Hydraulic Machines BME-51

Unit-4

(Lecture 1)

Reciprocating Pump

Lecture contains

- **Introduction**
- **Main Components**
- **working**

Introduction:-

INTRODUCTION

- Pumps are used to increase the energy level of water by virtue of which it can be raised to a higher level.
- Reciprocating pumps are positive displacement pump, i.e. initially, a small quantity of liquid is taken into a chamber and is physically displaced and forced out with pressure by a moving mechanical elements.
- The use of reciprocating pumps is being limited these days and being replaced by centrifugal pumps.

INTRODUCTION

- For industrial purposes, they have become obsolete due to their high initial and maintenance costs as compared to centrifugal pumps.
- Small hand operated pumps are still in use that include well pumps, etc.
- These are also useful where high heads are required with small discharge, as oil drilling operations.

Main Components of a Reciprocating Pump:-

The following are the main parts of a reciprocating pump as shown in Fig. 1 :

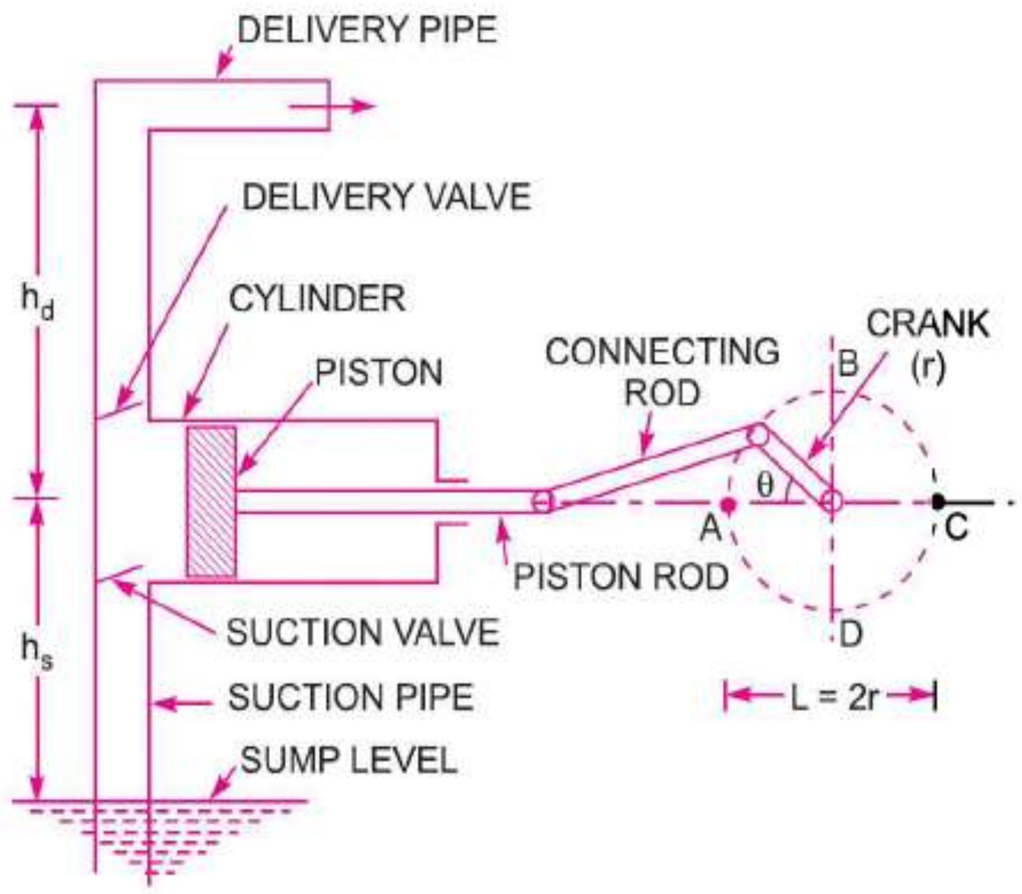

Fig. 1 *Main parts of a reciprocating pump.*

Main components

- A reciprocation pumps consists of a plunger or a piston that moves forward and backward inside a cylinder with the help of a connecting rod and a crank. The crank is rotated by an external source of power.
- The cylinder is connected to the sump by a suction pipe and to the delivery tank by a delivery pipe.
- At the cylinder ends of these pipes, non-return valves are provided. A non-return valve allows the liquid to pass in only one direction.
- Through suction valve, liquid can only be admitted into the cylinder and through the delivery valve, liquid can only be discharged into the delivery pipe.

Working of Reciprocating Pump:-

Fig. 1 shows a single acting reciprocating pump, which consists of a piston which moves forwards and backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one way valves or non-return valves, which allow the water to flow in one direction only. Suction valve allows water from suction pipe to the cylinder which delivery valve allows water from cylinder to delivery pipe only.

When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at *A*., the piston is at the extreme left position in the cylinder. As the crank is rotating from *A* to *C*, (*i.e.*, from $\theta = 0^o$ to $\theta = 180°$), the piston is moving towards right in the cylinder. The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus, the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder.

When crank is rotating from *C* to *A* (*i.e.*, from $\theta = 180°$ to $\theta = 360°$), the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.

Hydraulic Machines BME-51

Unit-4

(Lecture 2)

Lecture contains

- **Classification of Reciprocating Pump**

- **Discharge through a Reciprocating Pump**

- **Work done by Reciprocating Pump**

Classification of Reciprocating pumps

Following are the main types of reciprocating pumps:

- According to use of piston sides
  - Single acting Reciprocating Pump:

    If there is only one suction and one delivery pipe and the liquid is filled only on one side of the piston, it is called a single-acting reciprocating pump.
  - Double acting Reciprocating Pump:

    A double-acting reciprocating pump has two suction and two delivery pipes, Liquid is receiving on both sides of the piston in the cylinder and is delivered into the respective delivery pipes.

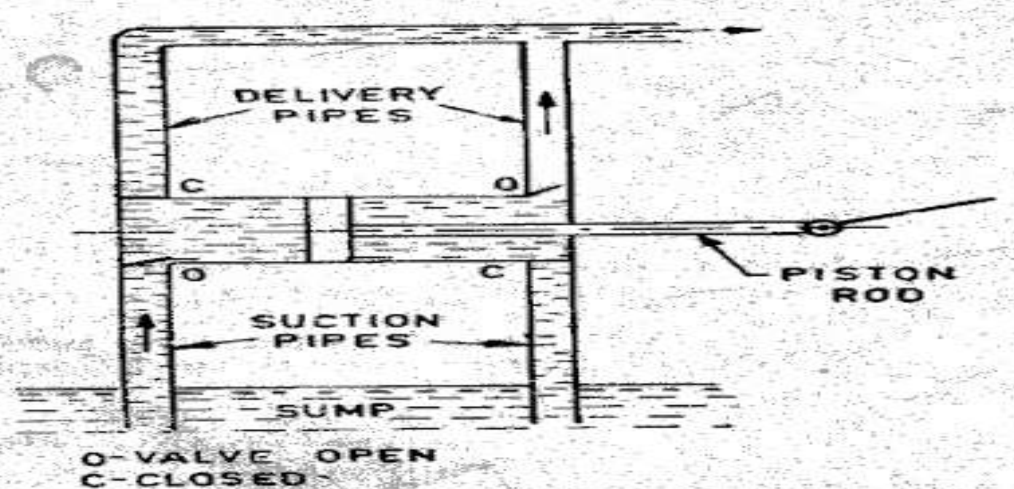

Fig. 11·2. Double-acting reciprocating pump.

Classification of Reciprocating pumps

- According to number of cylinder

  Reciprocating pumps having more than one cylinder are called multi-cylinder reciprocating pumps.

  - Single cylinder pump
  - Double cylinder pump (or two throw pump)
  - Triple cylinder pump (three throw pump)
  - There can be four-cylinder and five cylinder pumps also, the cranks of which are arranged accordingly.

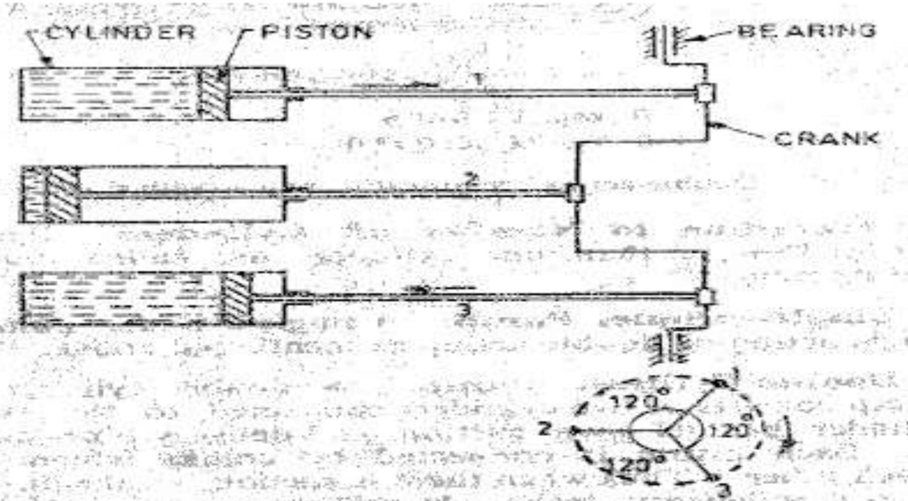

Fig. 11·5. Triple-cylinder pump.

Discharge through a Reciprocating Pump:-

Consider a single* acting reciprocating pump as shown in Fig. 1.

Let D = Diameter of the cylinder

A = Cross-sectional area of the piston or cylinder

$$= \frac{\pi}{4} D^2$$

r = Radius of crank

N = r.p.m. of the crank

L = Length of the stroke = $2 \times r$

h_s = Height of the axis of the cylinder from water surface in sump.

h_d = Height of delivery outlet above the cylinder axis (also called delivery head)

Volume of water delivered in one revolution or discharge of water in one revolution

$$= \text{Area} \times \text{Length of stroke} = A \times L$$

Number of revolution per second, $= \dfrac{N}{60}$

$\therefore$ Discharge of the pump per second,

$$Q = \text{Discharge in one revolution} \times \text{No. of revolution per second}$$

$$= A \times L \times \frac{N}{60} = \frac{ALN}{60} \quad \ldots(1)$$

---

* Single acting means the water is acting on one side of the piston only.

Weight of water delivered per second,

$$W = \rho \times g \times Q = \frac{\rho g A L N}{60}. \quad \ldots(\quad 2)$$

Work done by Reciprocating Pump. Work done by the reciprocating pump per second is given by the reaction as

Work done per second = Weight of water lifted per second × Total height through which water is lifted

$$= W \times (h_s + h_d) \quad \ldots(i)$$

where $(h_s + h_d)$ = Total height through which water is lifted.

From equation (2), Weight, W, is given by

$$W = \frac{\rho g \times A L N}{60}.$$

Substituting the value of W in equation (i), we get

$$\text{Work done per second} = \frac{\rho g \times A L N}{60} \times (h_s + h_d) \quad \ldots(\quad 3)$$

∴ Power required to drive the pump, in kW

$$P = \frac{\text{Work done per second}}{1000} = \frac{\rho g \times A L N \times (h_s + h_d)}{60 \times 1000}$$

$$= \frac{\rho g \times A L N \times (h_s + h_d)}{60{,}000} \text{ kW} \quad \ldots(\quad 4)$$

Hydraulic Machines BME-51
Unit-4
(Lecture 3)

Lecture contains

- **Discharge, Work done and power required to drive a Double- Acting Reciprocating pump**
- **Slip of Reciprocating pump**

Discharge, Work done and power required to drive a Double- Acting Reciprocating pump:-

In case of double-acting pump, the water is acting on both sides of the piston as shown in Fig. 2 Thus, we require two suction pipes and two delivery pipes for double-acting pump. When there is a suction stroke on one side of the piston, there is at the same time a delivery stroke on the other side of the piston. Thus for one complete revolution of the crank there are two delivery strokes and water is delivered to the pipes by the pump during these two delivery strokes.

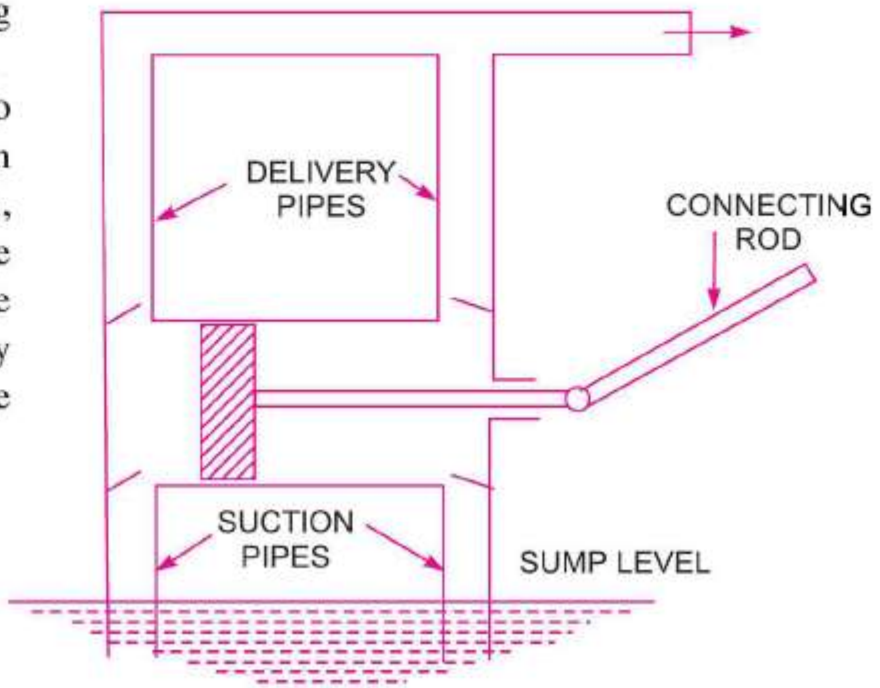

Fig. 2

Let D = Diameter of the piston,

d = Diameter of the piston rod

∴ Area on one side of the piston,

$$A = \frac{\pi}{4} D^2$$

Area on the other side of the piston, where piston rod is connected to the piston,

$$A_1 = \frac{\pi}{4} D^2 - \frac{\pi}{4} d^2 = \frac{\pi}{4} (D^2 - d^2).$$

$\therefore$ Volume of water delivered in one revolution of crank

$$= A \times \text{Length of stroke} + A_1 \times \text{Length of stroke}$$

$$= AL + A_1L = (A + A_1)L = \left[\frac{\pi}{4}D^2 + \frac{\pi}{4}\left(D^2 - d^2\right)\right] \times L$$

$\therefore$ Discharge of pump per second

= Volume of water delivered in one revolution × No. of revolution per second

$$= \left[\frac{\pi}{4}D^2 + \frac{\pi}{4}\left(D^2 - d^2\right)\right] \times L \times \frac{N}{60}$$

If 'd' the diameter of the piston rod is very small as compared to the diameter of the piston, then it can be neglected and discharge of pump per second,

$$Q = \left(\frac{\pi}{4}D^2 + \frac{\pi}{4}D^2\right) \times \frac{L \times N}{60} = 2 \times \frac{\pi}{4}D^2 \times \frac{L \times N}{60} = \frac{2ALN}{60} \quad \text{...(5)}$$

Equation (5) gives the discharge of a double-acting reciprocating pump. This discharge is two times the discharge of a single-acting pump.

Work done by double-acting reciprocating pump

Work done per second = Weight of water delivered × Total height

$$= \rho g \times \text{Discharge per second} \times \text{Total height}$$

$$= \rho g \times \frac{2ALN}{60} \times (h_s + h_d) = 2\rho g \times \frac{ALN}{60} \times (h_s + h_d) \quad \ldots(6)$$

∴ Power required to drive the double-acting pump in kW,

$$P = \frac{\text{Work done per second}}{1000} = 2\rho g \times \frac{ALN}{60} \times \frac{(h_s + h_d)}{1000}$$

$$= \frac{2\rho g \times ALN \times (h_s + h_d)}{60{,}000} \quad \ldots(7)$$

Slip of Reciprocating pump:-

Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump. The discharge of a single-acting pump given by equation (1) and of a double-acting pump given by equation (5) are theoretical discharge. The actual discharge of a pump is less than the theoretical discharge due to leakage. The difference of the theoretical discharge and actual discharge is known as slip of the pump. Hence, mathematically.

$$\text{Slip} = Q_{th} - Q_{act} \qquad ...(\ 8)$$

But slip is mostly expressed as percentage slip which is given by,

$$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100$$

$$= (1 - C_d) \times 100 \qquad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right) \qquad ...(\ 9)$$

where C_d = Co-efficient of discharge.

Negative Slip of the Reciprocating Pump. Slip is equal to the difference of theoretical discharge and actual discharge. If actual discharge is more than the theoretical discharge, the slip of the pump will become –ve. In that case, the slip of the pump is known as negative slip.

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high speed.

Hydraulic Machines BME-51

Unit-4

(Lecture 4)

Lecture contains

- **Solve example**
- **Comparison of Centrifugal Pump and Reciprocating pump**
- **Application of Reciprocating pump**
- **Problems**

Problem-1: A single-acting reciprocating pump discharge 0.018 m^3/s of water per second when running at 60 rpm. Stroke length is 50 cm and the diameter of the piston is 22 cm. If the total lift is 15 m, determine:

a) Theoretical discharge of the pump
b) Slip and percentage slip of the pump
c) Co-efficient of discharge
d) Power required running the pump

Solution:

$L = 0.5$ m

$Q_a = 0.018 m^3/s$

$D = 0.22$ m

$N = 60$ rpm

$H_{st} = 15$ m

Solution:

(a) $$Q_{th} = A \times L \times \frac{N}{60} = \left(\frac{\pi}{4} D^2\right) \frac{LN}{60}$$

$Q_{th} = (\pi/4) \times (0.22)^2 \times (0.5 \times 60/60)$

$Q_{th} =$ **0.019 m³ /s**

(b) Slip $= Q_{th} - Q_a$

Slip $= 0.019 - 0.018$

= 0.001 m³ /s

Percentage slip $= (Q_{th} - Q_a)/ Q_{th}$

$= (0.019-0.018)/0.019$

= 0.0526 or 5.26%

Solution:

(c) $C_d = Q_a / Q_{th}$

$= 0.018/0.019$

= 0.947

(d) Power Input

$= \rho \, g \, H_{st} Q_{th}$ (Neglecting Losses)

$= 1000 \times 0.019 \times 9.81 \times 15$

= 2796 w or 2.796 kW

APPLICATIONS

- *Agriculture.*
- *Chemical.*
- *Desalination.*
- *Horizontal Drilling.*
- *General Industries.*
- *Mining.*
- *Oil and Gas.*
- *Pulp and Paper.*
- *Sewer Cleaning.*
- *Steel.*

Comparison of Centrifugal and Reciprocating Pumps

Centrifugal Pumps	Reciprocating Pumps
1. Steady and even flow	1. Intermittent and pulsating flow
2. For large discharge, small heads	2. For small discharge, high heads.
3. Can be used for viscous fluids e.g. oils, muddy water.	3. Can handle pure water or less viscous liquids only otherwise valves give frequent trouble.
4. Low initial cost	4. High initial cost.
5. Can run at high speed. Can be coupled directly to electric motor.	5. Low speed. Belt drive necessary.
6. Low maintenance cost. Periodic check up sufficient.	6. High maintenance cost. Frequent replacement of parts.
7. Compact less floors required.	7. Needs 6-7 times area than for centrifugal pumps.
8. Low head pumps have high efficiency	8. Efficiency of low head pumps as low as 40 per cent due to the energy losses.
9. Uniform torque	9. Torque not uniform.
10. Simple constructions. Less number of spare parts needed	10. Complicated construction. More number of spare parts needed.

Problem *A single-acting reciprocating pump, running at 50 r.p.m., delivers 0.01 m^3/s of water. The diameter of the piston is 200 mm and stroke length 400 mm. Determine :*

(i) The theoretical discharge of the pump, (ii) Co-efficient of discharge, and (iii) Slip and the percentage slip of the pump.

Problem *A double-acting reciprocating pump, running at 40 r.p.m., is discharging 1.0 m^3 of water per minute. The pump has a stroke of 400 mm. The diameter of the piston is 200 mm. The delivery and suction head are 20 m and 5 m respectively. Find the slip of the pump and power required to drive the pump.*

Hydraulic Machines BME-51

Unit-4

(Lecture 5)

Lecture contains

- **Effect of acceleration of Piston**

Effect of acceleration of Piston:- Fig. shows the cylinder of a reciprocating single-acting pump, fitted with a piston which is connected to the crank. Let the crank is rotating at a constant angular speed.

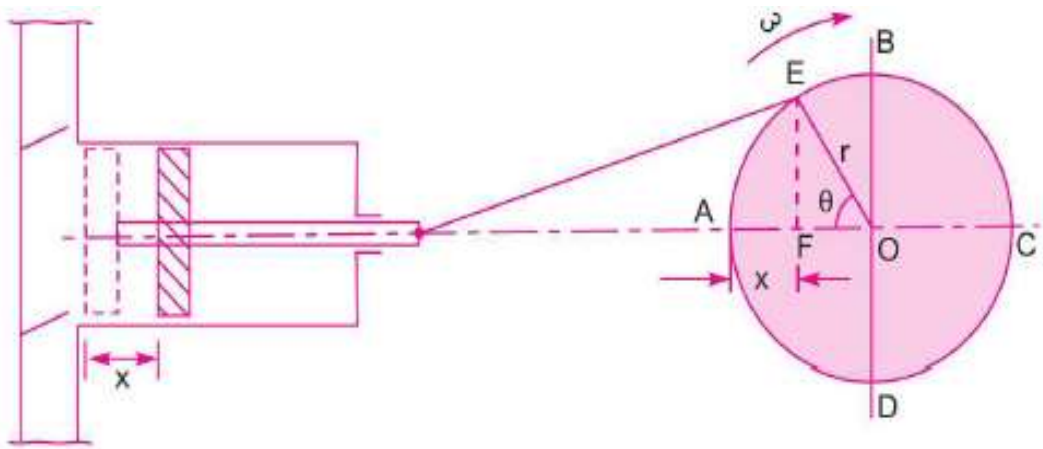

Fig. *Velocity and acceleration of piston.*

Let ω = Angular speed of the crank in rad./s,

A = Area of the cylinder,

a = Area of the pipe (suction or delivery),

l = Length of the pipe (suction or delivery), and

r = Radius of the crank.

$$h_a = \frac{\text{Intensity of pressure due to acceleration}}{\text{Weight density of liquid}}$$

$$= \frac{\rho l \times \frac{A}{a} \omega^2 r \cos\theta}{\rho g} = \frac{l}{g} \times \frac{A}{a} \omega^2 r \cos\theta. \quad \text{...(1)}$$

The pressure head due to acceleration in the suction and delivery pipes is obtained by using subscripts '*s*' and '*d*' as

$$h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r \cos\theta$$

$$h_{ad} = \frac{l_d}{g} \times \frac{A}{a_d} \omega^2 r \cos\theta.$$

The pressure head (h_a) due to acceleration, given by equation (1) varies with θ. The values of 'h_a' for different values of θ are :

1. When $\theta = 0°$, $h_a = \frac{l}{g} \times \frac{A}{a} \omega^2 r$ as $\cos 0° = 1$

2. When $\theta = 90°$, $h_a = 0$ as $\cos 90° = 0$

3. When $\theta = 180°$, $h_a = -\frac{l}{g} \times \frac{A}{a} \omega^2 r$ as $\cos 180° = -1$

∴ Maximum pressure head due to acceleration

$$(h_a)_{max} = \frac{l}{g} \times \frac{A}{a} \omega^2 r$$

EFFECT OF VARIATION OF VELOCITY ON FRICTION IN THE SUCTION AND DELIVERY PIPES

The velocity of water in suction or delivery pipe is given by

$$v = \frac{A}{a} \omega r \sin \omega t = \frac{A}{a} \omega r \sin \theta \qquad ...(i)$$

Loss of head due to friction in pipes is given by

$$h_f = \frac{4 f l v^2}{d \times 2g} \qquad ...(ii)$$

where f = Co-efficient of friction, l = Length of pipe,
d = Diameter of pipe, and v = Velocity of water in pipe.

Substituting equation (*i*) into equation (*ii*), we get

$$h_f = \frac{4 f l}{d \times 2g} \times \left[\frac{A}{a} \omega r \sin \theta\right]^2 \qquad ...(1)$$

The variation of h_f with θ is parabolic. The loss of head due to friction in suction and delivery pipes is obtained from equation (1) by using subscripts '*s*' for suction pipe and '*d*' for delivery pipe as

$$h_{fs} = \frac{4 f l_s}{d_s \times 2g} \times \left[\frac{A}{a_s} \omega r \sin \theta\right]^2$$

$$h_{fd} = \frac{4 f l_d}{d_d \times 2g} \times \left[\frac{A}{a_d} \omega r \sin \theta\right]^2$$

The loss of head due to friction in pipes given by equation (1) varies with θ as :

1. When $\theta = 0°$, $\quad \sin\theta = 0 \quad \therefore \quad h_f = \frac{4fl}{d \times 2g} \times 0 = 0$

2. When $\theta = 90°$, $\quad \sin 90° = 1 \quad \therefore \quad h_f = \frac{4fl}{d \times 2g} \times \left[\frac{A}{a}\omega r\right]^2$

3. When $\theta = 180°$, $\quad \sin 180° = 0 \quad \therefore \quad h_f = 0$

$\therefore$ Maximum value of loss of head due to friction ;

$$(h_f)_{max} = \frac{4fl}{d \times 2g} \times \left[\frac{A}{a}\omega r\right]^2$$

Problem *The cylinder bore diameter of a single-acting reciprocating pump is 150 mm and its stroke is 300 mm. The pump runs at 50 r.p.m. and lifts water through a height of 25 m. The delivery pipe is 22 m long and 100 mm in diameter. Find the theoretical discharge and the theoretical power required to run the pump. If the actual discharge is 4.2 litres/s, find the percentage slip. Also determine the acceleration head at the beginning and middle of the delivery stroke.*

Hydraulic Machines BME-51

Unit-4

(Lecture 6)

Lecture contains

- **Indicator Diagram**
- **Air Vessels**

Indicator Diagram:-

The indicator diagram for a reciprocating pump is defined as the graph between the pressure head in the cylinder and the distance travelled by piston from inner dead centre for one complete revolution of the crank. As the maximum distance travelled by the piston is equal to the stroke length and hence the indicator diagram is a graph between pressure head and stroke length of the piston for one complete revolution. The pressure head is taken as ordinate and stroke length as abscissa.

I Ideal Indicator Diagram. The graph between pressure head in the cylinder and stroke length of the piston for one complete revolution of the crank under ideal conditions is known as ideal indicator diagram. Fig. shows the ideal indicator diagram, in which line *EF* represents the atmospheric pressure head equal to 10.3 m of water.

Let H_{atm} = Atmospheric pressure head

= 10.3 m of water,

L = Length of the stroke,

h_s = Suction head, and

h_d = Delivery head.

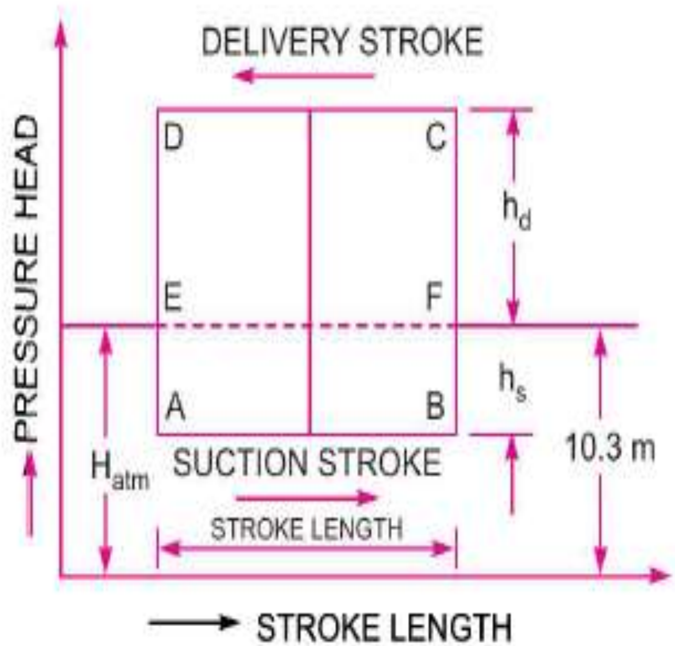

Fig. *Ideal indicator diagram.*

During suction stroke, the pressure head in the cylinder is constant and equal to suction head (h_s), which is below the atmospheric pressure head (H_{atm}) by a height of h_s. The pressure head during suction stroke is represented by a horizontal line AB which is below the line EF by a height of 'h_s'.

During delivery stroke, the pressure head in the cylinder is constant and equal to delivery head (h_d), which is above the atmospheric head by a height of (h_d). Thus, the pressure head during delivery stroke is represented by a horizontal line CD which is above the line EF by a height of h_d. Thus, for one complete revolution of the crank, the pressure head in the cylinder is represented by the diagram A-B-C-D-A. This diagram is known as ideal indicator diagram.

we know that the work done by the pump per second

$$= \frac{\rho \times g \times ALN}{60} \times (h_s + h_d)$$

$$= K \times L(h_s + h_d) \qquad \left(\text{where } K = \frac{\rho g A N}{60} = \text{Constant}\right)$$

$$\propto L \times (h_s + h_d) \qquad \ldots(i)$$

But from Fig. area of indicator diagram

$$= AB \times BC = AB \times (BF + FC) = L \times (h_s + h_d).$$

Substituting this value in equation (i), we get

Work done by pump $\propto$ Area of indicator diagram.

2 Effect of Acceleration in Suction and Delivery Pipes on Indicator Diagram.

The pressure head due to acceleration in the suction pipe is given by

$$h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r \cos\theta$$

When $\theta = 0°$, $\cos\theta = 1$, and $h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r$

When $\theta = 90°$, $\cos\theta = 0$, and $h_{as} = 0$

When $\theta = 180°$, $\cos\theta = -1$, and $h_{as} = -\frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r$.

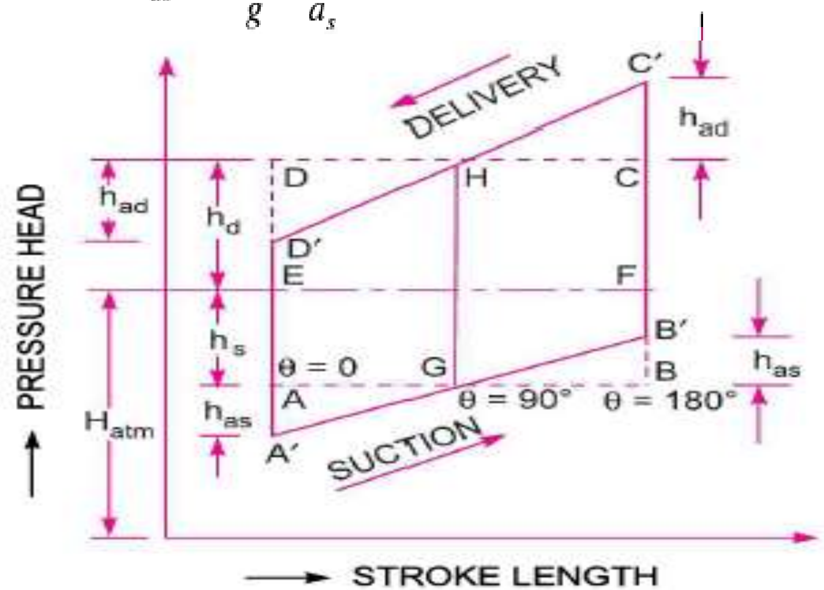

Fig. *Effect of acceleration on indicator diagram.*

Problem . *A single-acting reciprocating pump has piston diameter 12.5 cm and stroke length 30 cm. The centre of the pump is 4 m above the water level in the sump. The diameter and length of suction pipe are 7.5 cm and 7 m respectively. The separation occurs if the absolute pressure head in the cylinder during suction stroke falls below 2.5 m of water. Calculate the maximum speed at which the pump can run without separation. Take atmospheric pressure head = 10.3 m of water.*

Solution. Given :

Diameter of piston, $D = 12.5 \text{ cm} = 0.125 \text{ m}$

∴ Area, $A = \frac{\pi}{4}(.125)^2 = .01227 \text{ m}^2$

Stroke length, $L = 30 \text{ cm} = 0.30 \text{ m}$

∴ Crank radius, $r = \frac{L}{2} = \frac{0.30}{2} = 0.15 \text{ m}$

Suction head, $h_s = 4.0 \text{ m}$

Diameter of suction pipe, $d_s = 7.5 \text{ cm} = 0.075 \text{ m}$

∴ Area of suction pipe, $a_s = \frac{\pi}{4}(.075)^2 = .004418 \text{ m}^2$

Length of suction pipe, $l_s = 7.0 \text{ m}$

Separation pressure head, $h_{sep} = 2.5 \text{ m (absolute)}$

Atmospheric pressure head, $H_{atm} = 10.3 \text{ m}$

From the indicator diagram, it is clear that the absolute pressure head during suction stroke is minimum at the beginning of the stroke. Thus, the separation can take place at the beginning of the stroke only. In that case the pressure head in the cylinder at the beginning of stroke becomes = h_{sep}.

But pressure head in the cylinder at the beginning of suction stroke

$$= (h_s + h_{as}) \text{ m below atmospheric pressure head}$$
$$= \text{Atmospheric pressure head} - (h_s + h_{as}) \text{ m absolute}$$
$$= H_{atm} - (h_s + h_{as}) \text{ m (abs.)}$$
$$= 10.3 - (4.0 + h_{as})$$

$\therefore$
$$h_{sep} = 10.3 - (4.0 + h_{as})$$
$$2.5 = 10.3 - 4.0 - h_{as}$$

or
$$h_{as} = 10.3 - 4.0 - 2.5 = 3.80 \text{ m.} \qquad \text{...}(i)$$

But from equation , h_{as} at the beginning of suction stroke is given by the relation

$$h_{as} = \frac{l_s}{g} \times \frac{A}{a_s} \omega^2 r \qquad (\because \theta = 0^\circ, \because \cos\theta = 1) \text{ ...}(ii)$$

Equating equations (*i*) and (*ii*), we get

$$3.80 = \frac{l_s}{g} \times \frac{A}{a_s} \times \omega^2 r = \frac{7.0}{9.81} \times \frac{.01227}{.004418} \times \omega^2 \times .15$$

$\therefore$
$$\omega^2 = \frac{3.80 \times 9.81 \times .004418}{7.0 \times .01227 \times .15} = 12.783$$

or
$$\omega = \sqrt{12.783} = 3.575 \text{ radian/s.}$$

But
$$\omega = \frac{2\pi N}{60}$$

$\therefore$
$$N = \frac{60 \times \omega}{2\pi} = \frac{60 \times 3.575}{2\pi} = \mathbf{34.14 \text{ r.p.m. Ans.}}$$

Thus, the maximum speed at which the pump can run without separation is 34.14 r.p.m.

Hydraulic Machines BME-51
Unit-4
(Lecture 7)

Lecture contains

- **Air Vessels**
- **Fluid system**

Hydraulic Machines BME-51

Unit-4

(Lecture 7)

Lecture contains

- **Air Vessels**

- **Fluid system**

Air Vessels:-

An air vessel is a closed chamber containing compressed air in the top portion and liquid (or water) at the bottom of the chamber. At the base of the chamber there is an opening through which the liquid (or water) may flow into the vessel or out from the vessel. When the liquid enters the air vessel, the air gets compressed further and when the liquid flows out the vessel, the air will expand in the chamber.

An air vessel is fitted to the suction pipe and to the delivery pipe at a point close to the cylinder of a single-acting reciprocating pump :

(*i*) to obtain a continuous supply of liquid at a uniform rate,

(*ii*) to save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes, and

(iii) To run the pump at a high speed without separation

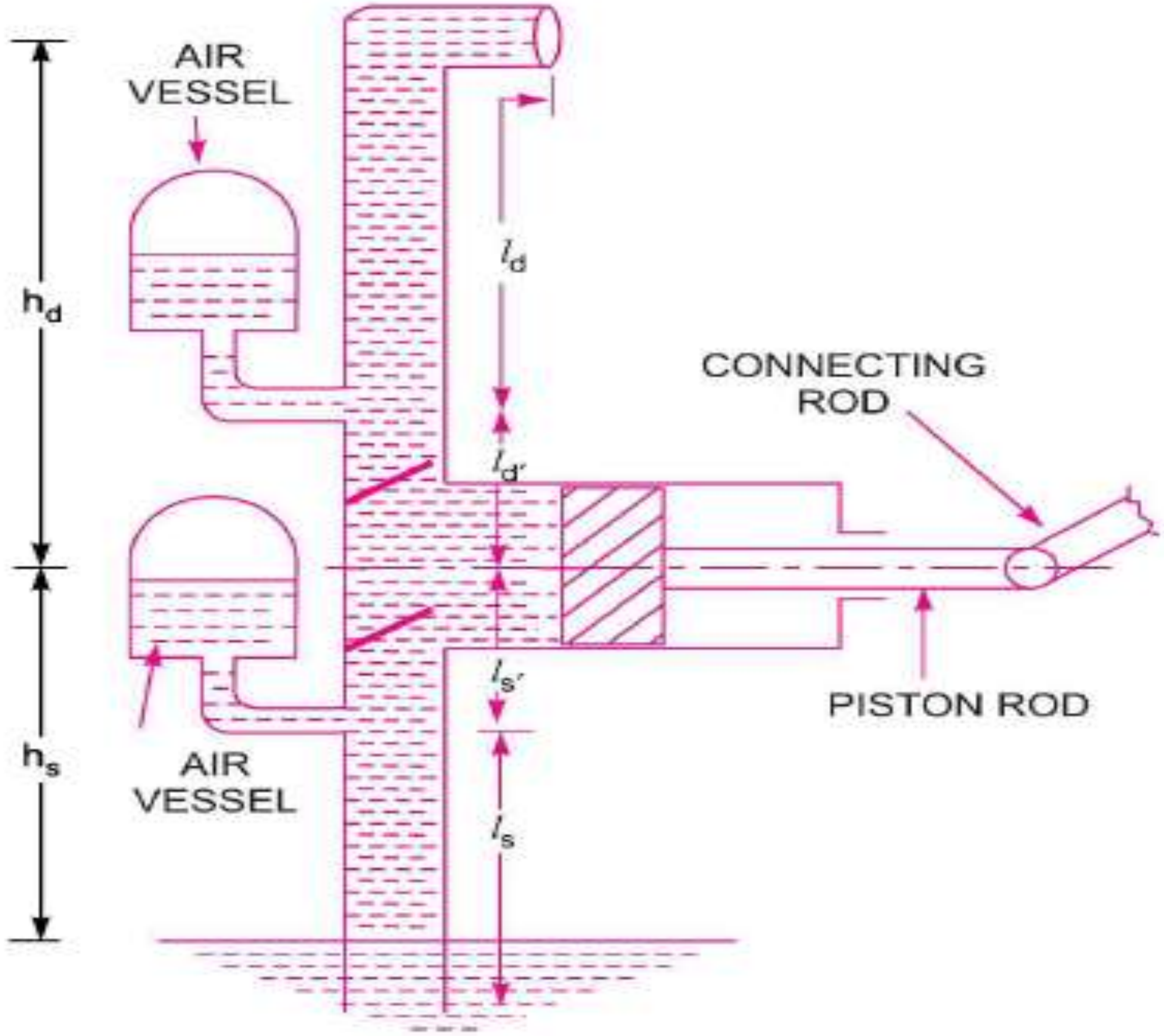

Fig. *Air vessels fitted to reciprocating pump.*

Fluid system:-

Fluid system is defined as the device in which power is transmitted with the help of a fluid which may be liquid (water or oil) or a gas (air) under pressure. Most of these devices are based on the principles of fluid statics and fluid kinematics. In this chapter, the following devices will be discussed:

1. The hydraulic press,
2. The hydraulic accumulator,
3. The hydraulic intensifier,
4. The hydraulic ram,
5. The hydraulic lift,
6. The hydraulic crane,
7. The fluid or hydraulic coupling,
8. The fluid or hydraulic torque converter,
9. The air lift pump, and
10. The gear-wheel pump.

1. THE HYDRAULIC PRESS

The hydraulic press is a device used for lifting heavy weights by the application of a much smaller force. It is based on Pascal's law, which states that the intensity of pressure in a static fluid is transmitted equally in all directions.

The hydraulic press consists of two cylinders of different diameters. One of the cylinder is of large diameter and contains a ram, while the other cylinder is of smaller diameter and contains a plunger as shown in Fig. 1. The two cylinders are connected by a pipe. The cylinders and pipe contain a liquid through which pressure is transmitted.

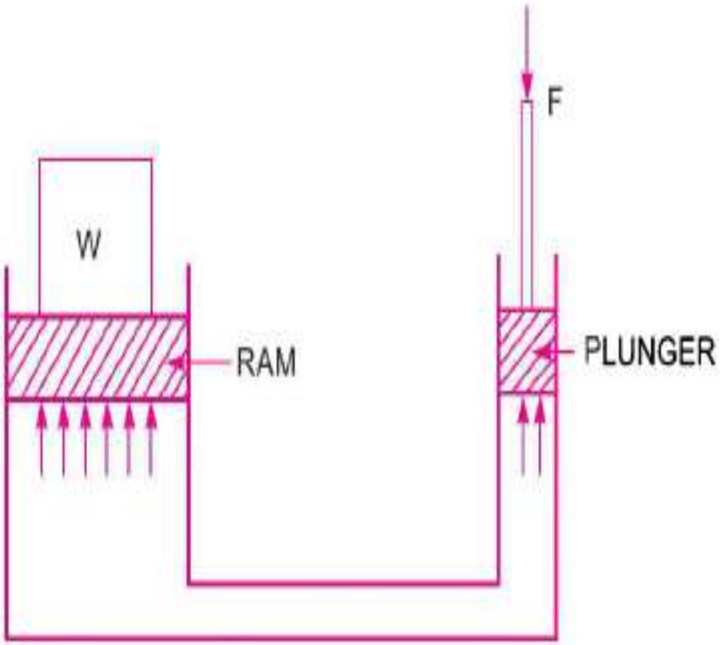

Fig. 1 *The hydraulic press.*

When a small force F is applied on the plunger in the downward direction, a pressure is produced on the liquid in contact with the plunger. This pressure is transmitted equally in all directions and acts on the ram in the upward direction as shown in Fig. 1. The heavier weight placed on the ram is then lifted up.

Let W = Weight to be lifted,

F = Force applied on the plunger,

A = Area of ram,

a = Area of plunger, and

A = Area of ram,

a = Area of plunger, and

p = Pressure intensity produced by force F.

$$= \frac{\text{Force } F}{\text{Area of plunger}} = \frac{F}{a}$$

Due to Pascal's law, the above intensity of pressure will be equally transmitted in all directions.

Hence, the pressure intensity at the ram will be $= p = \frac{F}{a}$.

But the pressure intensity on ram is also $= \frac{\text{Weight}}{\text{Area of ram}} = \frac{W}{A}$.

Equating the pressure intensity on ram, $\frac{F}{a} = \frac{W}{A}$

$$\therefore \quad W = \frac{F}{a} \times A. \qquad \text{...(1)}$$

Mechanical Advantage. The ratio of weight lifted to the force applied on the plunger is defined as the mechanical advantage. Mathematically, mechanical advantage is written as

$$\text{M. A.} = \frac{W}{F}. \qquad \text{...(2)}$$

defined as the mechanical advantage. Mathematically, mechanical advantage is written as

$$\text{M. A.} = \frac{W}{F}. \qquad \text{...(2)}$$

Hydraulic Machines BME-51

Unit-4

(Lecture 8)

Lecture contains

- **Fluid system**

Hydraulic accumulator :-

The hydraulic accumulator is a device used for storing the energy of a liquid in the form of pressure energy, which may be supplied for any sudden or intermittent requirement. In case of hydraulic lift or the hydraulic crane, a large amount of energy is required when lift or crane is moving upward. This energy is supplied from hydraulic accumulator. But when the lift is moving in the downward direction, no large external energy is required and at that time, the energy from the pump is stored in the accumulator.

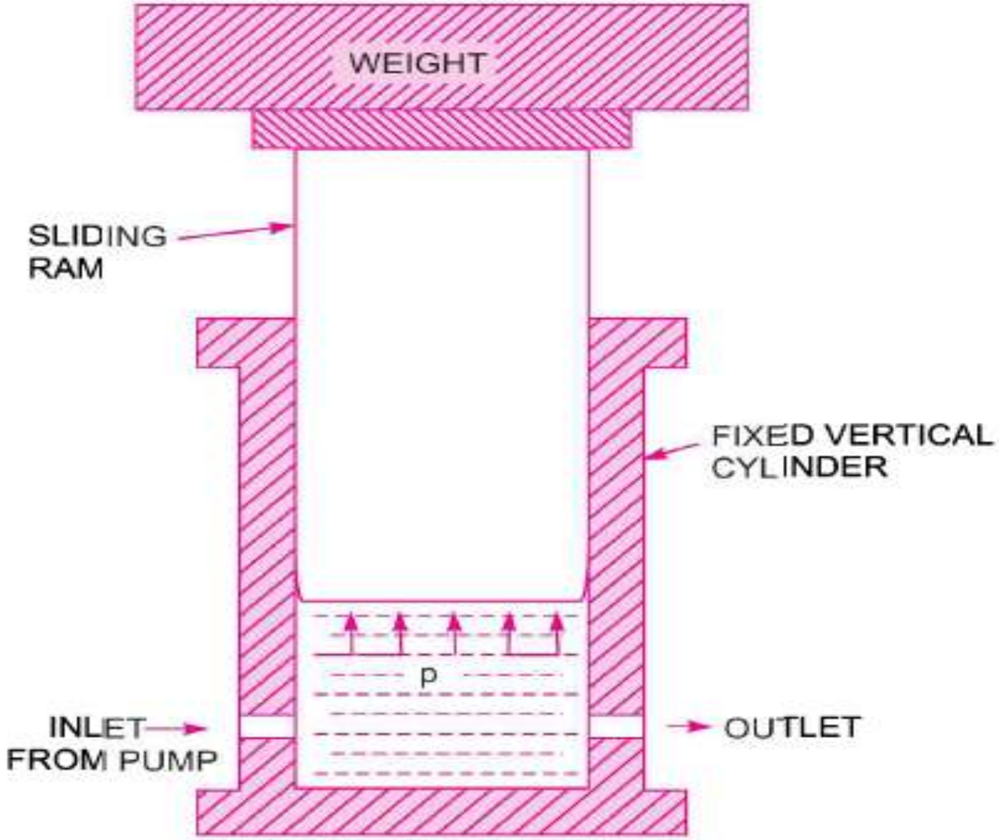

Fig. *The hydraulic accumulator.*

Hydraulic intensifier :-

The device, which is used to increase the intensity of pressure of water by means of hydraulic energy available from a large amount of water at a low pressure, is called the hydraulic intensifier. Such a device is needed when the hydraulic machines such as hydraulic press requires water at very high pressure which cannot be obtained from the main supply directly.

A hydraulic intensifier consists of fixed ram through which the water, under a high pressure, flows to the machine. A hollow inverted sliding cylinder, containing water under high pressure, is mounted over the fixed ram. The inverted sliding cylinder is surrounded by another fixed inverted cylinder which contains water from the main supply at a low pressure as shown in Fig.

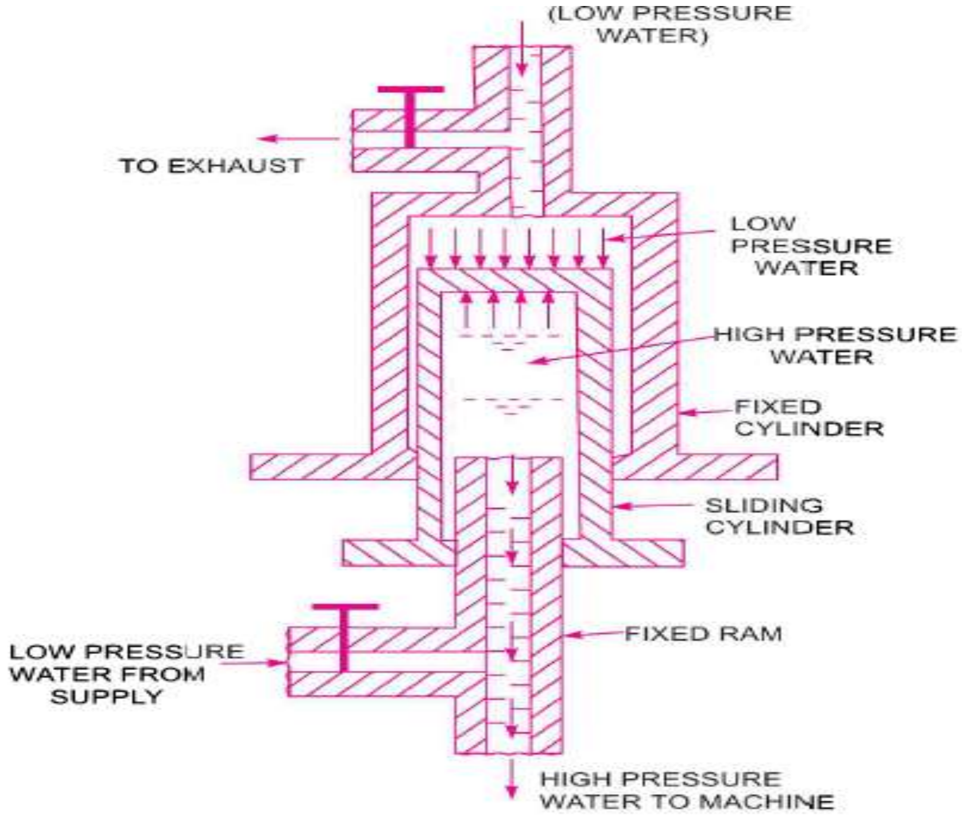

Fig. *The hydraulic intensifier.*

Hydraulic Ram

The hydraulic ram is a pump which raises water without any external power for its operation. When large quantity of water is available at a small height, a small quantity of water can be raised to a greater height with the help of hydraulic ram. It works on the principle of water hammer.

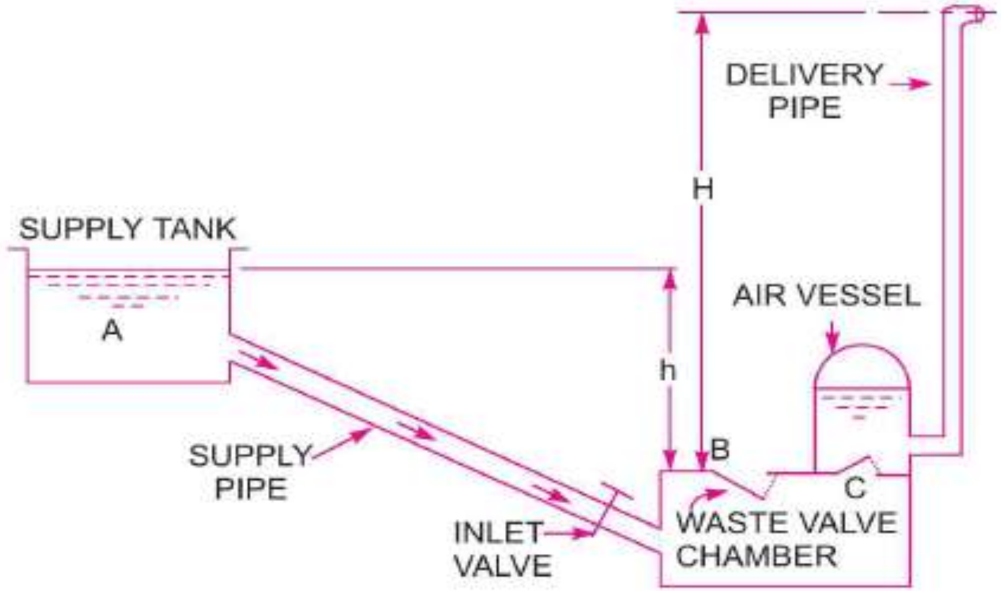

Fig. *The hydraulic ram.*

Fig. shows the main components of the hydraulic ram. When the inlet valve fitted to the supply pipe is opened, water starts flowing from the supply tank to the chamber, which has two valves at *B* and *C*. The valve *B* is called waste valve and valve *C* is called the delivery valve. The valve *C* is fitted to an air vessel. As the water is coming into the chamber from supply tank, the level of water rises in the chamber and waste valve *B* starts moving upward. *A* stage comes, when the waste valve *B* suddenly closes. This sudden closure of waste valve creates high pressure inside the chamber. This high pressure force opens the delivery valve *C*. The water from chamber enters the air vessel and compresses the air inside the air vessel. This compressed air exerts force on the water in the air vessel and small quantity of water is raised to a greater height as shown in Fig.

Lecture contains

- **Fluid system**

Hydraulic lift :-

The hydraulic lift is a device used for carrying passenger or goods from one floor to another in multi-storeyed building. The hydraulic lifts are of two types, namely,

1. Direct acting hydraulic lift, and 2. Suspended hydraulic lift.

1 Direct Acting Hydraulic Lift. It consists of a ram, sliding in fixed cylinder as shown in Fig. 1 At the top of the sliding ram, a cage (on which the persons may stand or goods may be placed) is fitted. The liquid under pressure flows into the fixed cylinder. This liquid exerts force on the sliding ram, which moves vertically up and thus raises the cage to the required height.

The cage is moved in the downward direction, by removing the liquid from the fixed cylinder.

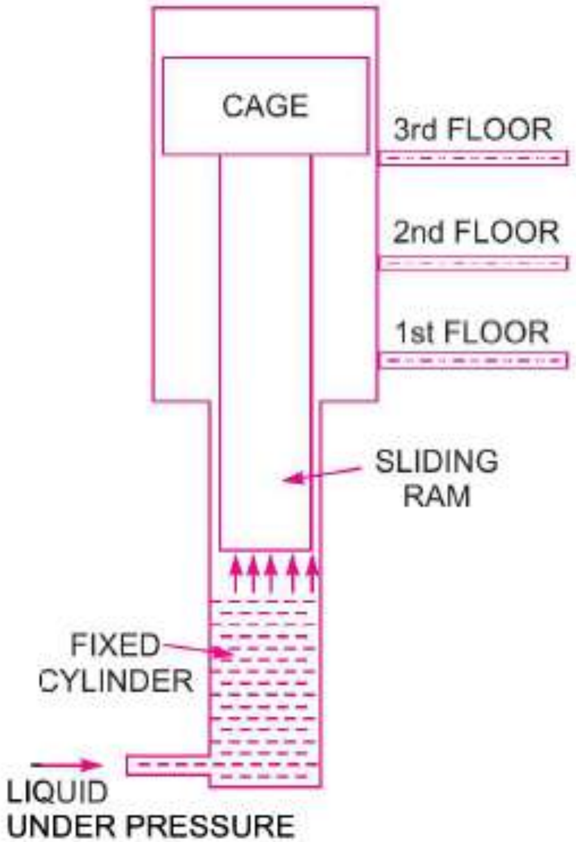

Fig. 1

2 Suspended Hydraulic Lift. Fig. shows the suspended hydraulic lift. It is a modified form of the direct acting hydraulic lift. It consists of a cage (on which persons may stand or goods may be placed) which is suspended from a wire rope. A jigger, consisting of a fixed cylinder, a sliding ram and a set of two pulley blocks, is provided at the foot of the hole of the cage. One of the pulley block is movable and the other is a fixed one. The end of the sliding ram is connected to the movable pulley block. A wire rope, one end of which is fixed at *A* and the other end is taken round all the pulleys of the movable and fixed blocks and finally over the guide pulleys as shown in Fig. . The cage is suspended from the other end of the rope. The raising or lowering of the cage of the lift is done by the jigger as explained below.

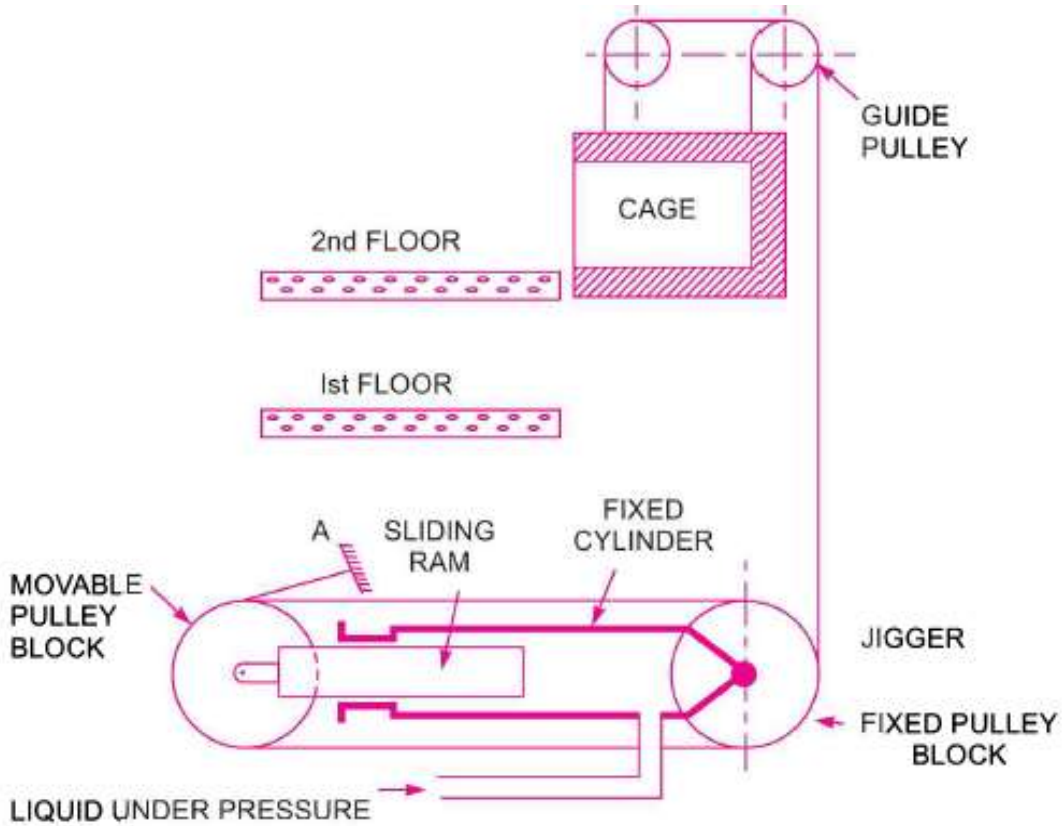

Fig. *Suspended hydraulic lift.*

When water under high pressure is admitted into the fixed cylinder of the jigger, the sliding ram is forced to move towards left. As one end of the sliding ram is connected to the movable pulley block and hence the movable pulley block moves towards the left, thus increasing the distance between two pulley blocks. The wire rope connected to the cage is pulled and the cage is lifted. For lowering the cage, water from the fixed cylinder is taken out. The sliding ram moves towards right and hence movable pulley blocks also moves towards right. This decreases the distance between two pulley blocks and the cage is lowered due to increased length of the rope.

Air lift pumps :-

The air lift pump is a device which is used for lifting water from a well or sump by using compressed air. The compressed air is made to mix with the water. The density of the mixture of air and water is reduced. The density of this mixture is much less than that of pure water. Hence a very small column of pure water can balance a very long column of air water mixture. This is the principle on which the air lift pump works.

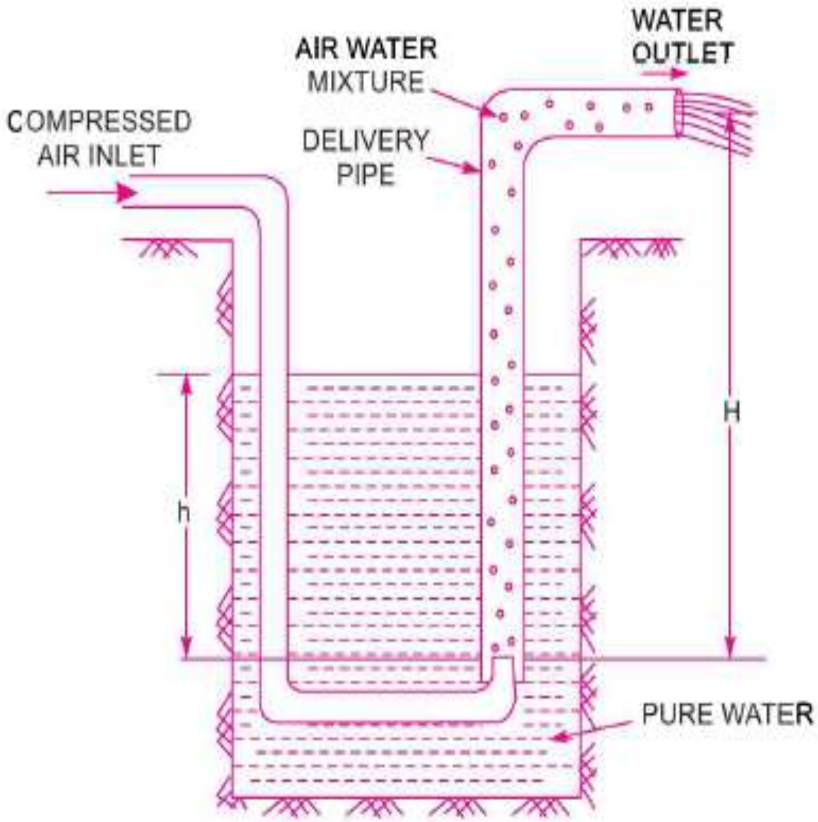

Fig. *Air lift pump.*

Fig. shows the air lift pump. The compressed air is introduced through one or more nozzles at the foot of the delivery pipe, which is fixed in the well from which water is to be lifted. In the delivery pipe, a mixture of air and water is formed. The density of this air water mixture becomes very less as compared to the density of pure water. Hence, a small column of pure water will balance a very long column of air water mixture. This air water mixture will be discharged out of the delivery pipe. The flow will continue as long as there is supply of compressed air.

Let h = Height of static water level above the tip of the nozzle,

H = Height to which water is lifted above the tip of the nozzle.

The $(H - h)$ is known as the useful lift. The best results are obtained if the useful lift $(H - h)$ is less than the height of static water (h) above the tip of the nozzle. Hence for best results, $(H - h)$ should be less than h.

Thanks