LECTURE 24 TO 26 – HYDRAULIC CIRCUIT DESIGN

SELF EVALUATION QUESTIONS AND ANSWERS

1 A hydraulic cylinder is to compress a car body in 10 seconds. The operation requires a stroke of 3 m and a force of 40,000 N. If a 7.5 N/mm^2 pump has been selected, find the following:

- **i) Required piston area and piston diameter.**
- **ii) The necessary pump flow.**
- **iii) The hydraulic power capacity in kW**

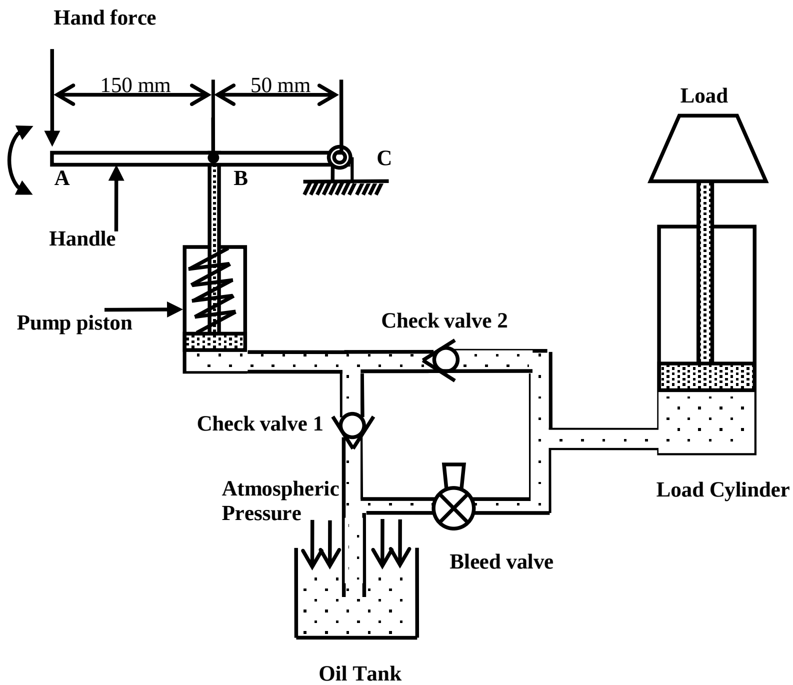
2: A pump supplies oil at 20 gallons/min to a 50 mm diameter double acting hydraulic cylinder. If the load acting during the extending and retracting stroke is 5000 N and diameter of rod is 25 mm, find:

- **(a) Hydraulic pressure during extension stroke**
- **(b) The piston velocity during extension stroke**
- **(c) The cylinder kW capacity during extension stroke**
- **(d) Hydraulic pressure during return stroke**
- **(e) The piston velocity during return stroke**
- **(f) The cylinder kW capacity during return stroke**

3 Operator of a hydraulic jack makes one complete cycle per second using hand pump. Each complete cycle consists of two punch strokes (intake and power strokes). The pump has a 25 mm diameter cylinder and load cylinder is of 90 mm diameter. If the average hand force is 150 N during power stroke, determine:

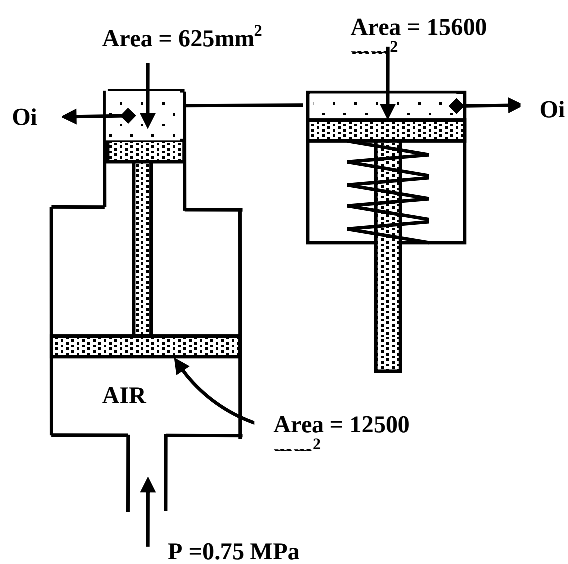
- **i. The load that can be lifted**
- **ii. The number of cycles required to lift the load through 250 mm, assuming pump piston has 50 mm stroke and there is no oil leakage.**
- **iii. The power exerted by the operator assuming 100 % efficiency**

The details of the pump are given in below diagram



4 Determine the force that can be applied by a hydraulic booster with the following details:

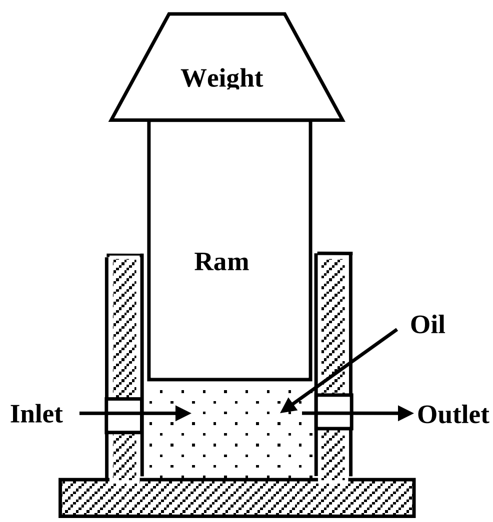
Air Piston area	**=**	**12500 mm^2**
Oil piston area	**=**	**625 mm^2**
Load piston area	**=**	**15600 mm^2 .**
Air Pressure	**=**	**0.75 N/mm^2**



5 Design a hydraulic circuit for a punching press with five stations operated by 5 parallel cylinders connected to an intensifier. The cylinders are spring return type and the punching stroke required is 10 mm travel and used for punching 10 mm diameter holes on sheet metal of 1.5mm thickness of mild steel. The ultimate shear stress of the material of the sheets is 300 N/mm^2. determine the oil pressure of hydraulic system. The details of the intensifier used and cylinder details are as below:

Number of load cylinders	**= 5**
Inlet Piston area of intensifier	**= 12500 mm^2**
Outlet piston area of Intensifier	**= 625 mm^2**
Load piston area	**= 15600 mm^2**

6 Hydraulic ram type accumulator is shown in the figure below. Write an expression for the capacity of accumulator. If A=2m^2, lift of the ram = 10 m. a) Calculate the capacity of accumulator. b) If the displacement volume of the accumulator is 4 litres of fluid and diameter of its plunger is 375mm. find the stroke.



7.An accumulator is loaded with 500 kN weight. The ram has a diameter of 30cm and a stroke of 6m. Its friction may be taken as 3%. It takes 120 sec to fall through its full stroke. Find the total work supplied and power delivered to the hydraulic appliance by the accumulator, when 7.5 LPM delivered by a pump, while the accumulator descends with the stated velocity. Take specific weight and density of oil as 1000 units.

8.An accumulator has a ram of 37.5 cm diameter and 7.5 m lift. It .is loaded with 120 tonnes of total weight. If the packing friction accounts for 2.5 % of the total force on the ram, determine power being delivered at the mains, if the ram falls steadily through its full range in 2.5 min and if pumps are delivering 900 LPM at the same time.

Q1 Solution

Load required = 4000 N.

Stroke length = 3 m.

Time taken to compress = 10 s.

Pump discharge pressure = 7.5 N/ mm^2.

We know,

i) Force acting on the piston rod = Area of piston × Pressure from the pump

40,000 = A × 7.5

Required piston area, A = 5333.33 mm^2

Piston area $A = \frac{\pi}{4}(D)^2$ = 5333.33 mm^2

Piston diameter, D = 82.4 mm

ii) Pump flow = Area × Velocity = 5333.33 × 0.3 = 1.6 × 10^{-3} m^3/s

(Velocity = stroke length / time taken = 3000/10 = 300 mm/s = 0.3 m/s)

iii) Power capacity in kW = Force × Velocity

= 40000 × 0.3 = 12 kW

Q2 Solution

Pump discharge = 20 gallons/min

Piston diameter = 50 mm

Rod diameter = 25 mm

Load = 5000 N

Let us first consider extension stroke

i) To calculate hydraulic pressure during extension stroke

Force = Pressure × Area

Pressure during extension P = (4 × 5000)/(π × 50^2)

= 2.55 N/ mm^2.

ii) To calculate piston velocity during extension

Pump discharge = Area × Velocity

Pump discharge = 20 gallons/min

= 20 × 3.785 litres/min (1 gallon = 30785 litres)

= $(20 \times 3.785 \times 10^{-3}) / 60\ m^3/s$

Substituting the values,

$$(20 \times 3.785 \times 10^{-3}) / 60 = (\pi/4) \times (50 \times 10^{-3})^2 \times \text{Velocity}$$

Velocity V = 0.643 m/s

iii) To calculate Kilowatt capacity:

Kilowatt capacity = Force × Velocity

= (5000 × 0.643) / 1000 = 3.21 kW

Let us now consider Return Stroke

iv) To calculate hydraulic pressure during retraction stroke

Pressure = Force / Area

$$= (4 \times 5000) / (\pi \times (50^2 - 25^2)) = 3.40\ N/mm^2.$$

v) To calculate piston velocity during return

$$\text{Velocity} = Q / A = [(20 \times 3.785 \times 10^{-3}) \times 4)/(\pi \times [(50 \times 10^{-3})^2 – [(25 \times 10^{-3})^2])]$$

= 0.857 m/s

vi) To calculate Kilowatt capacity

Kilowatt capacity = Force × Velocity

= (5000 × 0.857) / 1000 = 4.28 kW

Q3 Solution

Length of the lever = 200 mm

Hand force = 150 N

Pump piston diameter = 25 mm

Load cylinder diameter = 90 mm

Lift required = 250 mm

Pump piston stroke = 50mm

As per Pascal's Law,

Pressure in the System = Force applied (F_p) / Area of pump cylinder piston

Taking moment at the hinge of the hand lever, Force F_p can be calculated as below:

$F_p \times 50 = 150 \times 200$

$F_p = (150 \times 200) / 50 = 600$ N

Pressure P = $(600 \times 4)/ (\pi \times 25^2) = 1.22\text{N/mm}^2$

(i) Load that can be lifted = Pressure ×Area of the load cylinder

= $(1.22 x\pi\ x90^2)/4=7761$N

(ii) Number of Cycles:

Let N be number of cycles

The amount of volume required to lift through 250mm

= (N ×Volume displaced per cycle of the piston pump.)

Rearranging,

$(N \times \pi\ \times 25^2 \times 50) / 4= (250\ x\pi \times 90^2) /4$

$N = 65$ cycles

Since 1 cycle takes 1 second,

Total time taken = 65 seconds

(iii) Kilowatt capacity = Force ×Velocity

Velocity = Lift/ Time taken = $250 \times 10^{-3} / 65$

Therefore,

Kilowatt capacity = $(7761 \times 250 \times 10^{-3}) / (65 \times 1000) = 29.85$ W = 0.029 kW.

Q4 Solution

Air Piston area	=	$A_1 = 12500\ mm^2$ (given)
Oil piston area	=	$A_2 = 625\ mm^2$ (given)
Air pressure	=	$P_1 = 0.75\ N/mm^2$ (given)
Lord position area	=	$156000 mm^2$
Oil Pressure	=	P_2

For intensifier / boosters, we can write

$A_1 x P_1 = A_2 \times P_2$

Therefore,

Pressure at oil cylinder P_2 $(A_1 \times P_1) / A_2$ $(12500 \times 0.75) /625 = 15\ N/mrn^2$

This pressure acts on the load piston area.

Thus, the force applied = Pressure ×Area = 15 ×15600 = 234 kN

Q5 Solution

Diameter of hole to be punched (D) = 10 mm

Stroke length required (L) = 10 mm

Thickness of the sheet material (t) = 1.5 mm

Shear stress of the sheet material = 300 N/mm^2

The shear area on the sheet metal = $\pi \times D \times t = \pi \times 10 \times 1.5 = 47.12$ mm^2

The cutting force required to shear the above area = Shear stress $\times$ Shear area

= $300 \times 47.12 = 14137.16$ N

Therefore, the pressure required at the load cylinder

= (Cutting Force / Cross section of load cylinder piston)

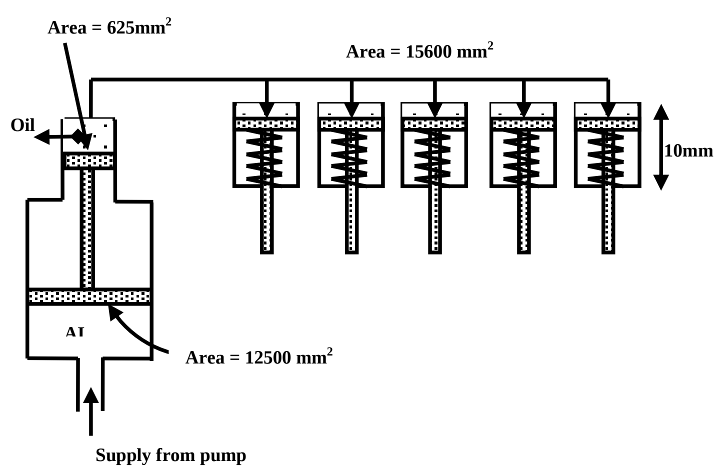
= 14137.16 / 15600 N/mm^2 = 0.91 N/mm^2

This pressure is to be delivered at the outlet of the intensifier

Therefore, the pressure required at the inlet of the intensifier from the pump is

$$P \times 12500 = 0.91 \times 625$$

Pump pressure required $P = 0.0455$ N/mm^2



To determine the stroke of the Intensifier to have a punching stroke of 10 mm at all five load cylinders:

Let, Length of Intensifier stroke required to supply oil to 5 load cylinders= L_1

Volume of fluid required at the punching end, Q_p= 5 ×Area of load piston ×Stroke

$$= 5 \times 15600 x 10 = 780000 mm^3$$

Volume at the Intensifier, Q_p = Area of Outlet piston ×L_1 = 625 ×L_1

Therefore, The stroke of Intensifying cylinder required, L_1 780000/625 = 1248 mm = 1.248 mm

Q6 Solution

Part (a)

The Sliding rum is loaded with weights. When the fluid under pressure enters the accumulator cylinder through the inlet valve, it lifts the loaded ram until the cylinder is full of fluid. At this stage, the accumulator has stored its maximum amount of energy, which is known as capacity of the accumulator**,**

Let, A = Area of the cylinder

H = Lift of the cylinder

P =Intensity of fluid pressure supplied by the accumulator

Then,

The capacity of the accumulator = PAH

If A=2m^2, lift of the ram = 10 m

and fluid pressure = 1.5 kg/cm^2 = 150000 N/m^2)

Capacity of accumulator = 150000 ×2 ×10 = 3000000 N/m

The above diagram shows the ram type of accumulator

Part (b)

Displacement volume = 4 litres = 4000 cm^3

Diameter of plunger (D) = 375 mm = 37.5 cm

Area of the plunger = $(\pi/4)D^2 = (\pi/4)\ 37.5^2 = 1104.47$ cm

Length of the stroke = Displacement Volume / Area of the plunger

= 4000 / 1104.47 = 36.2mm

Q7Solution

Load on the accumulator = 500 kN = 500000 N

Diameter of the ram, D = 30 cm = 0,3 m

Length of the stroke = 6 m

Friction in the accumulator =3 %

Time taken to fall one stroke =120 sec

Discharge of the pump, Q =7.5 lit/mm = 0.0075 m^3/min

Area of the ram = $(\pi/4)\ D^2$ = $(\pi/4)\ 0.3^2 = 0.070685\ m^2$

Net load on accumulator = Actual load ×(l – percentage of friction)

= 500000 ×0.97 = 4,85,000 N

To calculate work supplied to the hydraulic machine:

Work supplied by the accumulator per mm = Load ×velocity

Velocity to descend, V =6 m in 120 sec = 6 m in 2min

Work supplied by the accumulator per min = 4,85,000 ×(6/2)

14,55,00 Nm/min

Intensity of pressure in the accumulator, P= Net load / Area

= 4,85,000 / 0.070685

6861427.46 N/m^2

$P = H \times density \times g$

Rearranging, $H = p/ (density \times g)$

$= 6861427.46 / (1000 \times 9.81)$

$= 699.43$ m

Work supplied by the pump per min = (Sp.wt ×Q) ×H

$= 1000 \times .81 \times 0.0075 \times 699.43$

= 51460.56 Nm/min

Total work supplied to the hydraulic machine = 14,55,000 + 51460.56

= 1506460.56 Nm/min

Total Power delivered to the hydraulic machine:

Power delivered in watts = Work supplied per second

= 150646056 / 60

= 25107.676 Nm/sec = 25107.676W

Power delivered = 25.107 kW

Q8 Solution

Total weight of the ran = 120 tonnes $= 120 \times 10^3 \times 9.81N$

Frictional force = 2.5 %

Net force = Total weight ×(1-2.5%)

= 0.975 ×Total weight

$= 0.975 \times 120 \times 10^3 \times 9.81$ N = 1147770 N

Diameter of the rain, D = 37.5 cm = 0.375 m^2

Pump discharge = 900 LPM

Lift = 7.5m

Time to fall = 2.5min

Pressure of fluid leaving the accumulator = Net force/Area

$p = (1147770)/(\pi/4)D^2$

$p = 1147770 / (\pi /4)\ 0.375^2$

$p = 10392079.3\ N/rn^2$

$p = 10.39\ N/mm^2 = 10.39\ MPa$

Rate of discharge from the accumulator, Q1 = (Area ×lift)/ Time to emptying

$= (\pi /4)\ 0.375^2 \times 7.5) / (2.5 \times 61)$

$= 0.00552\ m^3/sec$

Rate of discharge from pump, $Q_2 = 900$ LPM

$= 900 \times 10^{-3}/60 = 0.015\ m^3/sec$

Total rate of supply to the mains $Q = Q_1 + Q_2$

$= 0.00552 + 0.015\ m^3/sec = 0.02052\ m^3/sec$

Power delivered to the mains $= Q \times p = 0.02052 \times 10392079.3$

$= 213245.467$ W=213.2kW