21 CHAPTER

FLUID SYSTEM

▶ 21.1 INTRODUCTION

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.

▶ 21.2 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. 21.1. The two cylinders are connected by a pipe. The cylinders and pipe contain a liquid through which pressure is transmitted.

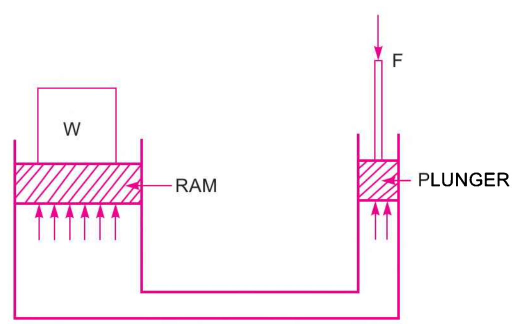

Fig. 21.1 *The hydraulic press.*

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. 21.1. 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
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, $\frac{F}{a} = \frac{W}{A}$

$$\therefore \quad W = \frac{F}{a} \times A. \quad \text{...(21.1)}$$

21.2.1 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

$$\text{M. A.} = \frac{W}{F}. \quad \text{...(21.2)}$$

21.2.2 Leverage of the Hydraulic Press. If a lever is used for applying force on the plunger, then a force F' smaller than F can lift the weight W as shown in Fig. 21.2. The ratio of L/l is called the leverage of the hydraulic press.

Taking moments about Q, $F' \times L = F \times l$

$$\therefore \quad F = F' \times \frac{L}{l} \quad \text{...(21.3)}$$

Substituting the value of F in equation (21.1), we get the expression for weight lifted as

$$W = \left(F' \times \frac{L}{l}\right) \times \frac{A}{a} = F' \times \frac{L}{l} \times \frac{A}{a} \quad \text{...(21.4)}$$

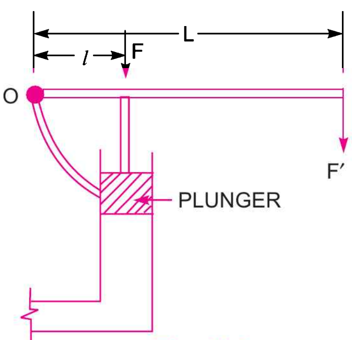

Fig. 21.2

21.2.3 Actual Heavy Hydraulic Press. Based on the nature of the work required, actual hydraulic press is different in shape. But all actual hydraulic press consist of a ram sliding in a cylinder to which high-pressure liquid is forced.

Fig. 21.3 shows one of the actual hydraulic press. It consists of a fixed cylinder in which a ram is sliding. To the lower end of the ram, movable plate is attached. As the ram moves up and down, the movable plate attached to the ram also moves up and down between two fixed plates. When any liquid under high pressure is supplied into the cylinder, the ram

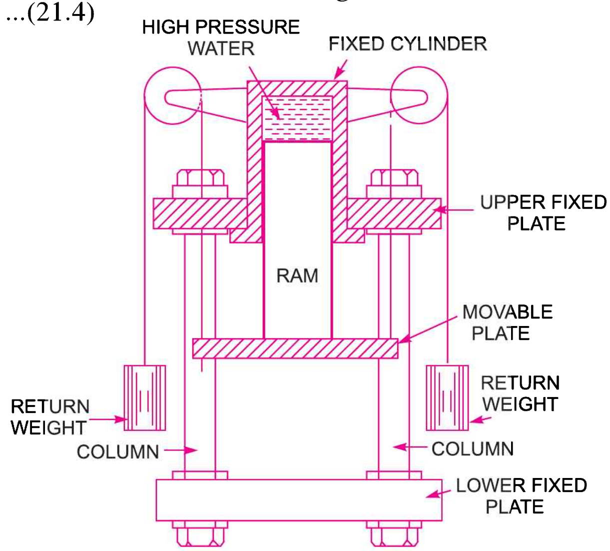

Fig. 21.3 *Actual hydraulic press.*

moves in the downward direction and exerts a force equal to the product of intensity of pressure supplied and area of the ram, on any material placed between the lower fixed plate and the movable plate. Thus the material gets pressed.

To bring back the ram in the upward position, the liquid from the cylinder is taken out. Then by the action of the return weights, the ram along with the movable plate will move up.

Problem 21.1 *A hydraulic press has a ram of 300 mm diameter and a plunger of 45 mm diameter. Find the weight lifted by the hydraulic press when the force applied at the plunger is 50 N.*

Solution. Given :

Diameter of ram, $D = 300 \text{ mm} = 0.30 \text{ m}$

Diameter of plunger, $d = 45 \text{ mm} = 0.045 \text{ m}$

Force on plunger, $F = 50 \text{ N}$

Let weight lifted $= W \text{ N}$

Area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.30)^2 = 0.07068 \text{ m}^2$

Area of plunger, $a = \frac{\pi}{4} d^2 = \frac{\pi}{4} (.045)^2 = .00159 \text{ m}^2$

The weight lifted (W) is given by equation (21.1) as

$$W = \frac{F}{a} \times A = \frac{50 \times .07068}{.00159} = \mathbf{2222.64 \text{ N. Ans.}}$$

Problem 21.2 *A hydraulic press has a ram of 200 mm diameter and a plunger of 30 mm diameter. It is used for lifting a weight of 3 kN. Find the force required at the plunger.*

Solution. Given :

Diameter of ram, $D = 200 \text{ mm} = 0.20 \text{ m}$

∴ Area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times (0.20)^2 = 0.0314 \text{ m}^2$

Diameter of plunger, $d = 30 \text{ mm} = .03 \text{ m}$

∴ Area of plunger, $a = \frac{\pi}{4} (.03)^2 = 7.068 \times 10^{-4} \text{ m}^2$

Weight lifted, $W = 3 \text{ kN} = 3 \times 1000 = 3000 \text{ N}.$

Let the force on plunger $= F.$

Using relation given equation (21.1),

$$W = \frac{F}{a} \times A$$

$$F = \frac{W \times a}{A} = \frac{3000 \times 7.068 \times 10^{-4}}{.0314} = \mathbf{67.52 \text{ N. Ans.}}$$

Problem 21.3 *If in the problem 21.2, a lever is used for applying force on the plunger, find the force required at the end of the lever if the ratio l/L is 1/10.*

Solution. Given :

$$D = 0.20 \text{ m}, \; A = 0.0314 \text{ m}^2$$

$$d = 0.03 \text{ m}, \; a = 7.068 \times 10^{-4} \text{ m}^2$$

$$W = 3000 \text{ N}, \frac{l}{L} = \frac{1}{10}$$

Let F' = Force required at the end of the lever.

Using equation (21.4), $$W = F' \times \frac{L}{l} \times \frac{A}{a}$$

$$\therefore \quad F' = W \times \frac{l}{L} \times \frac{a}{A} = 3000 \times \frac{1}{10} \times \frac{7.068 \times 10^{-4}}{0.0314} = \mathbf{6.752 \text{ N. Ans.}}$$

Problem 21.4 *If in the problem 21.1, the stroke of the plunger is 100 mm, find the distance travelled by the weight in 100 strokes. Determine the work done during 100 strokes.*

Solution. The data given in problem 21.1 :

$D = 0.30$ m, $A = 0.07068$ m^2, $d = 0.045$ m, $a = .00159$ m^2

$F = 50$ N and W (calculated) = 2222.64 N

Stroke of plunger = 100 mm = 0.10 m

Number of strokes = 100

Volume of liquid displaced by plunger in one stroke

= Area of plunger × Stroke of plunger

$= a \times 0.10$ m^3 = $.00159 \times 0.10$ = .000159 m^3.

The liquid displaced by plunger will enter the cylinder in which ram is fitted and this liquid will move the ram in the upward direction.

Let the distance moved by the ram or weight in one stroke

$= x$ m

Then volume displaced by ram in one stroke

= Area of ram $\times x = A \times x = 0.07068 \times x$ m^3

As volume displaced by plunger and ram is the same,

$$\therefore \quad .000159 = .07068 \times x$$

$$\therefore \quad x = \frac{.000159}{.07068} = .00225 \text{ m}$$

∴ Distance moved by weight in 100 strokes

$= x \times 100 = .00225 \times 100 =$ **0.225 m. Ans.**

Work done during 100 strokes = Weight lifted × Distance moved

$= W \times 0.225 = 2222.64 \times 0.225$ Nm = **500.094 Nm. Ans**.

Problem 21.5 *A hydraulic press has a ram of 150 mm diameter, plunger of 20 mm diameter. The stroke of the plunger is 200 mm and weight lifted is 800 N. If the distance moved by the weight is 1.0 m in 20 minutes determine :*

(*i*) *The force applied on the plunger,* (*ii*) *Power required to drive the plunger, and*

(*iii*) *Number of strokes performed by the plunger.*

Solution. Given :

Diameter of ram, $D = 150$ mm = 0.15 m

Diameter of plunger, $d = 20$ mm = 0.02 m

Stroke of plunger = 200 mm = 0.20 m

Weight lifted, $W = 800$ N

Distance moved by weight = 1.0 m

Time taken by weight = 20 minutes

Now, area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (.15)^2 = 0.01767 \text{ m}^2$

Area of plunger, $a = \frac{\pi}{4} (.02)^2 = .00031416 \text{ m}^2$.

(*i*) Let the force applied on the plunger = F.

Using equation (21.1), we have $W = \frac{F}{a} \times A$

$$\therefore \quad F = \frac{W \times a}{A} = \frac{800 \times .00031416}{.01767} = \textbf{14.22 N. Ans.}$$

(*ii*) Work done by the press per second

$$= \frac{\text{Weight lifted} \times \text{Distance travelled}}{\text{Time}}$$

$$= \frac{800 \times 1.0}{20 \times 60} = 0.6667 \text{ Nm/s}$$

∴ Power required to drive the plunger

$$= \frac{\text{Work done per sec}}{1000} = \frac{0.6667}{1000} = \textbf{0.000666 kW. Ans.}$$

(*iii*) Volume of liquid displaced by plunger in one stroke

= Area of plunger × Stroke length

$= .00031416 \times 0.20 = .000062832 \text{ m}^3$

Total volume of liquid displaced in cylinder

= Area of ram × Distance moved by weight

$= .01767 \times 1.0 = 0.01767 \text{ m}^3$

∴ Number of strokes performed by plunger or pump

$$= \frac{\text{Total volume of liquid displaced}}{\text{Volume of liquid displaced per stroke}}$$

$$= \frac{0.01767}{.000062832} = 281.22 \simeq \textbf{281. Ans.}$$

▶ 21.3 THE 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. 21.4 shows a hydraulic accumulator which consists of a fixed vertical cylinder containing a sliding ram. A heavy weight is placed on the ram. The inlet of the cylinder is connected to the pump, which continuously supplies water under pressure to the cylinder. The outlet of the cylinder is connected to the machine (which may be lift or crane etc.)

The ram is at the lowermost position in the beginning. The pump supplies water under pressure continuously. If the water under pressure is not required by the machine (lift or crane), the water under pressure will be stored in the cylinder. This will raise the ram on which a heavy weight is placed. When the ram is at the uppermost position, the cylinder is full of water and accumulator has stored the maximum amount of pressure energy. When the machine (lift or crane) requires a large amount of energy, the hydraulic accumulator will supply this energy and ram will move in the downward direction.

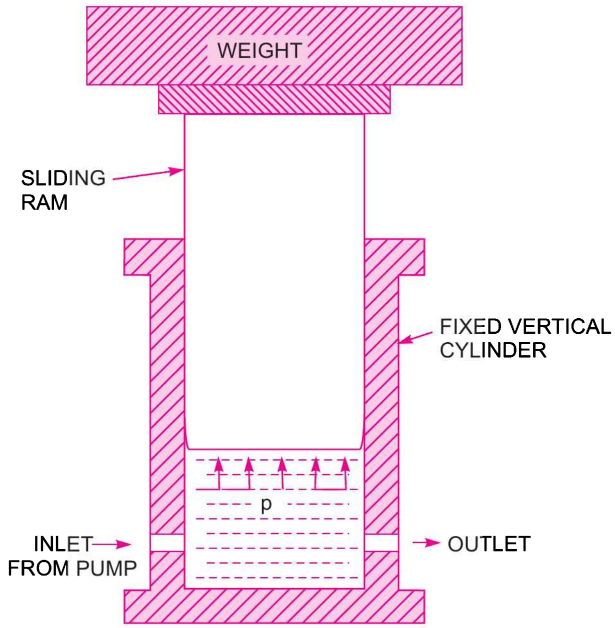

Fig. 21.4 *The hydraulic accumulator.*

21.3.1 Capacity of Hydraulic Accumulator.

It is defined as the maximum amount of hydraulic energy stored in the accumulator. The expression for the capacity of accumulator is obtained as :

Let A = Area of the sliding ram,

L = Stroke or lift of the ram,

p = Intensity of water pressure supplied by the pump, and

W = Weight placed on the ram (including the weight of ram),

Then W = Intensity of pressure × Area of ram

$= p \times A$

The work done in lifting the ram $= W \times$ Lift of ram $= WL$

$= p \times A \times L$ $\quad (W = p \times A)$

The work done in lifting the ram is also the energy stored in the accumulator. And energy stored is equal to the capacity of the accumulator.

∴ Capacity of accumulator = Work done in lifting the ram

$= p \times A \times L$ ...(21.5)

But $A \times L$ = Volume of accumulator

∴ Capacity of accumulator $= p \times$ Volume of accumulator. ...(21.6)

Problem 21.6 *Determine the length of stroke for an accumulator having a displacement of 115 litres. The diameter of the plunger is 350 mm.*

Solution. Given :

Displacement = 115 litres = 0.115 m^3

or Volume of accumulator = 0.115 m^3

Dia. of plunger, D = 350 mm = 0.35 m

∴ Area of plunger, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times .35^2 \text{ m}^2$

But volume of accumulator $= A \times L$

where L = length of stroke.

∴ Volume $= \frac{\pi}{4} D^2 \times L$ or $0.115 = \frac{\pi}{4} \times (0.35)^2 \times L$

∴ $L = \frac{0.115 \times 4}{\pi \times 0.35^2}$ = **1.195 m. Ans.**

Problem 21.7 *The water is supplied at a pressure of 14 N/cm² to an accumulator, having a ram of diameter 1.5 m. If the total lift of the ram is 8 m, determine :*

(*i*) *The capacity of the accumulator, and*

(*ii*) *Total weight placed on the ram (including the weight of ram).*

Solution. Given :

Supply pressure, $p = 14 \text{ N/cm}^2 = 14 \times 10^4 \text{ N/m}^2$

Dia. of ram, D = 1.5 m

∴ Area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (1.5)^2 = 1.767 \text{ m}^2$

Lift of ram, L = 8 m.

(*i*) Capacity of accumulator is given by equation (21.5) as

Capacity $= p \times A \times L = 14 \times 10^4 \times 1.767 \times 8$

$= 1979.04 \times 10^3$ Nm = **1979.04 kNm. Ans.**

(*ii*) Total weight (W), placed on the ram is given by

$W = p \times A = 14 \times 10^4 \times 1.767$ N = **247380 N. Ans.**

Problem 21.8 *The total weight (including the self-weight of ram) placed on the sliding ram of a hydraulic accumulator is 40 kN. The diameter of the ram is 500 mm. If the frictional resistance against the movement of the ram is 5% of the total weight, determine the intensity of pressure of water when :*

(*i*) *The ram is moving up with a uniform velocity, and*

(*ii*) *The ram is moving down with uniform velocity.*

Solution. Given :

Total weight, $W = 40 \text{ kN} = 40 \times 1000 = 40000$ N

Dia. of ram, D = 500 mm = 0.50 m

$\therefore$ Area of ram, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (.50)^2 = 0.1963 \text{ m}^2$

Frictional resistance against the movement of ram = 5% of total weight = $\frac{5}{100} \times 40000 = 2000$ N.

(*i*) *Intensity of pressure of water when ram is moving up with a uniform velocity.* When ram is moving up, the frictional resistance is acting opposite to the direction of movement of the ram, *i.e.*, frictional resistance is acting in the downward direction. Weight is also acting in the downward direction.

$\therefore$ Total force on the ram = Total weight + Frictional resistance

= 40000 + 2000 = 42000 N.

$\therefore$ Pressure intensity (p) $= \frac{\text{Total force on ram}}{\text{Area of ram}} = \frac{42000}{0.1963}$

= 213958 N/m^2 = **21.3958 N/cm^2. Ans.**

(*ii*) *Intensity of pressure when ram is moving down with a uniform velocity.* In this case, the frictional resistance is acting in the upward direction.

$\therefore$ Total force on the ram = Total weight – Frictional resistance

= 40000 – 2000 = 38000 N

$\therefore$ Pressure intensity (p) $= \frac{\text{Total force}}{\text{Area}} = \frac{38000}{0.1963}$

= 193581 N/m^2 = **19.3581 N/cm^2. Ans.**

Problem 21.9 *If in the problem 21.8, the stroke of the ram is 10 m and the ram falls through the full stroke in 4 minutes steadily, find the work done by the accumulator per second. If the pump, connected to the inlet of the accumulator, supplies .01 m^3/s at the same time, determine the work supplied by the pump per second and also power delivered by the accumulator to the hydraulic machine, connected at the outlet of the hydraulic accumulator, when ram is moving downwards.*

Solution. The data from problem 21.8, when ram is moving downward :

Total weight = 40000 N

Frictional resistance = 2000 N

Total force on ram = Total weight – Frictional resistance

= 40000 – 2000 = 38000 N

Area, $A = 0.1963 \text{ m}^2$

Pressure intensity of water when ram is moving downward

$p = 193581 \text{ N/m}^2$

Stroke of ram, $L = 10$ m

Time taken by ram to fall through full stroke, $t = 4$ minutes $= 4 \times 60 = 240$ s

Discharge supplied $Q = .01 \text{ m}^3/\text{s}$

Distance moved by ram in one second $= \frac{\text{Stroke of ram}}{\text{Time}} = \frac{L}{t} = \frac{10}{240} = \frac{1}{24}$ m/s.

(*i*) Work done by accumulator per second

= Total force on ram × Distance moved by ram per sec

$= 38000 \times \frac{1}{24}$ = **1583.33 Nm. Ans.**

(*ii*) Work supplied by the pump per sec = Weight of water supplied by pump per second × Head of supply pressure

$$= \rho g \times Q \times H = 1000 \times 9.81 \times .01 \times H \text{ Nm}$$

where H = Pressure head of water supplied $= \dfrac{p}{\rho \times g} = \dfrac{193581}{1000 \times 9.81} = 19.733$ m

∴ Work supplied by pump per sec = 1000 × 9.81 × 0.01 × 19.733 = **1935.81 Nm. Ans.**

(*iii*) Power delivered by the accumulator to the hydraulic machine connected at the outlet of accumulator

$$= \frac{1}{1000} \text{ (Work done by accumulator per second + Work supplied by pump per second)}$$

$$= \frac{1}{1000} (1583.33 + 1935.81) = \mathbf{3.519 \text{ kW. Ans.}}$$

Problem 21.10 *An accumulator is loaded with 40 kN weight. The ram has a diameter of 30 cm and stroke of 6 m. Its friction may be taken as 5%. It takes two min. to fall through its full stroke. Find the total work supplied and power delivered to the hydraulic appliance by the accumulator, when 7.5 lit/s is being delivered by a pump, while the accumulator descends with the stated velocity.*

Solution. Given :

Total weight = 40 kN = 40 × 1000 = 40000 N

Dia. of ram, $D = 30$ cm $= 0.3$ m

∴ Area of ram, $A = \dfrac{\pi}{4} (.3)^2 = 0.07068 \text{ m}^2$

Stroke of ram, $L = 6$ m

Friction = 5%

∴ Net load on accumulator (when it descends)

$$= 40000 \times 0.95 = 38000 \text{ N}$$

Time taken by ram to fall through full stroke, $t = 2$ min $= 2 \times 60 = 120$ sec

∴ Distance moved by ram per sec $= \dfrac{L}{t} = \dfrac{6}{120} = \dfrac{1}{20}$ m/s

Water supplied by pump = 7.5 lit/s $= \dfrac{7.5}{1000} \text{ m}^3/\text{s} = .0075 \text{ m}^3/\text{s}$

Work supplied by accumulator per second

= Net load on ram × Distance moved by ram per sec

$$= 38000 \times \frac{1}{20} = 1900 \text{ Nm/s}$$

Intensity of pressure of water, $p = \dfrac{\text{Net load}}{\text{Area}} = \dfrac{38000}{0.07068} = 542857 \dfrac{\text{N}}{\text{m}^2}$

Head due to pressure, $H = \dfrac{p}{\rho g} = \dfrac{542857}{1000 \times 9.81} = 55.337$ m

Work supplied by pump per second = Weight of water supplied per second × Head of supplied pressure

$= \rho g \times Q \times H = 1000 \times 9.81 \times .0075 \times 55.337 = 4071.35$ Nm/s

∴ Total work supplied per second to hydraulic machine

= Work supplied by accumulator and by pump

= 1900 + 4071.35 Nm/s = **5971.35 Nm/s. Ans.**

Power delivered to the hydraulic machine

$$= \frac{\text{Total work supplied per sec}}{1000} = \frac{5971.35}{1000} = \mathbf{5.9713\ kW.\ Ans.}$$

Problem 21.11 *An accumulator has a ram of diameter 250 mm and a lift of 8 m. The total weight on accumulator is 70 kN. The packing friction is 5% of the load on the ram. Find the power delivered to the machine if ram falls through the full height in 100 sec and at the same time the pumps are delivering 0.028 m^3/s through the accumulator.*

Solution. Given :

Dia. of ram, $D = 250$ mm = 0.25 m

∴ Area of ram, $A = \frac{\pi}{4}(.25)^2 = \frac{\pi}{64}$ m^2

Lift of ram, $L = 8$ m

Total weight = 70 kN = 70 × 1000 = 70000 N

Packing friction = 5% of 70000 = $\frac{5}{100} \times 70000 = 3500$ N

∴ Net load on accumulator, when the ram is moving downwards

= 70000 – 3500 = 66500 N

Time taken by ram to fall through 8 m, $t = 100$ sec

Water supplied by pump, $Q = 0.028$ m^3/s.

When ram is moving downwards, the pressure intensity (p) is given by,

$$p = \frac{\text{Net load}}{\text{Area}} = \frac{66500}{\left(\frac{\pi}{64}\right)} = \frac{66500 \times 64}{\pi} \text{ N/m}^2$$

Head corresponding to the above pressure intensity,

$$h = \frac{p}{\rho g} = \frac{66500 \times 4}{1000 \times 9.81 \times \pi} = 138.09 \text{ m of water.}$$

Power delivered by pump $= \frac{\rho g . Q . H}{1000} = \frac{1000 \times 9.81 \times 0.028 \times 138.09}{1000} = 37.931$ kW

Power supplied by accumulator $= \frac{\text{Net load on ram} \times \text{Lift}}{1000 \times \text{Time}} = \frac{66500 \times 8}{1000 \times 100} = 5.32$ kW.

∴ Total power = 37.931 + 5.32 = **43.251 kW. Ans.**

21.3.2 Differential Hydraulic Accumulator.

It is a device in which the liquid is stored at a high pressure by a comparatively small load on the ram. It consists of a fixed vertical cylinder of small diameter as shown in Fig. 21.5. The fixed vertical cylinder is surrounded by closely fitting brass bush, which is surrounded by an inverted moving cylinder, having circular projected collar at the base on which weights are placed.

The liquid from the pump is supplied to the fixed vertical cylinder. The liquid moves up through the small diameter of fixed vertical cylinder and then enters the inverted cylinder. The water exerts an upward pressure force on the internal annular area of the inverted moving cylinder, which is loaded at the base. The internal annular area of the inverted moving cylinder is equal to the sectional area of the brass bush. When the inverted moving cylinder moves up, the hydraulic energy is stored in the accumulator.

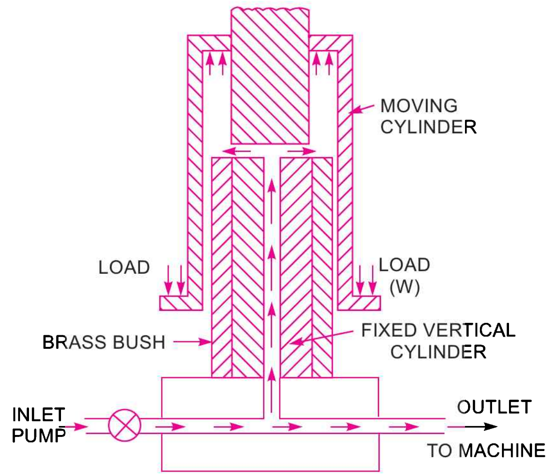

Fig. 21.5 *Differential hydraulic accumulator.*

Let p = Intensity of pressure of liquid supplied by pump,

a = Area of brass-bush,

L = Vertical lift of the moving cylinder,

W = Total weight placed on the moving cylinder including the weight of cylinder.

Then $W = p \times a$

$$\therefore \quad P = \frac{W}{a} \qquad ...(21.7)$$

From equation (21.7), it is clear that pressure intensity can be increased with a small load W, by making area 'a' small.

Now total energy stored in the accumulator = Total weight × Vertical lift

$$= W \times L \text{ Nm.} \qquad ...[21.7\ (a)]$$

▶ 21.4 THE 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. 21.6

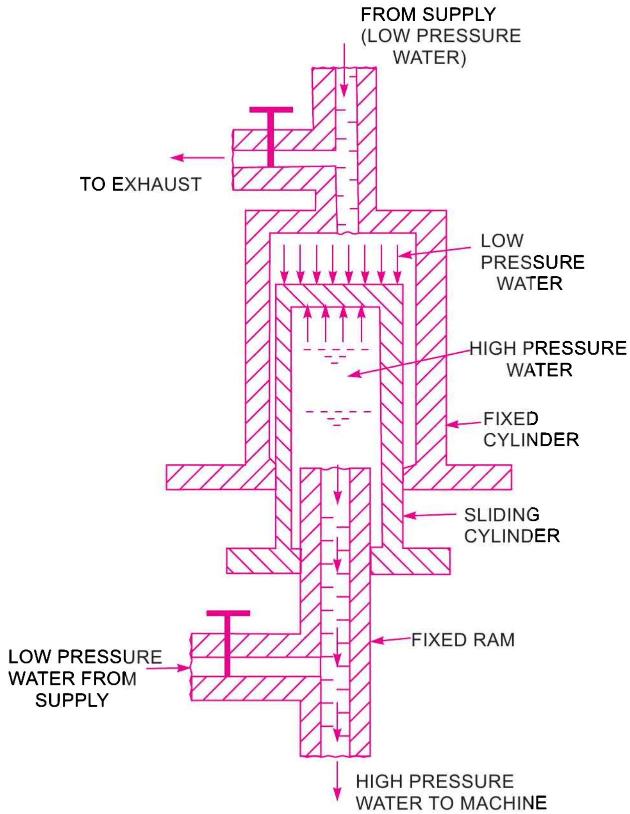

Fig. 21.6 *The hydraulic intensifier.*

A large quantity of water at low pressure from supply enters the inverted fixed cylinder. The weight of this water pressure the sliding cylinder in the downward direction. The water in the sliding cylinder gets compressed due to the downward movement of the sliding cylinder and its pressure is thus increased. The high pressure water is forced out of the sliding cylinder through the fixed ram, to the machine as shown in Fig. 21.6.

Let p = Intensity of pressure of water from supply to the fixed cylinder (low pressure water),

A = External area of the sliding cylinder,

a = Area of the end of the fixed ram, and

p^* = Intensity of the pressure of water in the sliding cylinder (high pressure water).

The force exerted by low pressure water on the sliding cylinder in the downward direction

$$= p \times A.$$

The force exerted by the high pressure water on the sliding cylinder in the upward direction

$$= p^* \times a.$$

Equating the upward and downward forces,

$$p \times A = p^* \times a.$$

$$p^* = \frac{p \times A}{a}. \quad \text{...(21.8)}$$

Problem 21.12 *The diameters of fixed ram and fixed cylinder of an intensifier are 8 cm and 20 cm respectively. If the pressure of the water supplied to the fixed cylinder is 300 N/cm², find the pressure of the water flowing through the fixed ram.*

Solution. Given :

Dia. of fixed ram, $d = 8$ cm

∴ Area of fixed ram, $a = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times 8^2 = 16\,\pi\ \text{cm}^2$

Dia. of fixed cylinder, $D = 20$ m

∴ Area of fixed cylinder, $A = \frac{\pi}{4} \times 20^2 = 100\,\pi\ \text{cm}^2$

Intensity of supply pressure, $p = 300\ \text{N/cm}^2$

Let the intensity of pressure of water flowing through fixed ram

$= p^*$

Using equation (21.8), $p^* = \frac{p \times A}{a} = \frac{300 \times 100\pi}{16\pi}$ = **1875 N/cm². Ans.**

Problem 21.13 *The pressure intensity of water supplied to an intensifier is 20 N/cm² while the pressure intensity of water leaving the intensifier is 100 N /cm². The external diameter of the sliding cylinder is 20 cm. Find the diameter of the fixed ram of the intensifier.*

Solution. Given :

Supply pressure, $p = 20\ \text{N/cm}^2$

Intensity of pressure leaving the intensifier,

$p^* = 100\ \text{N/cm}^2$

External dia. of sliding cylinder, $D = 20$ cm

∴ Area of sliding cylinder, $A = \frac{\pi}{4} \times 20^2 = 100\,\pi\ \text{cm}^2$

Let the dia. of the fixed ram $= d$

∴ Area of the fixed ram, $a = \frac{\pi}{4} d^2$

Using equation (21.8), $p^* = \frac{p \times A}{a}$

$$100 = \frac{20 \times 100\pi}{\frac{\pi}{4} d^2} = \frac{20 \times 100 \times 4}{d^2}$$

∴ $d = \sqrt{\frac{20 \times 100 \times 4}{100}} = \sqrt{80}$ = **8.94 cm. Ans.**

▶ 21.5 THE 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.

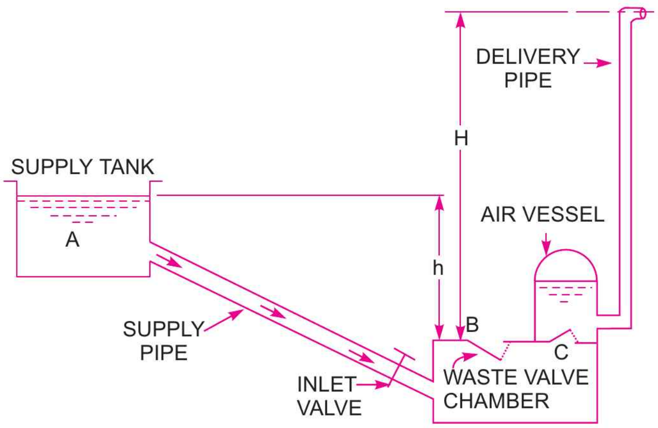

Fig. 21.7 *The hydraulic ram.*

Fig. 21.7 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. 21.7.

When the water in the chamber loses its momentum, the waste valve *B* opens in the downward direction and the flow of water from supply tank starts flowing to the chamber and the cycle will be repeated.

Let W = Weight of water flowing per second into chamber,

w = Weight of water raised per second,

h = Height of water in supply tank above the chamber,

H = Height of water raised from the chamber.

The energy supplied by the supply tank to ram

= Weight of water supplied × Height of supply water

$= W \times h$ ...(*i*)

Energy delivered by the ram = Weight of water raised × Height through which water is raised

$= w \times H$ ...(*ii*)

∴ Efficiency of the hydraulic ram,

$$\eta = \frac{\text{Energy delivered by the ram}}{\text{Energy supplied to the ram}} = \frac{w \times H}{W \times h} \quad \text{...(21.9)}$$

The above expression of efficiency was given by D' Aubuisson and hence known as *D' Aubuisson's efficiency*.

Rankine gave another form of the above efficiency. According to him, the weight of water (w) is raised to a height of ($H - h$) and not H. The water is initially at a height of h from the ram and hence the water is only raised to a height equal to ($H - h$). Hence according to Rankine :

Energy delivered by the ram $= w \times (H - h)$

Energy supplied $= (W - w)\, h$

$\therefore$ Efficiency, $$\eta = \frac{w \times (H - h)}{(W - w) \times h} \quad ...(21.10)$$

Equation (21.10) is known as *Rankine's efficiency.*

The above two efficiencies, in terms of discharge is written as,

D' Aubuisson's $$\eta = \frac{q \times H}{Q \times h} \quad ...(21.11)$$

Rankine's $$\eta = \frac{q(H - h)}{(Q - q) \times h} \quad ...(21.12)$$

where q = Discharge of delivery pipe,

Q = Discharge through supply pipe.

Problem 21.14 *The water is supplied at the rate of 0.02 m^3 per second from a height of 3 m to a hydraulic ram, which raises 0.002 m^3/s to a height of 20 m from the ram. Determine D' Aubuisson's and Rankine's efficiencies of the hydraulic ram.*

Solution. Given :

Discharge through supply pipe, $Q = 0.02\ m^3/s$

Supply head, $h = 3$ m

Discharge raised, $q = 0.002\ m^3/s$

Height of water raised from hydraulic ram, $H = 20$ m

Using equation (21.11),

D' Aubuisson's $$\eta = \frac{q \times H}{Q \times h} = \frac{.002 \times 20}{.02 \times 3} = .6667 = \textbf{66.67\%. Ans.}$$

Rankine's efficiency is given by equation (21.12) as

Rankine's $$\eta = \frac{q(H - h)}{(Q - q) \times h}$$

$$= \frac{0.002 \times (20 - 3)}{(0.020 - .0002) \times 3} = \frac{0.002 \times 17}{.018 \times 3} = 0.6296 = \textbf{62.96\%. Ans.}$$

Problem 21.15 *The water is supplied at the rate of 3000 litres per minute from a height of 4 m to a hydraulic ram, which raises 300 litres/minute to a height of 30 m from the ram. The length and diameter of the delivery pipe is 100 m and 70 mm respectively. Calculate the efficiency of the hydraulic ram if the co-efficiency of friction f = .009.*

Solution. Given :

Discharge supplied, $Q = 3000$ litres/minute

$$= \frac{3000}{60} \text{ lit/s} = \frac{3000}{60 \times 1000} m^3/s = 0.05\ m^3/s$$

Supply head, $h = 4$ m

Discharge raised, $q = 300 \text{ lit/min} = \dfrac{0.3}{60} = .005 \text{ m}^3\text{/s}$ $(\because \; 300 \text{ lit} = 0.3 \text{ m}^3)$

Height of water raised from hydraulic ram, $H = 30$ m

Length of delivery pipe, $L = 100$ m

Dia. of delivery pipe, $d = 70 \text{ mm} = .07$ m

Co-efficient of friction, $f = .009$

Head lost due to friction in delivery pipe is

$$h_f = \frac{4fLV^2}{d \times 2g} = \frac{4 \times .009 \times 100 \times V^2}{.07 \times 2 \times 9.81} \quad ...(i)$$

But V = Velocity of water in delivery pipe

$$= \frac{\text{Discharge in delivery pipe}}{\text{Area}}$$

$$= \frac{q}{\frac{\pi}{4}d^2} = \frac{0.005}{\frac{\pi}{4} \times (.07)^2} = 1.299 \simeq 1.3 \text{ m/s.}$$

Substituting this value of V in equation (i), we get

$$h_f = \frac{4 \times .009 \times 100 \times (1.3)}{.07 \times 2 \times 9.81} = 4.43 \text{ m}$$

∴ Effective head developed by the ram

$$= H + h_f = 30 + 4.43 = 34.43 \text{ m}$$

D' Aubuisson's efficiency is given by equation (21.11), as

$$\eta = \frac{q \times \text{Effective head}}{Q \times h} \quad \text{(Here } H = \text{Effective head)}$$

$$= \frac{.005 \times 34.43}{0.05 \times 4} = 0.8607 = \mathbf{86.07\%.\ Ans.}$$

Rankine's efficiency is given by equation (21.12) as

$$\eta = \frac{q(\text{Effective head} - h)}{(Q - q) \times h}$$

$$= \frac{.005\,(34.43 - 4.0)}{(.05 - .005) \times 4.0} = \frac{.005 \times 30.43}{.045 \times 4.0} = 0.8453 = \mathbf{84.53\%.\ Ans.}$$

▶ 21.6 THE 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.

21.6.1 Direct Acting Hydraulic Lift. It consists of a ram, sliding in fixed cylinder as shown in Fig. 21.8. 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.

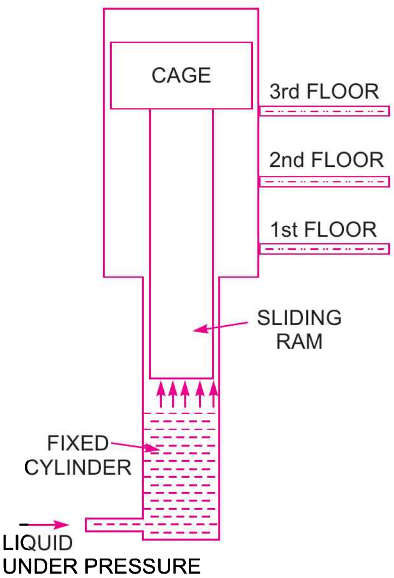

Fig. 21.8 *Suspended hydraulic lift.*

21.6.2 Suspended Hydraulic Lift. Fig. 21.9 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. 21.9. 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.

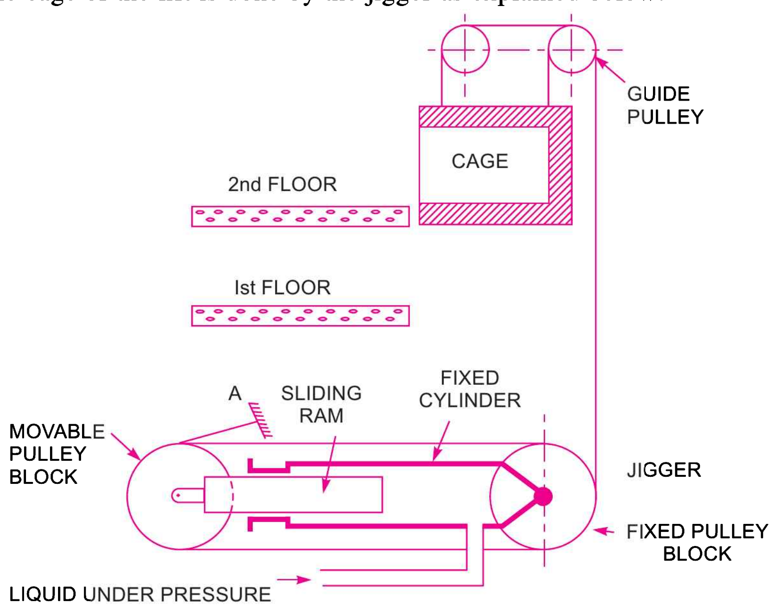

Fig. 21.9 *Suspended hydraulic lift.*

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.

Problem 21.16 *A hydraulic lift is required to lift a load of 8 kN through a height of 10 metres, once in every 80 seconds. The speed of the lift is 0.5 m per second. Determine :*

(i) Power required to drive the lift, *(ii) Working period of lift in seconds, and*

(iii) Idle period of the lift in seconds.

Solution. Given :

Load lifted, $W = 8 \text{ kN} = 8 \times 1000 = 8000 \text{ N}$

Height, $H = 10 \text{ m}$

Time for one operation, $t = 80 \text{ s}$

Speed of lift, $v = 0.5 \text{ m/s}$.

(*i*) Work done in lifting the load in 80 seconds

$$= W \times H = 8000 \times 10 = 80000 \text{ Nm}$$

$\therefore$ Work done/s $= \dfrac{80000}{80} = 1000 \text{ Nm/s}$

$\therefore$ Power required to drive the lift $= \dfrac{1}{1000} \times \text{Work done/s} = \dfrac{1}{1000} \times 1000 = \mathbf{1.0\ kW.\ Ans.}$

(*ii*) Working period of the lift $= \dfrac{\text{Height of the lift}}{\text{Velocity of lift}} = \dfrac{10}{0.50} = \mathbf{20\ sec.\ Ans.}$

(*iii*) Idle period of the lift = Total time – Working period of lift

$$= 80 - 20 = \mathbf{60\ sec.\ Ans.}$$

Problem 21.17 *A hydraulic lift is required to lift a load of 12 kN through a height of 10 m, once in every 1.75 minutes. The speed of the lift is 0.75 m/s. During working stroke of the lift, water from accumulator and the pump at a pressure of 400 N/cm² is supplied to the lift. If the efficiency of the pump is 8% and that of lift is 75%, find the power required to drive the pump and the minimum capacity of the accumulator. Neglect friction losses in the pipe.*

Solution. Given :

Load lifted, $W = 12 \text{ kN} = 12 \times 1000 = 12000 \text{ N}$

Height, $H = 10 \text{ m}$

Total time for one operation, $t = 1.75 \text{ min} = 1.75 \times 60 = 105 \text{ s}$

Speed of lift, $v = 0.75 \text{ m/s}$

Water pressure from accumulator and pump,

$$p = 400 \text{ N/cm}^2 = 400 \times 10^4 \text{ N/m}^2$$

Efficiency of pump, $\eta_p = 80\% = 0.80$

Efficiency of lift, $\eta_l = 75\% = 0.75$

Work done by water (supplied from accumulator and pump) in raising lift per second

$$= \text{Load lifted} \times \text{Distance travelled per s}$$
$$= W \times \text{Velocity of lift}$$
$$= W \times v = 12000 \times 0.75 = 9000 \text{ Nm/s}$$

$\therefore$ Useful power $= \dfrac{\text{Work done per second}}{1000} = \dfrac{9000}{1000} = 9 \text{ kW}$

$\therefore$ Actual power supplied to lift $= \dfrac{\text{Useful horse power}}{\eta_l} = \dfrac{9.0}{0.75} = 12$ kW.

The power 12 kW has been supplied by the pump and by accumulator to the lift.

Let P_1 = Output of the pump in kW

Then $(12 - P_1)$ = Output of the accumulator in kW ...(*i*)

Now, working period of the lift $= \dfrac{\text{Height of lift}}{\text{Velocity of lift}} = \dfrac{H}{v} = \dfrac{10}{0.75} = 13.33$ s

Idle period of lift = Total time – Working period of lift

$= 105 - 13.33 = 91.67$ s

Thus during idle period of lift, the energy will be stored in the accumulator and during working period of lift of 13.33 s, the energy will be supplied by the accumulator to the lift.

$\therefore$ Energy stored during idle period in accumulator

= Output of pump × Idle period

$= (P_1 \times 1000) \times 91.67$ Nm/s ($\because$ 1 kW = 1000 Nm/s) ...(*ii*)

The above energy is supplied by accumulator in 13.33 seconds.

$\therefore$ Energy supplied by accumulator per second

$$= \frac{(P_1 \times 1000) \times 91.67}{13.33} \text{ Nm/s}$$

$\therefore$ Power supplied by accumulator $= \dfrac{1}{1000}$ [Energy supplied by accumulator per second]

$$= \frac{1}{1000}\left[\frac{P_1 \times 1000 \times 91.67}{13.33}\right] = 6.877\, P_1.$$

But from equation (*i*), power supplied by accumulator is also

$= (12 - P_1)$

$\therefore$ Equating the two values of power supplied by accumulator,

$$6.877\, P_1 = 12 - P_1 \text{ or } 6.877\, P_1 + P_1 = 12 \text{ or } 7.877\, P_1 = 12$$

$$\therefore \quad P_1 = \frac{12}{7.877} = 1.523.$$

But we have assumed P_1 as the output of the pump.

$\therefore$ Input to the pump $= \dfrac{\text{Output}}{\text{Efficiency of pump}} = \dfrac{P_1}{\eta_p} = \dfrac{1.523}{0.80} = 1.90375$ kW.

(*i*) $\therefore$ Power required to drive the pump = **1.90375 kW. Ans.**

(*ii*) Minimum capacity of the accumulator.

From equation (*ii*), the energy stored in the accumulator

$= P_1 \times 1000 \times 91.67$ Nm

$= 1.523 \times 1000 \times 91.67$ Nm ($\because$ $P_1 = 1.523$)

$= 139613.4$ Nm.

The capacity of the accumulator means the amount of hydraulic energy stored in the accumulator.

$\therefore$ Minimum capacity of accumulator = Energy stored = **139613.4 Nm. Ans.**

▶ 21.7 THE HYDRAULIC CRANE

Hydraulic crane is a device, used for raising or transferring heavy loads. It is widely used in workshops, warehouses and dock sidings.

A hydraulic crane consists of a mast, tie, jib, guide pulley and a jigger. The jib and tie are attached to the mast. The jib can be raised or lowered in order to decrease or increase the radius of action of the crane. The mast along with the jib can revolve about a vertical axis and thus the load attached to the rope can be transferred to any place within the area of the crane's action. The jigger, which consists of a movable ram sliding in a fixed cylinder, is used for lifting or lowering the heavy loads. One end of the ram is in contact with water and the other end is connected to set of movable pulley block. Another pulley block, called the fixed pulley block is attached to the fixed cylinder. The pulley block, attached to the ram, moves up and down while the pulley block, attached to the fixed cylinder, is not having any movement.

A wire rope, one end of which is fixed to a movable pulley (which is attached to the sliding ram) is taken round all the pulleys of the two sets of the pulleys and finally passes over the guide pulley, attached to the jib as shown in Fig. 21.10. The other end of the rope is provided with a hook, for suspending the load.

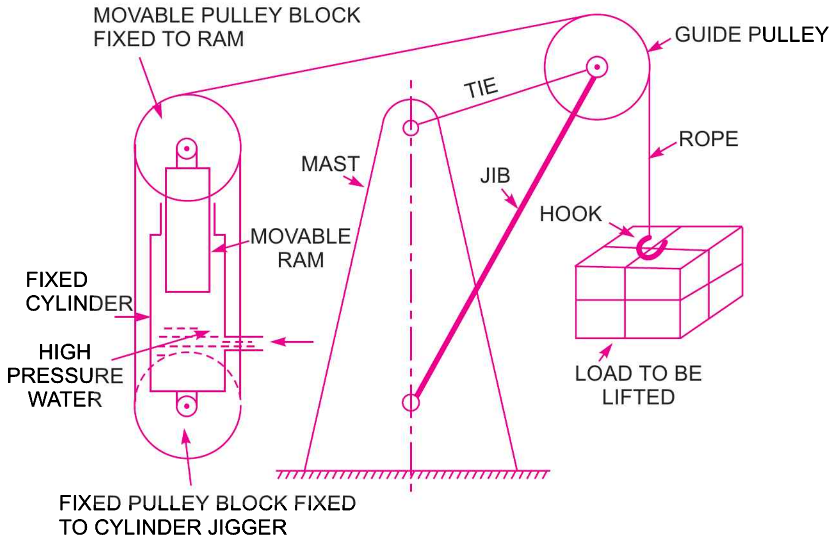

Fig. 21.10 *The hydraulic crane.*

For lifting the load by the crane, the water under high pressure is admitted into the cylinder of the jigger. This water forces the sliding ram to move vertically up. Due to the movement of the ram in the vertically up direction, the movable pulley block attached to the ram also moves upward. This increases the distance between two pulley blocks and hence the wire passing over the guide pulley is pulled by the jigger. This raises the load attached to the hook.

Problem 21.18 *Find the efficiency of a hydraulic crane, which is supplied 300 litres of water under a pressure of 60 N/cm² for lifting a weight of 12 kN through a height of 11 m.*

Solution. Given :

Water supplied, $Q = 300 \text{ litres} = 0.30 \text{ m}^3$

Pressure, $p = 60 \text{ N/cm}^2 = 60 \times 10^4 \dfrac{\text{N}}{\text{m}^2}$

Weight lifted, $W = 12$ kN $= 12 \times 1000 = 12000$ N

Height, $h = 11$ m

Output of the crane = Weight lifted × Height through which weight is lifted

$= W \times h = 12000 \times 11$ Nm

Input of the crane = Energy supplied by the water

= Work done by water on the ram

= Force on ram × Distance moved by ram

= Pressure × Area of ram × Stroke of ram

$= p \times A \times L$

$= 60 \times 10^4 \times$ Volume displaced

$= 60 \times 10^4 \times 0.30$ $\quad (\because \; A \times L = Q)$

$= 18 \times 10^4$ Nm

∴ Efficiency of the crane $= \dfrac{\text{Output}}{\text{Input}} = \dfrac{12000 \times 11}{18 \times 10^4} = 0.7333 =$ **73.33%. Ans.**

Problem 21.19 *The efficiency of a hydraulic crane, which is supplied water under a pressure of 70 N/cm² for lifting a weight through a height of 10 m, is 60%. If the diameter of the ram is 150 mm and velocity ratio is 6, find*

(*i*) *the weight lifted by the crane, and*

(*ii*) *the volume of water required in litres to lift the weight.*

Solution. Given :

Efficiency, $\eta = 60\% = 0.60$

Pressure of water, $p = 70 \text{ N/cm}^2 = 70 \times 10^4 \text{ N/m}^2$

Height through which weight is lifted, $h = 10$ m

Diameter of the ram, $D = 150$ mm $= 0.15$ m

∴ Area of ram, $A = \dfrac{\pi}{4} (.15)^2 = 0.01767 \text{ m}^2$

Velocity ratio = 6

Pressure force on ram, P = Pressure × Area of ram

$= p \times A = 70 \times 10^4 \times 0.01767 = 12369$ N.

(*i*) We know efficiency of the hydraulic crane is given as

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Weight} \times \text{Distance moved by weight}}{\text{Force} \times \text{Distance moved by force}}$$

or

$$0.60 = \frac{W \times \text{Distance moved by weight}}{P \times \text{Distance moved by force}}$$

But $\dfrac{\text{Distance moved by weight}}{\text{Distance moved by force}}$ = Velocity ratio = 6

$$\therefore \quad 0.60 = \frac{W}{P} \times 6 = \frac{W}{12369} \times 6$$

$$\therefore \quad W = \frac{0.60 \times 12369}{6} = \textbf{1236.9 N. Ans.}$$

(*ii*) Volume of water required to lift the weight :

$$\text{Velocity ratio} = \frac{\text{Distance moved by weight}}{\text{Distance moved by force on ram}}$$

or $$6 = \frac{h}{\text{Stroke of ram}} \quad (\because \text{ Distance moved by ram = Stroke of ram})$$

$\therefore$ Stroke of ram, $$L = \frac{h}{6} = \frac{10}{6} = 1.667 \text{ m}$$

$\therefore$ Volume of water $= \text{Area of ram} \times \text{Stroke of ram} = A \times L = 0.01767 \times 1.667$

$= 0.02945 \text{ m}^3 = 0.02945 \times 1000 =$ **29.45 litres. Ans.**

Problem 21.20 *A hydraulic crane is lifting a weight of 12000 N through a height of 12 m with a speed of 18 m per minute once in every two minutes. The efficiency of the hydraulic crane is 65% and it is working under a pressure of 500 N/cm² of water. The crane is fed from an accumulator to which water is supplied by a pump. Find :*

(*i*) *the capacity of the cylinder of the jigger in litres,*

(*ii*) *the capacity of the accumulator in litres, and*

(*iii*) *minimum power required for the pump.*

Solution. Given :

Weight lifted, $W = 12000$ N

Height, $h = 12$ m

Speed of weight, $V = 18$ m/min

No. of times the weight if lifted = Once in every two minutes

Efficiency, $\eta = 65\% = 0.65$

Pressure of water, $p = 500 \text{ N/cm}^2 = 500 \times 10^4 \text{ N/m}^2$

(*i*) Output of the crane = Weight lifted × Height

$= W \times h = 12000 \times 12 = 144000$ Nm.

Input of the crane = Work done by water on ram

= Force on ram × Distance moved by ram

$= p \times A \times L$

$= p \times$ Volume of cylinder $\quad (\because A \times L = \text{Volume of cylinder})$

$= 500 \times 10^4 \times$ Volume of cylinder

$$\therefore \quad \eta = \frac{\text{Output}}{\text{Input}} = \frac{144000}{500 \times 10^4 \times \text{volume of cylinder}}$$

$$\therefore \quad \text{Volume of cylinder} = \frac{144000}{500 \times 10^4 \times \eta} = \frac{144000}{500 \times 10^4 \times 0.65} = 0.0443 \text{ m}^3 = 44.3 \text{ litres.}$$

$\therefore$ Capacity of the cylinder of the jigger = **44.3 litres. Ans.**

(*ii*) Input of the crane $= p \times \text{Volume of cylinder} = 500 \times 10^4 \times 0.0443 = 221500$ Nm.

This input is given to the crane once in every two minutes.

$$\therefore \text{Input to crane per min.} = \frac{221500}{2} = 110750 \text{ Nm.}$$

The weight 12000 N is lifted to a height of 12 m with a speed of 18 m/min.

Time required to lift the weight through height of 12 m $= \dfrac{\text{Height}}{\text{Speed}} = \dfrac{12}{18} = \dfrac{2}{3}$ min.

∴ Work done by the pump during lifting

$= \text{Work done per min.} \times \text{Time required to lift the weight}$

$= 110750 \times \dfrac{2}{3} = 73833.33 \text{ Nm}$

∴ Energy supplied by accumulator = Total input energy to the crane – Work done during lifting

$= 221500 - 73833.33 = 147666.67 \text{ Nm}$ ...(*i*)

But energy supplied by accumulator = Force on the ram of accumulator × Lift of ram

$= p \times A \times H = p \times \text{Capacity of accumulator}$

$= 500 \times 10^4 \times \text{Capacity of accumulator}$ ...(*ii*)

Equating the two values given by equations (*i*) and (*ii*),

$$147666.67 = 500 \times 10^4 \times \text{Capacity of accumulator}$$

∴ Capacity of accumulator $= \dfrac{147666.67}{500 \times 10^4} = 0.0295 \text{ m}^3$ = **29.5 litres. Ans.**

(*iii*) Minimum power required for the pump

$= \dfrac{\text{Work input per minute}}{1000 \times 60} = \dfrac{110750}{1000 \times 60}$ = **1.846 kW. Ans.**

▶ 21.8 THE FLUID OR HYDRAULIC COUPLING

The fluid or hydraulic coupling is a device used for transmitting power from driving shaft to driven shaft with the help of fluid (generally oil). There is no mechanical connection between the two shafts. It consists of a radial pump impeller mounted on a driving shaft *A* and a radial flow reaction turbine mounted on the driven shaft *B*. Both the impeller and runner are identical in shape and they together form a casing which is completely enclosed and filled with oil.

In the beginning, both the shafts *A* and *B* are at rest. When the driving shaft *A* is rotated, the oil starts moving from the inner radius to the outer radius of the pump impeller as shown in Fig. 21.11. The pressure energy and kinetic energy of the oil increases at the outer radius of the pump impeller. This oil of increased energy enters the runner of the reaction turbine at the outer radius of the turbine runner and flows inwardly to the inner radius of the turbine runner. The oil, while flowing through the runner, transfers its energy to the blades of the runner and makes the runner to rotate. The oil, from the runner then flows back into the pump impeller, thus having a continuous circulation.

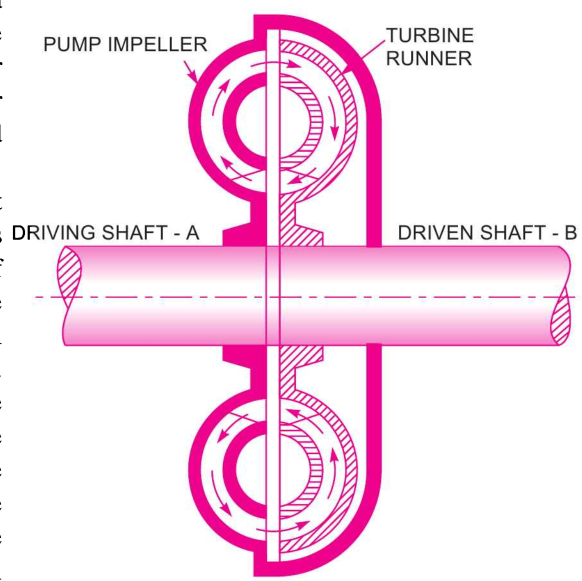

Fig. 21.11 *The hydraulic coupling.*

The power is transmitted hydraulically from the driving shaft to driven shaft and the driven shaft is free from engine vibrations. The speed of the driven shaft B is always less than the speed of the shaft A, by about 2 per cent. The efficiency of the power transmission by hydraulic coupling is about 98%. This is derived as given below.

$$\text{Efficiency of a fluid coupling} = \frac{\text{Power output}}{\text{Power input}}$$

or

$$\eta = \frac{\text{Power transmitted to shaft } B}{\text{Power available at shaft } A} \quad ...(i)$$

But power at any shaft

$$= \frac{2\pi NT}{60,000} \propto NT \propto \text{Speed} \times \text{Torque}$$

Let N_A = Speed of shaft A, ...(ii)

T_A = Torque at the shaft A,

N_B = Speed of shaft B,

T_B = Torque transmitted to shaft B.

From equation (*ii*), we have

Power available to shaft $A \propto$ (Speed of shaft A) $\times$ Torque of A

$$\propto N_A \times T_A.$$

Similarly, power transmitted to shaft $B \propto N_B \times T_B$.

Substituting these values of powers in equation (*ii*),

$$\eta = \frac{N_B \times T_B}{N_A \times T_A}$$

But $T_A = T_B$ (∵ Torque transmitted is same)

$$\therefore \quad \eta = \frac{N_B}{N_A} \quad ...(21.13)$$

Slip of fluid coupling is defined as the ratio of the difference of the speeds of the driving and driven shaft to the speed of the driving sharp. Mathematically,

$$\text{Slip, } S = \frac{N_A - N_B}{N_A} = 1 - \frac{N_B}{N_A} = 1 - \eta \qquad \left(\because \frac{N_B}{N_A} = \eta\right) \quad ...(21.14)$$

▶ 21.9 THE HYDRAULIC TORQUE CONVERTER

The hydraulic torque converter is a device used for transmitting increased torque at the driven shaft. The torque transmitted at the driven shaft may be more or less than the torque available at the driving shaft. The torque at the driven shaft may be increased about five times the torque available at the driving shaft with an efficiency of about 90%.

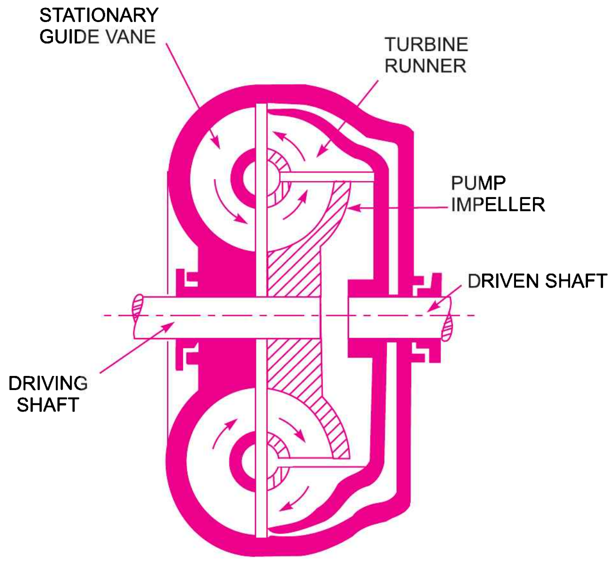

Fig. 21.12 *Fluid of hydraulic torque converter.*

As mentioned in Art. 21.8, the power at any shaft is proportional to the product of torque and speed of the shaft. Hence, if the torque at the driven shaft is to be increased, the corresponding value of the speed at the same shaft should be decreased. The speed of the driven shaft is decreased by decreasing the velocity of oil, which is allowed to flow from the pump impeller to the turbine runner and then through stationary guide vanes as shown in Fig. 21.12. Due to the decrease in speed at the driven shaft, the torque increases.

▶ 21.10 THE AIR LIFT PUMP

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.

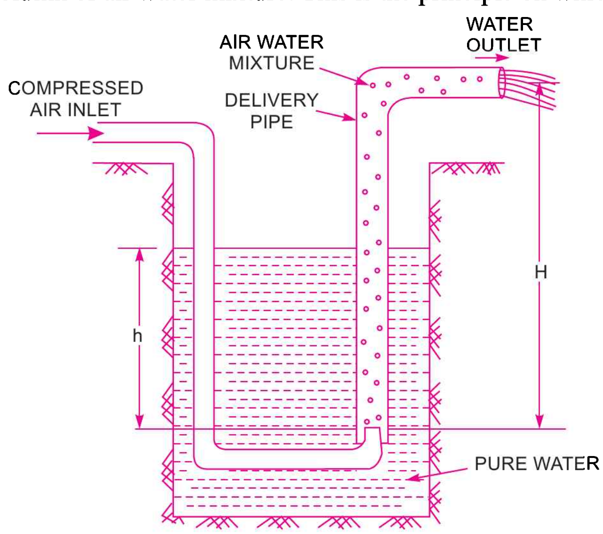

Fig. 21.13 *Air lift pump.*

Fig. 21.13 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.

The ratio $\left(\frac{h}{H-h}\right)$ generally varies from 4 to 1.

When $h = 30$ m, the ratio $\left(\frac{h}{H-h}\right)$ is about 4.

When $h = 90$ m, the ratio $\left(\frac{h}{H-h}\right)$ is 1.

For $h = 30$ m, $\frac{h}{(H-h)} = 4$ or $\frac{30}{(H-30)} = 4$ or $30 = 4H - 120$

or $30 + 120 = 4H$ or $H = \frac{150}{4} = 37.5$ m.

The air lift pump is not having any moving parts below water level and hence there are no chances of suspended solid particles damaging the pump. This is the main advantage of this pump. Also this pump can raise more water through a bore hole of given diameter than any other pump. But the efficiency of this pump is low as out of the energy expended in compressing the air, only 20 to 40% energy appears in the form of useful water horse-power.

▶ 21.11 THE GEAR-WHEEL PUMP

The gear pump is a rotary pump in which two gears mesh to provide the pumping action. This type of pump is mostly used for cooling water and pressure oil to be supplied for lubrication to motors, turbines, machine tools etc. Although the gear pump is a rotating machinery, yet its action on liquid to be pumped is not dynamic and it merely displaces the liquid from one side to the other. The flow of liquid to be pumped is continuous and uniform.

Fig. 21.14 shows the gear pump, which consists of two identical intermeshing gears working in a fine clearance inside a casing. One of the gear is keyed to a driving shaft. The other gear revolves due to driving gear. The space between teeth and the casing is filled with oil. The oil is carried round between the gears from the suction pipe to the delivery pipe.

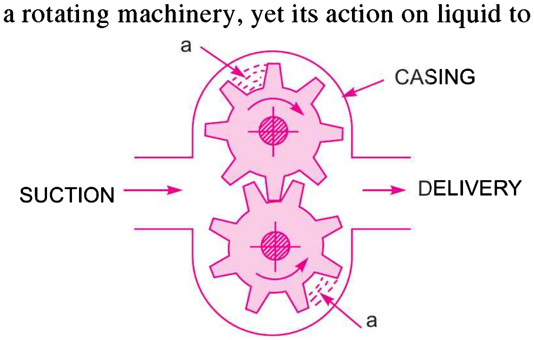

Fig. 21.14 *Gear-wheel pump.*

The mechanical contact between the gears does not allow the flow from inlet to outlet directly. The outer radial tips of the gears and sides of the gears form a part off moving oil.

The oil pushed into the delivery pipe, cannot back into the suction pipe due to the meshing of the gears. The theoretical oil pumped per second is obtained as :

Let N = Speed of rotating gear in r.p.m.,
a = Area enclosed between two successive teeth and casing,
n = Total number of teeth in each gear,
L = Axial length of teeth.

Volume of oil discharged per revolution = $2 \times a \times L \times N$ m^3

∴ Discharge/s = Volume of oil per revolution × No. of revolution in one second

$$= 2aLn \times \frac{N}{60} \text{ m}^3$$

The actual discharge will be less than the theoretical discharge.

Now, volumetric efficiency $= \dfrac{\text{Actual discharge}}{\text{Theoretical discharge}}$.

HIGHLIGHTS

1. The devices, based on the principles of fluid statics and fluid kinematics for the transmission of power with the help of a fluid (oil or air), are called fluid or hydraulic devices.
2. A device, which is used for lifting heavy weights by the application of a much smaller force is known as hydraulic press.
3. The 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, is known as hydraulic accumulator.
4. Capacity of the hydraulic accumulator is given as

   $$= p \times A \times L$$

   where p = Liquid pressure supplied by pump, A = Area of the sliding ram, L = Stroke or lift of the ram.
5. Differential hydraulic accumulator is a device in which liquid is stored at a high pressure by comparatively small load on the ram.
6. Hydraulic intensifier is a device, in which the pressure intensity of a liquid is increased by means of hydraulic energy available from a large amount of liquid at a low pressure. The increased pressure intensity (p^*) is given by the relation,

   $$p^* = \frac{p \times A}{a}$$

   where p = Low pressure intensity of liquid, A = External area of the sliding ram,
   a = Area of the end of the fixed ram.
7. Hydraulic ram is a pump which raises water without any external power (electricity etc.) for its operation. There are two efficiencies of a hydraulic ram namely D' Aubuisson's efficiency and Rankine efficiency.

   They are given by the relations, D' Aubuisson's $\eta = \dfrac{wh}{Wh}$ or $\dfrac{qH}{Qh}$

Rankine's $\eta = \dfrac{w \times (H - h)}{(W - w) \times h}$ or $\dfrac{q \times (H - h)}{(Q - q) \times h}$

where w = Weight of water raised per sec, W = Weight of water flowing per sec into chamber,

h = Height of water above chamber in supply tank, H = Height of water raised above chamber.

8. Hydraulic lift is a device used for carrying persons or goods from one floor to another floor in a multi-storeyed building. They are of two types namely direct acting hydraulic lifts and suspended hydraulic lifts.

9. Hydraulic crane is a device used for raising or transferring heavy weights.

10. Fluid coupling is a device, in which power is transmitted from driving shaft to driven shaft without any change of torque while torque converter is a device in which arrangement is provided for getting increased or decreased torque at the driven shaft.

EXERCISE

(A) THEORETICAL PROBLEMS

1. Explain the term,'Hydraulic devices'. Name any five hydraulic devices.

2. Draw a neat sketch and explain the principle and working of a hydraulic press.

3. Define the term, the hydraulic accumulator. Obtain an expression for the capacity of a hydraulic accumulator. Differentiate between hydraulic accumulator and differential accumulator.

4. What is a hydraulic intensifier ? Explain its principle and working.

5. Differentiate between a hydraulic ram and a centrifugal pump. Obtain an expression for the efficiencies of the hydraulic ram.

6. Explain with the help of a neat sketch, the principle and working of the following hydraulic devices :

(*a*) Hydraulic lift, (*b*) Hydraulic crane,

(*c*) Hydraulic coupling, and (*d*) Hydraulic torque converter.

7. What is a difference between a fluid coupling and fluid torque converter? Explain the torque converter with a sketch.

8. Explain with neat sketch, the working of air lift pump. Mention its advantages.

9. How does a torque converter differ from a fluid coupling ? Explain the working principle of any one of them.

(B) NUMERICAL PROBLEMS

1. A hydraulic press has a ram of 300 mm diameter and a plunger of 50 mm diameter. Find the weight lifted by the hydraulic press when the force applied at the plunger is 40 N. [**Ans.** 1440 N]

2. A hydraulic press has a ram of 150 mm diameter and plunger of 30 mm. The stroke of the plunger is 250 mm and weight lifted is 600 N. If the distance moved by the weight is 1.20 m in 20 minutes, determine : (*a*) the force applied on the plunger, (*b*) power required to drive the plunger, and (*c*) number of strokes performed by the plunger. [**Ans.** (*a*) 24 N, (*b*) 0.0006 kW, (*c*) 120]

3. The water is supplied at a pressure of 15 N/cm^2 to an accumulator, having a ram of diameter 2.0 m. If the total lift of the ram is 10 m, determine :

(*a*) the capacity of the accumulator, and

(*b*) total weight placed on the ram (including the weight of the ram).

[**Ans.** (*a*) 4712.4 kNm, (*b*) 471240 N]

4. The diameters of the fixed ram and fixed cylinder of an intensifier are 100 mm and 250 mm respectively. If the pressure of the water supplied to the fixed cylinder is 25 N/cm^2, find the pressure of the water flowing through the fixed ram. [**Ans.** 156.25 N/cm^2]
5. The water is supplied at the rate of 30 litres per second from a height of 4 m to a hydraulic ram, which raises 3 litres per second to a height of 18 m from the ram. Determine D' Aubuisson's and Rankine's efficiencies of the hydraulic ram. [**Ans**. 45%, 38.8%]
6. A hydraulic lift is required to lift a load of 98.1 kN through a height of 12 m, once in every 100 seconds. The speed of the lift is 600 mm/s. Determine :
   (*a*) power required to drive the lift, (*b*) working period of lift in seconds, and (*c*) idle period of the lift in seconds. [**Ans.** (*a*) 11.772 kW, (*b*) 20 sec, (*c*) 80 sec]
7. Find the efficiency of a hydraulic crane, which is supplied 400 litres of water under a pressure of 490.5 N/cm^2 for lifting a weight of 98.1 kN through a height of 10 m. [**Ans**. 50%]
8. In a hydraulic coupling, the speeds of the driving and driven shafts are 800 r.p.m. and 780 r.p.m. respectively. Find :
   (*a*) the efficiency of the hydraulic coupling, and (*b*) the slip of the coupling. [**Ans.** (*a*) 97.5%, (*b*) 2.5%]