gate openings etc. of the actual turbine, which produces unit power working under unit head i.e. under a head of 1m.* It is generally denoted by N_s.

Let P = Power developed by the turbine under a head H,

H = Actual head under which a turbine is working,

Q = Discharge passing through the turbine under a head H,

w = Specific weight of water.

Overall efficiency of turbine,

$$\eta_o = \frac{\text{Power developed}}{\text{Water power}}$$

$$= \frac{P}{wQH}$$

or $P = \eta_o \times w\,QH$

or $P \propto Q \times H \quad \ldots(i)$

Let D = Diameter of actual turbine,

N = Speed of actual turbine,

u = Tangential velocity of turbine,

N_s = Specific speed of turbine,

V = Absolute velocity of water.

The tangential velocity, absolute velocity and head of turbine are related as under :

$$u \propto V$$

and $V \propto \sqrt{H}$

$\therefore$ $u \propto \sqrt{H} \quad \ldots(ii)$

Also $u = \dfrac{\pi DN}{60}$

or $u \propto DN \quad \ldots(iii)$

From equations (*ii*) and (*iii*),

$$\sqrt{H} \propto DN$$

or $D \propto \dfrac{\sqrt{H}}{N} \quad \ldots(iv)$

Discharge through turbine,

$$Q = \text{Area of flow} \times \text{Velocity}$$
$$= A \times V$$

But $A \propto B \times D$

where B = Width.

Now $B \propto D$

$\therefore$ $A \propto D^2$

and $V \propto \sqrt{H}$

$\therefore$ $Q \propto D^2\sqrt{H}$

$Q \propto \dfrac{H}{N^2} \times \sqrt{H}$ $\quad \left(\because \text{ From equation } (iv), D \propto \dfrac{\sqrt{H}}{N}\right)$

or $Q \propto \dfrac{H^{3/2}}{N^2}$

Putting the value of Q in equation (*i*), we get

$$P \propto \frac{H^{3/2}}{N^2} \times H$$

or $P \propto \dfrac{H^{5/2}}{N^2}$

or

$$P = K \frac{H^{5/2}}{N^2} \quad \ldots(v)$$

where K = Constant of proportionality.

Now, If P = 1 and H = 1, then $N = N_s$.

Putting these values in equation (v), we get

$$1 = K \times \frac{(1)^{5/2}}{N_s^2}$$

or

$$N_s^2 = K$$

$\therefore$

$$P = N_s^2 \times \frac{H^{5/2}}{N^2}$$

or

$$N_s^2 = \frac{N^2 P}{H^{5/2}}$$

or

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

It should be noted that in the above relation P is to be takes in kW.

7.13 SELECTION OF WATER TURBINES BASED UPON SPECIFIC SPEEDS

Specific speed plays an important role in the selection of turbine. Also the performance of turbine can be predicted by knowing the specific speed. Table 7.1 gives the type of turbine for different specific speeds :

S. No.	Specific Speed	Type of Turbine
1.	8.5 to 30	Pelton wheel with single nozzle
2.	30 to 51	Pelton wheel with two or more nozzles
3.	51 to 225	Francis turbine
4.	225 to 860	Kaplan or propeller turbine

Problem 7.1. A turbine develops 9000 kW running at 100 r.p.m. The head of turbine is 30m. Determine the speed and power developed by turbine if the head of turbine is reduced to 18m.

Solution. Given, $P_1 = 9000$ kW, $N_1 = 100$ r.p.m., $H_1 = 30$m, $H_2 = 18$m .

Let N_2 and P_2 are the speed and power developed by the turbine at reduced head.

We know that

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$\frac{100}{\sqrt{30}} = \frac{N_2}{\sqrt{18}}$$

or

$$N_2 = \frac{100 \times \sqrt{18}}{\sqrt{30}}$$

$$= 77.5 \text{ r.p.m.} \quad \textbf{Ans.}$$

We also know that

$$\frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$\frac{9000}{(30)^{3/2}} = \frac{P_2}{(18)^{3/2}}$$

or

$$P_2 = \frac{9000 \times (18)^{3/2}}{(30)^{3/2}}$$

$$= 4182.8 \text{ kW} \quad \textbf{Ans.}$$

Problem 7.2. A turbine runs at a speed of 200 r.p.m. under a head of 25 m. The discharge is 9m³/s. If the efficiency of the turbine is 90%, determine the performance of turbine under a head of 20m.

Solution. Given, $N_1 = 200$ r.p.m., $H_1 = 25$m, $Q_1 = 9\text{m}^3/\text{s}$, $\eta_o = 90\% = 0.9$, $H_2 = 20$m.

Performance of turbine under a head of 20 m means to find speed, discharge and power of turbine working under a head of 20m.

Let N_2, Q_2 and P_2 are the speed, discharge and power under reduced head.

We know that

$$\eta_o = \frac{P_1}{w \times Q_1 \times H_1}$$

$$0.9 = \frac{P_1}{9810 \times 9 \times 25}$$

or

$$P_1 = 0.9 \times 9810 \times 9 \times 25$$

$$= 1986525 \text{ W} = 1986.5 \text{ kW}$$

Now, we know that

$$\frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$\frac{200}{\sqrt{25}} = \frac{N_2}{\sqrt{20}}$$

or

$$N_2 = \frac{200 \times \sqrt{20}}{\sqrt{25}}$$

$$= 178.9 \text{ r.p.m} \quad \textbf{Ans.}$$

Also

$$\frac{Q_1}{\sqrt{H_1}} = \frac{Q_2}{\sqrt{H_2}}$$

$$\frac{9}{\sqrt{25}} = \frac{Q_2}{\sqrt{20}}$$

or

$$Q_2 = \frac{9 \times \sqrt{20}}{\sqrt{25}}$$

$$= 8.05 \text{ m}^3/\text{s} \quad \textbf{Ans.}$$

Further,

$$\frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

$$\frac{1986.5}{(25)^{3/2}} = \frac{P_2}{(20)^{3/2}}$$

or

$$P_2 = \frac{1986.5 \times (20)^{3/2}}{(25)^{3/2}}$$

$$= 1421.4 \text{ kW} \quad \textbf{Ans.}$$

Problem 7.3. A Pelton wheel runs at a speed of 200 r.p.m. and develops 500 kW when working under a head of 200 m with an overall efficiency of 80%. Determine the unit speed, unit discharge and unit power.

Solution. Given, N = 200 r.p.m., P = 5000 kW = 5000 × 10^3 W, H = 200m, η_o = 80% = 0.8.

Let Q is the discharge passing through the turbine.

We know that

$$\eta_o = \frac{P}{w \times Q \times H}$$

$$0.8 = \frac{5000 \times 10^3}{9810 \times Q \times 200}$$

or

$$Q = \frac{5000 \times 10^3}{0.8 \times 9810 \times 200}$$

or

$$Q = 3.186 \text{ m}^3/\text{s}$$

$$\text{Unit speed, } N_u = \frac{N}{\sqrt{H}}$$

$$= \frac{200}{\sqrt{200}}$$

$$= 14.14 \text{ r.p.m.} \quad \textbf{Ans.}$$

$$\text{Unit discharge, } Q_u = \frac{Q}{\sqrt{H}}$$

$$= \frac{3.186}{\sqrt{200}}$$

$$= 0.225 \text{ m}^3/\text{s} \quad \textbf{Ans.}$$

$$\text{Unit power, } P_u = \frac{P}{H^{3/2}}$$

$$= \frac{5000}{(200)^{3/2}}$$

$$= 1.77 \text{ kW} \quad \textbf{Ans.}$$

Problem 7.4. A turbine develops 7000 kW at 150 r.p.m. when working under a head of 25m. Find the specific speed of the turbine. Also state the type of turbine.

Solution. Given, P = 7000 kW, N = 150 r.p.m., H = 25m.

We know that

$$\text{Specific speed of turbine, } N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$$= \frac{150 \times \sqrt{7000}}{(25)^{5/4}}$$

$$= 224.5 \quad \textbf{Ans.}$$

From table 7.1, it is observed that for a specific speed of 224.5, the turbine is Francis turbine. **Ans.**

Problem 7.5. A turbine works under a head of 25m at 250 r.p.m. The discharge is 10m³/s. Determine speed of the turbine. The efficiency of the turbine is 90%.

Solution. Given, H = 25m, N = 250 r.p.m., Q = 10m³/s η_o = 90% = 0.9.

Let P is the power developed by the turbine.

We know that

$$\eta_o = \frac{P}{wQH}$$

$$0.9 = \frac{P}{9810 \times 10 \times 25}$$

or

$$P = 0.9 \times 9810 \times 10 \times 25$$
$$= 2207250 \text{ W} = 2207 \text{ kW}$$

Specific speed of turbine, $N_s = \frac{N\sqrt{P}}{H^{5/4}}$

$$= \frac{250\sqrt{2207}}{(25)^{5/4}}$$

$= 210$ **Ans.**

7.14 HYDRAULIC PUMP

& uses from internet

The hydraulic machine which converts mechanical energy into hydraulic energy is called hydraulic pump. Here hydraulic energy means pressure energy. Thus, a hydraulic pump converts the mechanical energy into pressure energy of the liquid to lift it from lower level to higher level.

7.15 RECIPROCATING PUMP

Reciprocating pump is a positive displacement pump as it sucks and lifts the liquid by actually displacing it with the help of piston reciprocating in a closely fitted cylinder. The amount of liquid pumped is equal to the volume of liquid displaced by the piston. The efficiency of a reciprocating pump is about 10 to 20% higher as compared to a comparable centrifugal pump.

Reciprocating pumps for industrial uses have almost become obsolete due to their high capital cost and maintenance cost as compared to centrifugal pumps.

7.16 SINGLE ACTING RECIPROCATING PUMP

The main components of a reciprocating pump as shown in fig. 7.7 are as follow :

1. Cylinder,
2. Piston,
3. Suction valve,
4. Delivery valve,
5. Suction pipe,
6. Delivery pipe.

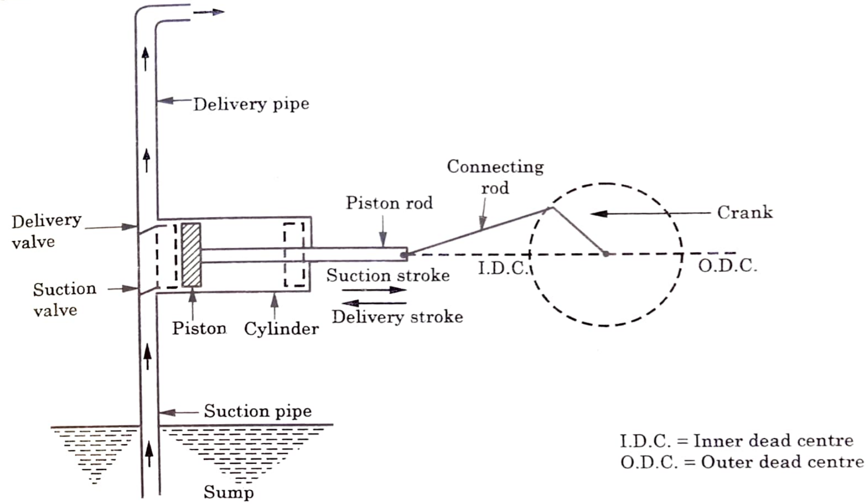

Fig. 7.7 : Reciprocating Pump

Working : A single acting reciprocating pump shown in fig. 7.7 has one suction pipe and one delivery pipe. Let initially the crank is at inner dead centre (I.D.C.) and let the crank rotates in the clockwise direction. As the crank rotates, the piston moves towards right and a vacuum is created on the left side of the piston due to which the suction valve gets open and the liquid is forced into the left side of the piston from the sump. When the crank is at outer dead centre (O.D.C.), the suction stroke is completed and the left side of piston is full of liquid. Now, when the crank rotates from O.D.C. to I.D.C., the piston moves towards left and high pressure is built up in the cylinder. Therefore, suction valve closes and delivery valve opens. The liquid is forced to the discharge tank through the delivery pipe. At the end of delivery stroke, the crank comes to I.D.C. and piston is at the extreme left position.

7.17 ROTARY PUMPS

These are the positive displacement pumps with rotary motion. These can pump thick viscous liquids as well as light liquids. These are self priming pumps. These are of following types :

1. Vane pumps,
2. Screw pumps,
3. Gear pumps.

7.17.1 Vane Pump

Vane pump as shown in fig. 7.8 consists of an eccentric rotor inside the casing of the pump. The rotor is provided with radial slots generally 4 to 8. Sliding vanes are placed in the radial slots. These vanes slide freely and radially in the slots.

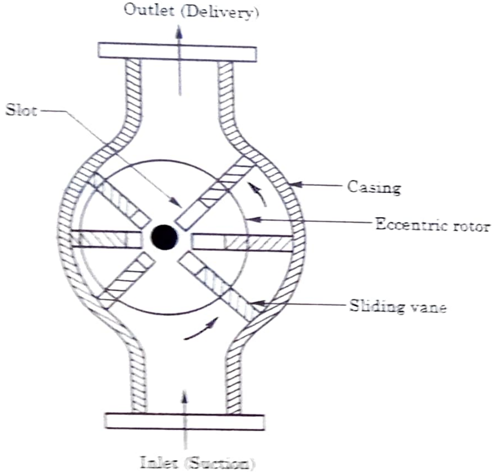

Fig. 7.8 : Vane Pump

Before starting the pump, the casing of the pump is completely filled with liquid. When the rotor starts rotating, the vanes are pressed against the casing due to centrifugal force. The liquid starts flowing in between the outer surface of rotor and casing and further the liquid is trapped by the vanes. Thus sufficient pressure is created on the liquid and the liquid is forced to flow to the delivery side creating a vacuum in the suction pipe. The vacuum fetches the liquid into the pump and the operation is repeated.

7.17.2 Screw Pump

A screw pump shown in fig. 7.9 consists of two rotors *i.e.* driver screw rotor and driven screw rotor or idler. Idler is coupled to driver screw rotor with the help of spur gears. Rotor and idler, both run at same speed, but in opposite direction. The screws may be single helical or double helical. However, the double helical screws are axially balanced and end thrust on bearings is minimum. Liquid flows from suction pipe to the outer end of the rotors and is discharged centrally. The liquid is carried forward to the discharge end along the rotor in pockets formed between screw and casing. In a screw pump, there may be one, two or three screws. In three screw pump, there will be one rotor and two idlers.

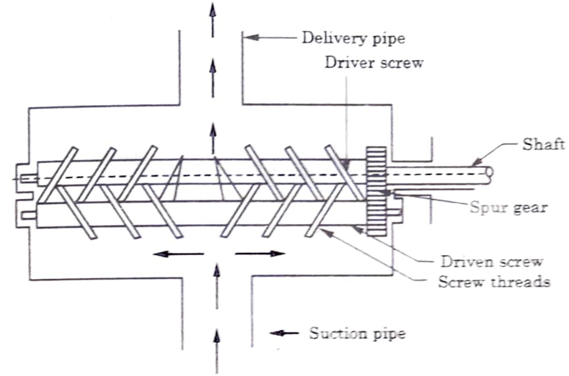

Fig. 7.9 : Screw Pump

7.17.3 Gear Pump

A gear pump is shown in fig. 7.10. It consists of two identical spur gears known as driver gear and driven gear. The two gears mesh with other. The driver gear gets power from an electric motor.

Before starting the pump, the casing of pump is filled with liquid. When the gears rotate, the liquid is trapped between their teeth and casing. The rotating gears force the liquid to flow towards delivery side of the pump and a vacuum is created in the suction pipe. The meshing of gears does not allow the liquid to slip back to the inlet.

The gear pump can develop a very high pressure of the order of 100 atmospheric pressure, but such a high pressure is not generated due to chances of internal leakage.

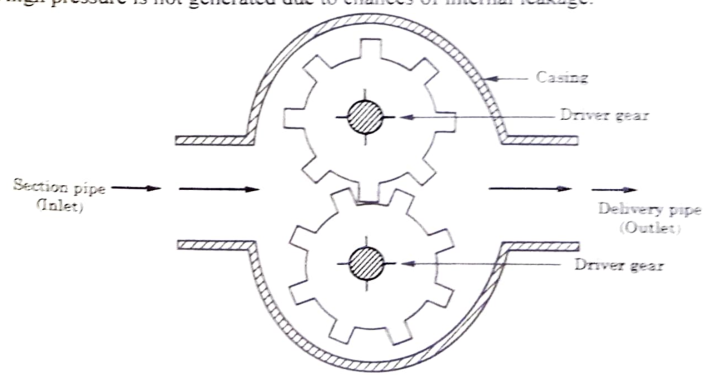

Fig. 7.10 : Gear Pump

7.18 CENTRIFUGAL PUMP

The hydraulic machine converts mechanical energy into pressure energy by means of centrifugal force acting on the liquid is called centrifugal pump. The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the pressure head of rotating liquid rises. This rise in pressure head at any point of rotating liquid is proportional to the tangential velocity of liquid at that point *i.e.* rise in pressure head $= \frac{v^2}{2g}$. Thus at the outlet of the impeller, the rise in pressure head will be more and the liquid can be lifted to a higher level.

Construction :

A centrifugal pump shown in fig. 7.11 consists of the following main components :

1. Impeller,
2. Casing,
3. Suction pipe,
4. Delivery pipe.

1. Impeller : *Impeller is the rotating part of the centrifugal pump mounted on a shaft. It consists of a series of backward curved vanes.*

2. Casing : *Casing is an air tight passage surrounding the impeller. It is designed in such a way that the kinetic energy of water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe.* The casings may be of following types :

(*i*) Volute casing,
(*ii*) Vortex casing,
(*iii*) Casing with guide blades.

(*i*) Volute Casing : In this type of casing shown in fig. 7.11, the area of flow gradually increases from impeller outlet to the delivery pipe so as to reduce the velocity of flow. The decrease in velocity increases the pressure of liquid flowing through the casing.

(*ii*) Vortex Casing : In this type of casing shown in fig. 7.12, circular chamber is provided between the impeller and the volute chamber. The circular chamber is known as vortex chamber. The vortex chamber converts some of the kinetic energy into pressure energy. The volute chamber further increases the pressure energy.

(*iii*) Casing with Guide Blades : In this type of casing shown in fig. 7.13, impeller is surrounded by a series of guide blades mounted on a ring called diffuser. The liquid leaving the impeller passes through the passage having gradually increasing area between guide blades. The velocity of flow decreases and kinetic energy is converted into pressure energy.

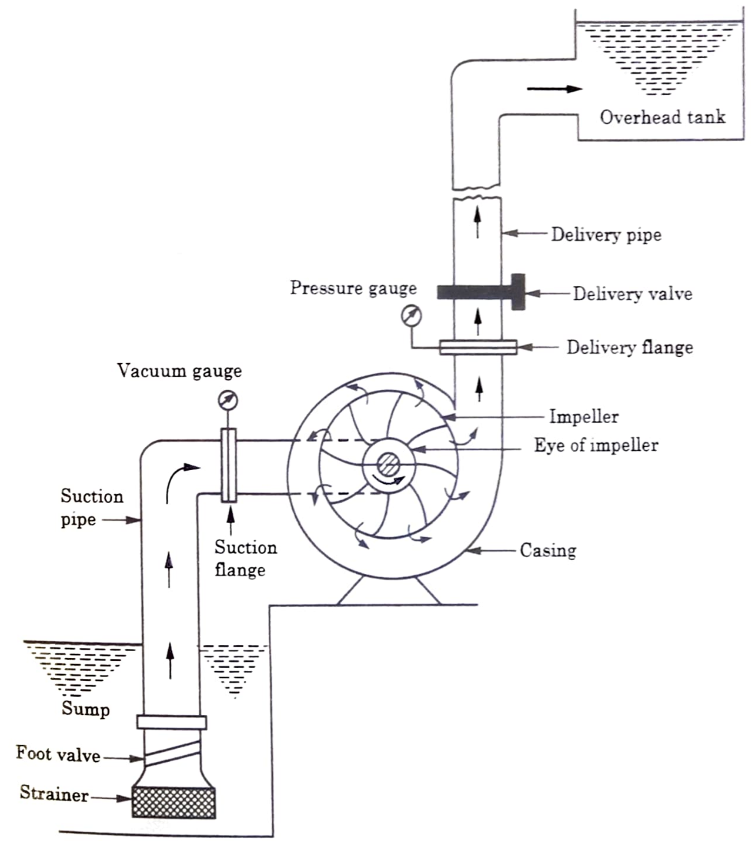

Fig. 7.11 : Centrifugal Pump with Volute Casing

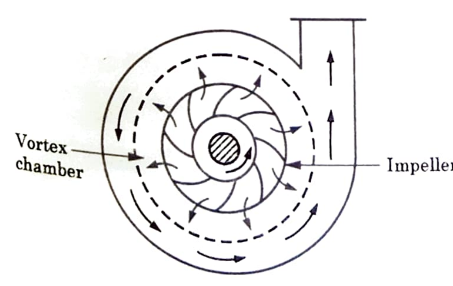

Fig. 7.12 : Vortex Casing

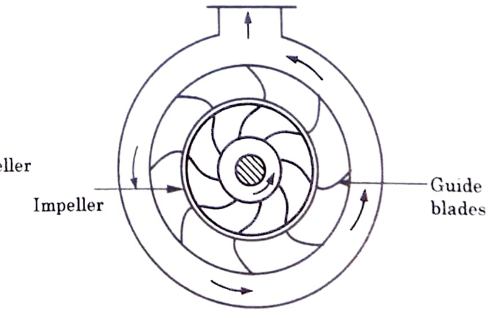

Fig. 7.13 : Casing with Guide Blades

3. **Suction Pipe :** *Suction pipe is an air tight pipe which connects the centre/eye of the impeller to the sump from which liquid is to be lifted.* A strainer is provided at the lower end of the pipe to prevent the entry of solid particles, debris etc. into the pump. Further, a non-return foot valve is also fitted at the lower end of the pipe which prevents the liquid to drain out of the suction pipe when the pump in not working. This also helps in priming.

4. **Delivery Pipe :** *The pipe which leads the liquid from the pump outlet to the required height is known as delivery pipe.* A regulating valve is provided on the delivery pipe to regulate the supply of liquid.

Working : The working of centrifugal pump is explained as follows :

1. The delivery valve is closed. The pump is then primed *i.e.* suction pipe, casing and delivery pipe upto delivery valve is filled with the liquid to be lifted so that no air is left.
2. Keeping the delivery valve still closed, the impeller is rotated by an electric motor. The rotation of the impeller causes strong suction at the eye of the casing.
3. After the impeller obtains normal speed, the delivery valve is opened and liquid passes through the eye of the casing to enter the impeller vanes at their inlet tips. This liquid is impelled out by rotating vanes and it comes into the casing.
4. From casing, the liquid passes to the delivery pipe and lifted to the required height.
5. When the pump is to be stopped, the delivery valve should be first closed, otherwise, there may be some backflow from the delivery tank.

7.19 HEADS AND EFFICIENCIES OF CENTRIFUGAL PUMP

1. **Suction Head :** *The vertical height of the centre line of the centrifugal pump above the water surface in the tank from where water is to be lifted as shown in fig. 7.10 is called suction head.* It is generally denoted by h_s.

2. **Delivery Head :** *The vertical distance between centre line of the pump and the water surface in the tank to which water is to be delivered as shown in fig. 7.10 is called delivery head.* It is generally denoted by h_d.

3. **Static Head :** *The sum of suction head and delivery head is called static head.* It is generally denoted by H_s.

$$H_s = h_s + h_d$$

4. **Manometric Head :** *The head against which a centrifugal pump works is called manometric head.* It is generally denoted by H_m.

$$H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{v_d^2}{2g}$$

where h_s = Suction head,

h_d = Delivery head,

h_{fs} = Loss of head due to friction in suction pipe,

h_{fd} = Loss of head due to friction in delivery pipe,

v_d = Velocity of water in delivery pipe.

5. **Efficiencies of a Centrifugal Pump :** Followings are the important efficiencies of a centrifugal pump :

(*i*) Manometric efficiency,

(*ii*) Mechanical efficiency,

(*iii*) Overall efficiency,

(*i*) **Manometric Efficiency :** *The ratio of manometric head to the head imparted by impeller to the water is called manometric efficiency.* It is generally denoted by $\eta_{man.}$

$$\text{Manometric efficiency, } \eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

Manometric efficiency may also be defined as *the ratio of power given to water at the outlet of pump to the power available at the impeller.*

(*ii*) **Mechanical Efficiency :** *The ratio of power available at the impeller to the power available at the shaft of centrifugal pump is called mechanical efficiency of centrifugal pump.* It is generally denoted by η_m.

$$\text{Mechanical efficiency, } \eta_m = \frac{\text{Power available at impeller}}{\text{Power available at shaft}}$$

(*iii*) **Overall Efficiency :** *The ratio of power output of the centrifugal pump to the power input to the centrifugal pump is called overall efficiency of centrifugal pump.* It is generally denoted by η_o.

$$\text{Overall efficiency, } \eta_o = \eta_{man.} \times \eta_m$$

7.20 PERFORMANCE OF CENTRIFUGAL PUMPS

Centrifugal pumps are designed to work under given set of conditions *i.e.* speed, discharge and head. But, in actual practice, the conditions may be different than those considered for designing the pumps. So it is important to know the behaviour and performance of pumps at different speeds, discharges and heads. Tests are conducted and results are plotted on a graph. The curves so obtained are called characteristic curves. The values of head and discharge at maximum efficiency are called designed head and designed discharge respectively. From the characteristic curves, it can be established whether the pump will give required discharge at designed head or not. The graph between power and discharge gives an idea about the size of motor required to operate the pump.

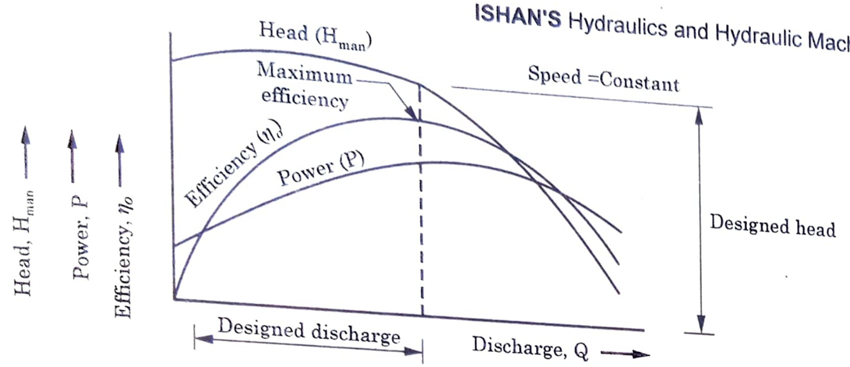

Fig. 7.14 : Characteristic Curves of Pump

7.21 SPECIFICATIONS OF A CENTRIFUGAL PUMP

The following specifications are required for selecting a centrifugal pump :

1. Discharge in litres/s.
2. Total head which includes suction head, delivery head, friction and other losses etc.
3. Type of liquid to be handled *i.e.* fresh water, viscous liquid or solids in suspension.
4. Field of application *i.e.* irrigation, boiler feed, condenser circulation etc.
5. Motive power to be used *i.e.* electric motor or *i.c.* engine.

7.22 TROUBLES IN CENTRIFUGAL PUMPS AND THEIR REMEDIAL MEASURES

S. No.	Trouble	Reasons of Trouble	Remedial Measures
1.	Pump fails to start.	(*i*) No proper priming. (*ii*) Very low speed. (*iii*) Clogging of either strainer or impeller. (*iv*) Opposite direction of rotation of impeller. (*v*) Total static head is more than the specified head.	Reprime the pump. Increase the speed. Change the strainer and clean the impeller. Change direction of rotation of impeller. Change a new pump.
2.	Pump first starts and then stops pumping.	(*i*) High suction lift. (*ii*) Presence of air in suction pipe. (*iii*) Leakage of suction pipe.	Lower the suction lift. Prime the pump to remove air. Stop the leakage by seals etc.

S. No.	Trouble	Reasons of Trouble	Remedial Measures
3.	Pump consumes too much power.	(*i*) High speed. (*ii*) High viscosity of liquid. (*iii*) Mechanical defects (Bending of shaft). (*iv*) Low head.	Run on specified speed. Use right pump for given liquid. Repair the defective parts. Replace the pump.
4.	Pump is not working upto pressure and capacity.	(*i*) Suction of air into the pump from outside. (*ii*) Excessive wear and tear of bearing rings.	Stop suction of air from outside by seals etc. Change the worn out parts or defective parts.
5.	Noise in operation of pump.	(*i*) Cavitation. (*ii*) Shaft misalignment. (*iii*) Packing of stuffing box may be defective.	Reduce the high pressure at eye. Make perfect alignment. Provide proper packing.
6.	Overheating of the pump.	(*i*) Shaft misalignment. (*ii*) Poor lubrication. (*iii*) Defective bearings.	Make perfect alignment. Use specified lubricants. Change defective bearings.
7.	Reduced discharge.	(*i*) Leakage of air. (*ii*) Very high suction lift. (*iii*) Foreign matter in the impeller. (*iv*) Foot valve too small.	Stop leakage of air. Reduce the suction lift. Clean the impeller. Change foot valve.
8.	Pressure not enough	(*i*) Presence of air pockets. (*ii*) Mechanical defects like defective bearings. (*iii*) Very small diameter of impeller. (*iv*) Total head more than the specified head.	Make the pump air tight. Change defective parts. Use impeller of correct size. Change the pump or check total head.

7.23 CAVITATION

The phenomenon of formation of vapour bubbles in a flowing liquid in the region where the pressure of liquid falls below its vapour pressure and then sudden collapsing of these vapour bubbles in the region of high pressure is called cavitation.

We know that a liquid starts boiling when the pressure of flowing liquid is less than its vapour pressure and vapour bubbles are formed. These vapour bubbles are carried alongwith the flowing liquid to the high pressure region where these vapours condense and bubbles collapse. Due to sudden collapsing of these bubbles on the metallic surfaces, high pressure is produced and metallic surfaces are subjected to high stresses. Thus the surfaces get damaged.

Cavitation in centrifugal pumps may occur at the inlet of the impeller or at the suction side of the pumps where the pressure is considerably reduced.

7.23.1 Harmful Effects of Cavitation

The followings are the harmful effects of cavitation :

1. Due to sudden collapsing of vapour bubbles, considerable noise and vibrations are produced.
2. The metallic surfaces are damaged and cavities are formed on these surfaces.
3. A sudden drop in efficiency occurs.

7.23.2 Precautions Against Cavitation

The followings precautions should be taken against cavitation :

1. The pressure of flowing liquid in any part of the pump should not be allowed to fall below its vapour pressure. If the flowing liquid is water, then the absolute pressure head should not be less than 2.5 m of water.
2. The coatings of cavitation resistant materials such as stainless steel or aluminium bronze should be used on the metallic surfaces.

7.24 PITTING

The erosion of pump material on the inside surface due to repeated hammering action caused by collapsing vapour bubbles at high pressure region is called pitting.

We know that a liquid starts boiling when the pressure of flowing liquid is less than its vapour pressure and vapour bubbles are formed. These vapour bubbles are carried alongwith the flowing liquid to the high pressure region where these vapours condense and bubbles collapse. Due to sudden collapsing of these bubbles on the metallic surfaces of the pump, high pressure is produced and these surfaces are subjected to high stresses. Thus the surfaces get damaged and cavities are formed.

7.25 PRIMING

The operation of filling the suction pipe, casing and a portion of delivery pipe (upto delivery valve) of the centrifugal pump from outside source with the liquid to be lifted by the pump before starting the pump is called priming of centrifugal pump.

Priming is needed to remove air from the suction pipe, casing and a portion of delivery pipe of the centrifugal pump which, if remains, the liquid will not be sucked continuously by the pump.

7.25.1 Methods of Priming

There are three methods of priming :

1. Manual priming,
2. Vacuum priming,
3. Self priming.

1. Manual Priming : In this method, delivery valve is closed before starting the pump. The air-cock is opened and liquid is filled by a funnel until it overflows. This ensures the removal of air from the pump. This method is used in small pumps.

2. Vacuum Priming : The air is extracted from the suction pipe of the pump with the help of vacuum pump. The liquid is thus fetched into the suction pipe from the sump. This method is used in large pumps.

3. Self Priming : The internal construction of the self priming pump is such that it primes automatically. These pumps are better, but expensive.

7.26 DIFFERENCE BETWEEN CENTRIFUGAL PUMP AND RECIPROCATING PUMP

S. No.	Centrifugal Pump	Reciprocating Pump
1.	It is steady in operation and delivery is continuous and smooth.	It is intermittent in operation and delivery is pulsating and fluctuating.
2.	It is used for large discharge and small heads.	It is used for small discharge and high heads.
3.	It operates at high speeds.	It operates at low speeds.
4.	It has few accessories and hence maintenance cost is low.	Due to more parts, maintenance cost is high and frequent.
5.	Initial cost is less.	Initial cost is approximately four times that of centrifugal pump.
6.	It is used for lifting highly viscous liquids.	It is used for lifting less viscous liquids free from impurities.