6 PUMPS AND WATER TURBINES

6.1 INTRODUCTION

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

6.2 HYDRAULIC PUMP

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.

6.3 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 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.

6.4 SINGLE ACTING RECIPROCATING PUMP

The main components of a reciprocating pump as shown in fig. 6.1 are as follow :

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

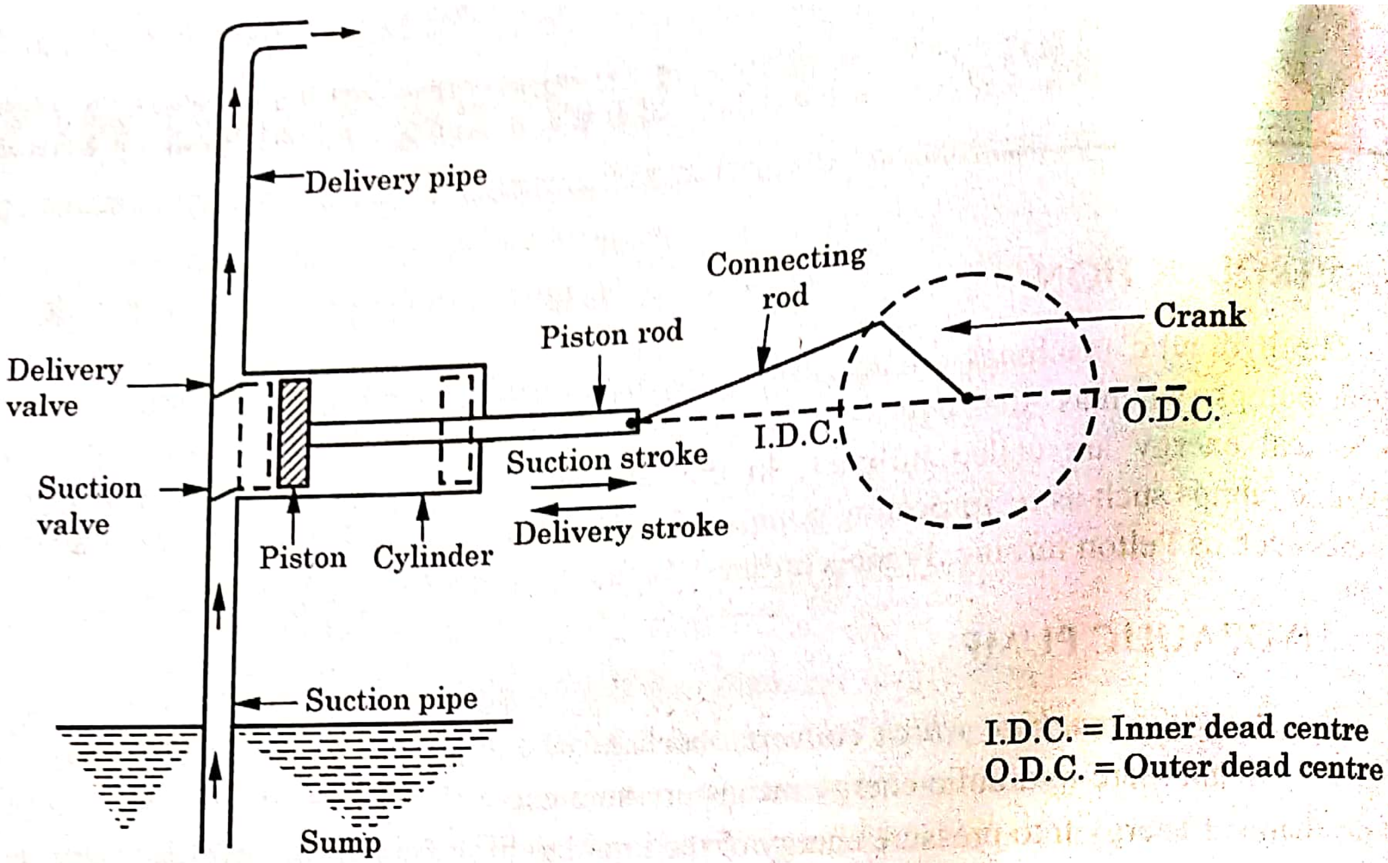

Fig. 6.1 : Reciprocating Pump

Working : A single acting reciprocating pump shown in fig. 6.1 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.

6.5 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.

6.5.1 Vane Pump

Vane pump as shown in fig. 6.2 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.

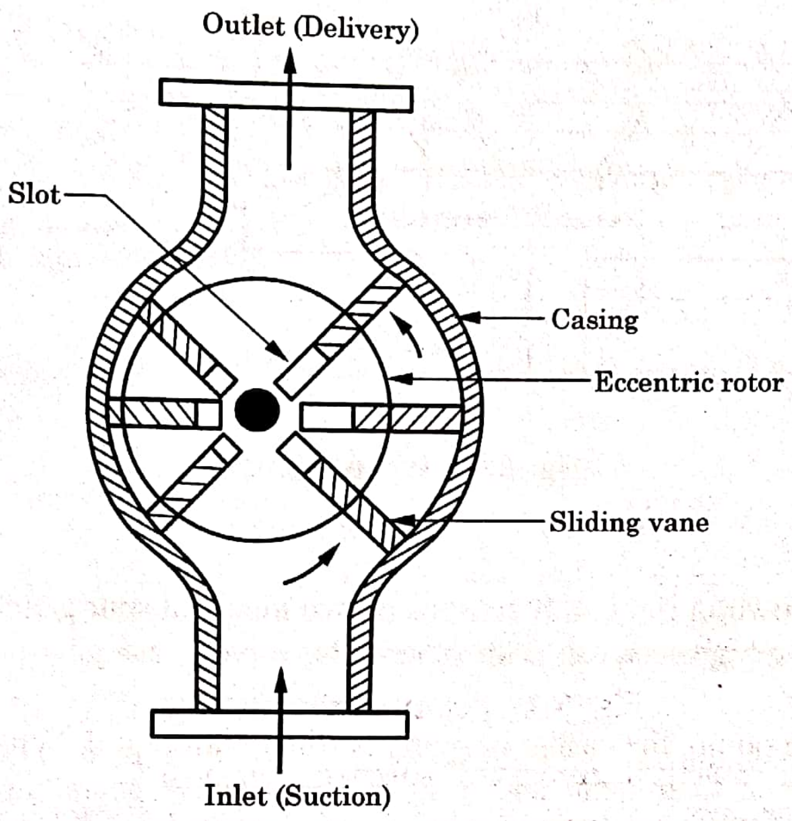

Fig. 6.2 : Vane Pump

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.

6.5.2 Screw Pump

A screw pump shown in fig. 6.3 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.

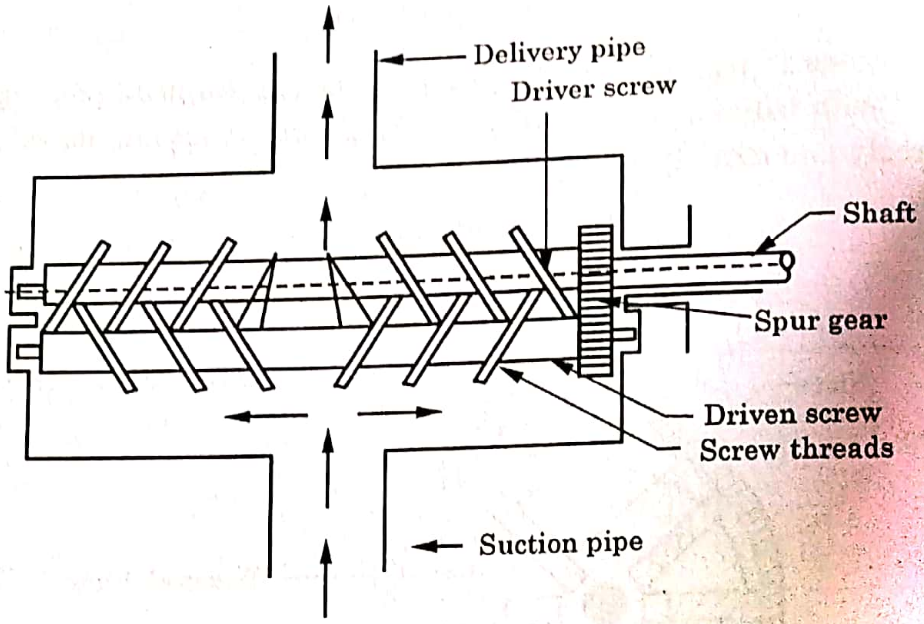

Fig. 6.3 : Screw Pump

6.5.3 Gear Pump

A gear pump is shown in fig. 6.4. 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.

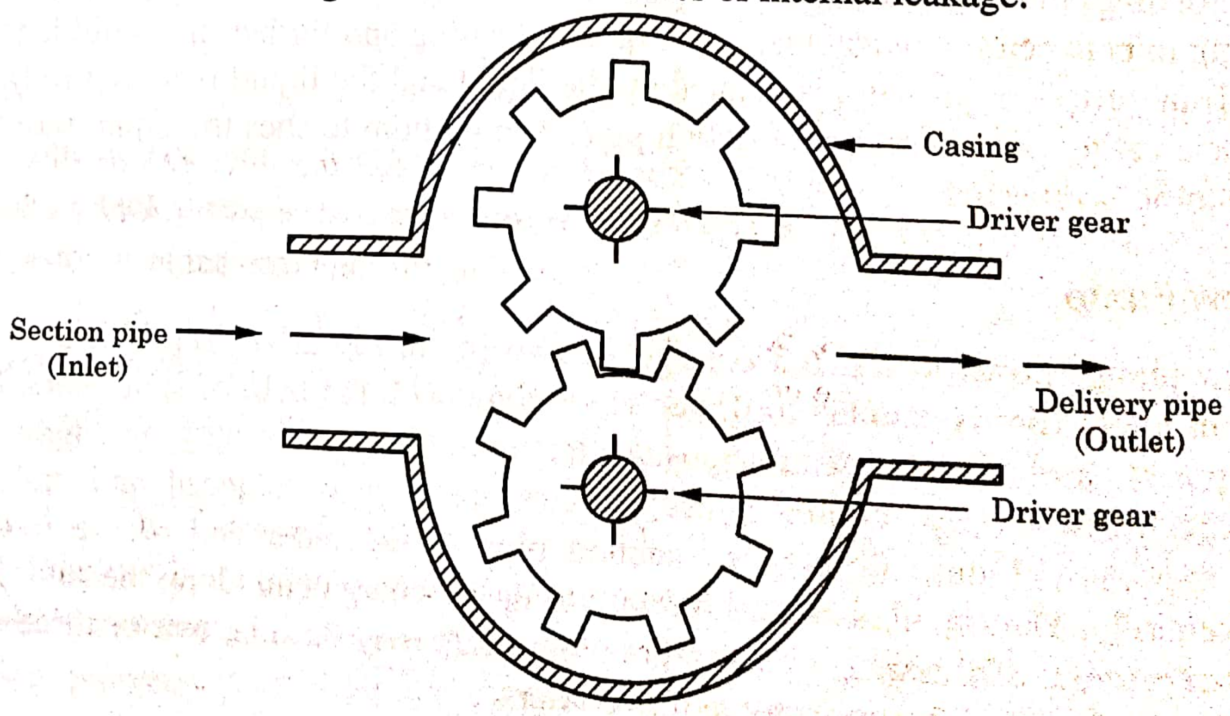

Fig. 6.4 : Gear Pump

6.6 CENTRIFUGAL PUMP

The hydraulic machine which 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. 6.5 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. 6.5, 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. 6.6, 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. 6.7, 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.

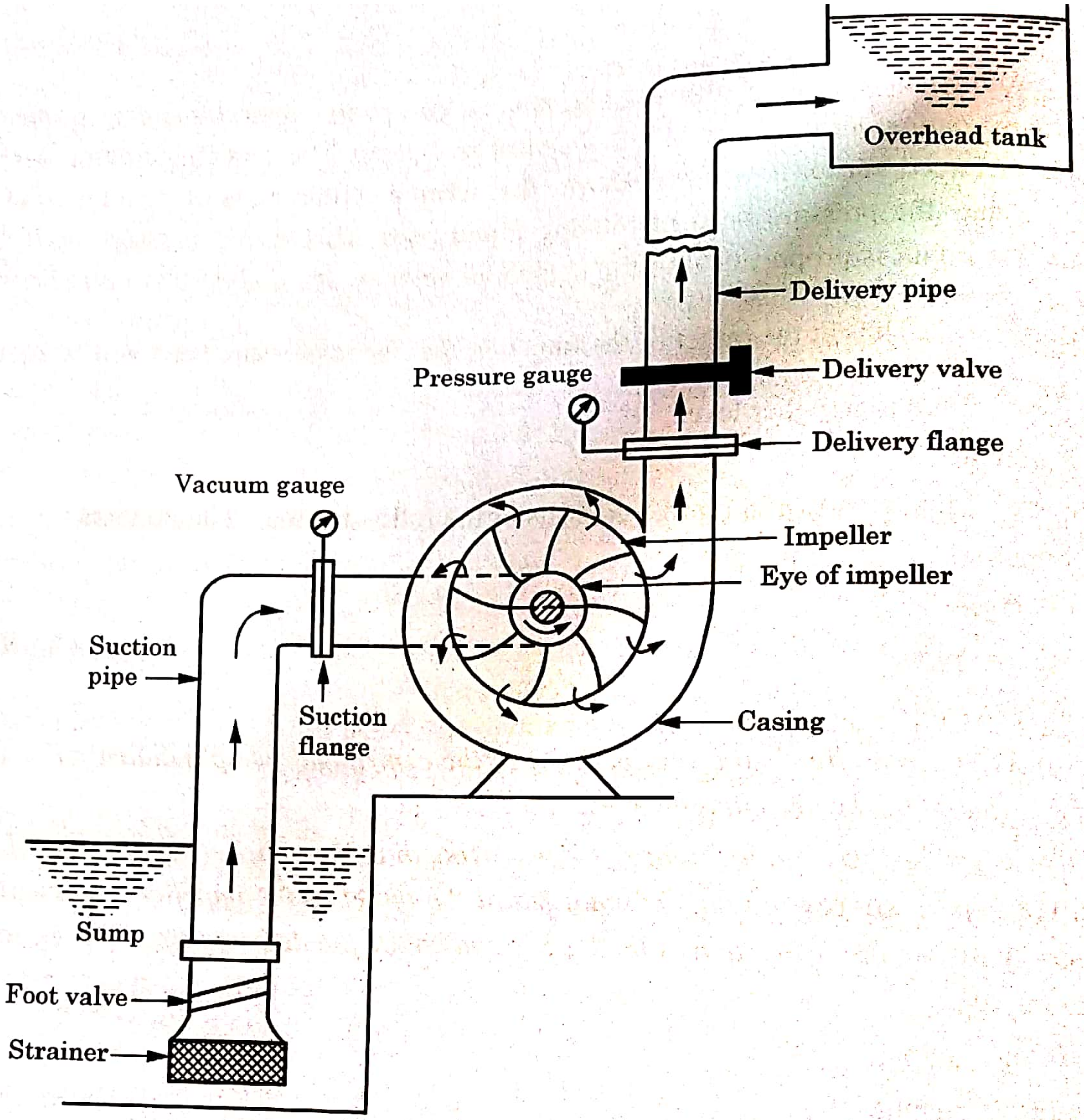

Fig. 6.5 : Centrifugal Pump with Volute Casing

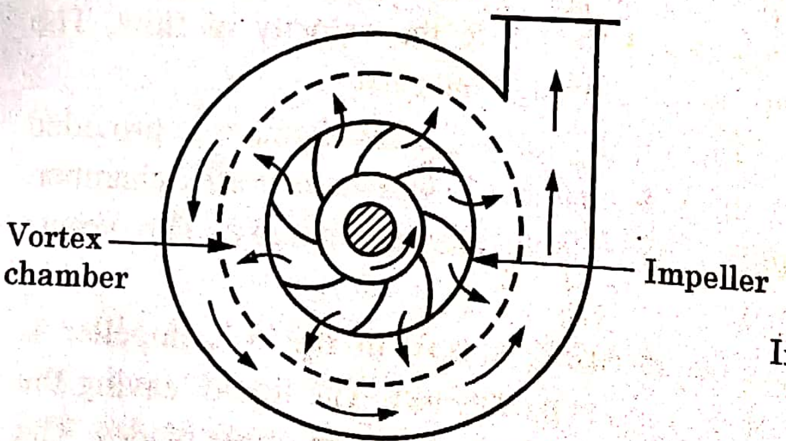

Fig. 6.6 : Vortex Casing

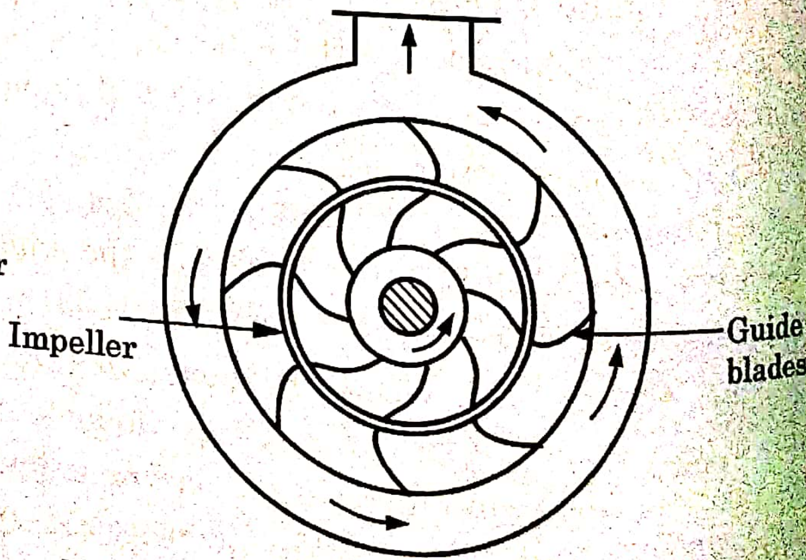

Fig. 6.7 : Casing with Guide Blades

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.

6.7 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.	Reprime the pump.
		(*ii*) Very low speed.	Increase the speed.
		(*iii*) Clogging of either strainer or impeller.	Change the strainer and clean the impeller.
		(*iv*) Opposite direction of rotation of impeller.	Change direction of rotation of impeller.
		(*v*) Total static head is more than the specified head.	Change a new pump.
2.	Pump first starts and then stops pumping.	(*i*) High suction lift.	Lower the suction lift.
		(*ii*) Presence of air in suction pipe.	Prime the pump to remove air.
		(*iii*) Leakage of suction pipe.	Stop the leakage by seals etc.

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

6.8 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.

6.9 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.

6.9.1 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.

6.9.2 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.

6.10 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.

6.10.1 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.

6.11 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.