SOLUTION 7

Operation of the system at the lifting phase: Actuators are connected in parallel and therefore they can operate at different times. Sequence of operation is determined by the pressure that is needed to operate the actuator against the load.

The first mass to rise is the one that requires lower pressure value and only after this the second mass can rise.

1) Pressure gauge reading

The actuator (cylinder, motor) input pressures depend also on the pressures at actuator outlets (cylinder rod side chamber pressure, motor's outlet pressure). Those pressures are related to flow rate dependent pressure losses in the directional control valve. Thus it is essential to know the flow rates in the system as well.

Pump produced flow $q_{\mathrm{V,p}}$

$$q_{\mathrm{V.p}} = nV_{g.p}\eta_{v.p} = \frac{1500}{60} \cdot 5 \cdot 10^{-6} \cdot 0.8 = 0.0001\ \mathrm{m}^3/s = 6\ \mathrm{l/min}$$

Pressures associated to the cylinder operation

This pump flow enters the cylinder. The exiting flow $q_{\mathrm{V,c}}$ is however lesser (N.B.: piston rod) and can be calculated using piston area ratio. Also the potential leakages in the cylinder would affect the flow rate ($\eta_{\mathrm{v,c}}$= 1).

$$q_{V,\mathrm{rod}} = \frac{A_{\mathrm{rod}}}{A_{\mathrm{piston}}} q_{\mathrm{V,piston}}$$

As piston and rod diameters are

D= 100 mm

d= 50 m

$$q_{V,\mathrm{rod}} = \frac{\frac{\pi}{4}D^2 - \frac{\pi}{4}d^2}{\frac{\pi}{4}D^2} q_{\mathrm{V,piston}}$$

$q_{\mathrm{V,rod}}$= 3/4 $q_{\mathrm{V,piston}}$

$q_{\mathrm{V,rod}}$= 4.5 l/min

In directional control valve these induce pressure losses of

Δp_{PB}= 5 bar (6 l/min)

Δp_{AT}= 2.2 bar (4.5 l/min)

We can now master the cylinder's force balance and calculate piston side pressure.

$$F = (p_{\mathrm{in}} A_{\mathrm{in}} - p_{\mathrm{out}} A_{\mathrm{out}})\eta_{\mathrm{hm}}$$

In our case (lifting).

$$F_{\mathrm{c}} = \left(p_{\mathrm{piston}} A_{\mathrm{piston}} - p_{\mathrm{rod}} \cdot A_{\mathrm{rod}}\right)\eta_{\mathrm{hm,c}}$$

$$p_{\mathrm{piston}} = \left(\frac{F_c}{\eta_{\mathrm{hm,c}}} + p_{\mathrm{rod}} \cdot A_{\mathrm{rod}}\right)\frac{1}{A_{\mathrm{piston}}}$$

As

$p_{\mathrm{rod}}= 0.22 \cdot 10^6$ Pa

$p_{\mathrm{piston}}= 11.26 \cdot 10^6$ Pa

(and required pump pressure would be $p_{\mathrm{p}}= p_{\mathrm{piston}} + \Delta p_{\mathrm{PB}} = 11.26 \cdot 10^6$ Pa $+ 0.5 \cdot 10^6$ Pa$= 11.76 \cdot 10^6$ Pa).

Pressures associated to the motor operation

$$\Delta p_{\mathrm{m}} = \frac{2\pi T}{V_{\mathrm{g,m}}\eta_{\mathrm{hm,m}}} = \frac{2\pi m_2 g \frac{d_s}{2}}{V_{\mathrm{g,m}}\eta_{\mathrm{hm,m}}} = \frac{2\pi \cdot 150 \cdot 9.81 \cdot \frac{0.5}{2}}{160 \cdot 10^{-6}\ 0.85}$$

$\Delta p_{\mathrm{m}}= 17.0 \cdot 10^6$ Pa

From this piece of information we can already see that cylinder piston will move before the motor shaft.

After the piston has reached the uppermost position in the cylinder the system pressure will rise and the motor will start to rotate as pump has reached the value Δp_{m} calculated earlier. The quasi steady state pressures in the system depend also on the flow rate losses in the directional control valve.

The flow entering the motor is 6 l/min, but the exiting flow is lesser due to external leakages (case drain) of the motor, and the exiting flow $q_{\mathrm{V,m2}}$ is

$$q_{\mathrm{V,m2}} = q_{\mathrm{V,p}}\eta_{\mathrm{v,m}} = q_{\mathrm{V,p}}\frac{\eta_{\mathrm{t,m}}}{\eta_{\mathrm{hm,m}}} = 6\ \mathrm{l/min}\frac{0.81}{0.85} = 5.7\ \mathrm{l/min}$$

Note!

1. In this case the leakage is totally external which is certainly very exceptional (or theoretical).
2. Potential leakage in the motor could also affect (reduce) the velocity of the piston during the operation of the cylinder.

These flows induce following pressure losses in directional control valve

$\Delta p_{\mathrm{PB}}= 5$ bar (6 l/min)

$\Delta p_{\mathrm{AT}}= 3.6$ bar (5.7 l/min)

Therefore when the motor lifts the mass 2, the pressure gauge reads

$p_g = \Delta p_{\mathrm{m}} + \Delta p_{\mathrm{PB}} + \Delta p_{\mathrm{AT}} = 170.0 + 5 + 3{,}6 = 178.6$ bar   ($17.86 \cdot 10^6$ Pa).

In this case the actuator is symmetric, so Δp_{AT} can be directly summed with other pressure losses.

2) Maximum power needed at the axle of the pump

Maximum axial power need appears when the motor is operated, in which case the pressure difference between pump ports $\Delta p_{\mathrm{p}} = 178.6$ bar (the pressure loss of nonreturn valve is omitted and the tank pressure is assumed to be 0 bar).

The pump produced hydraulic power is

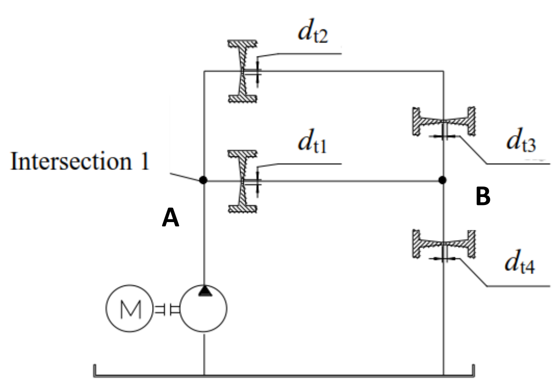
$P_{\mathrm{hydr}} = \Delta p_{\mathrm{p}} \cdot q_{\mathrm{V,\,p}}$

and correspondingly the input (shaft) power of the pump is

$$P_{\mathrm{shaft}} = \frac{P_{\mathrm{hydr}}}{\eta_{\mathrm{t,p}}} = \frac{\Delta p_{\mathrm{p}} q_{\mathrm{V,p}}}{\eta_{\mathrm{hm,p}} \cdot \eta_{\mathrm{v,p}}} = \frac{178.6 \cdot 10^5 \, \frac{6}{60000}}{0.9 \cdot 0.8} = 2480\ W \ \approx 2.5\ \mathrm{kW}$$

ANSWER:
Operation: At first the cylinder lifts mass 1 while the pressure gauge reads 117.6 bar and after the cylinder has reached the end position the motor lifts mass 2 while the pressure gauge reads 178.6 bar. The maximum needed axle power is 2.5 kW.

SOLUTION 8



The flow coefficients of all throttles are the same. Pressure difference (Δp_4) that forms across throttle t4 is determined by the flow rate that runs through the throttle. **It does not, however, affect the flow division between the two flow paths since the total pump flow runs through it anyway**. (Throttle t4 only rises the pressure forming at pump outlet port by Δp_4)

Classical orifice equation is

$$q_v = C_{\mathrm{q}} A \sqrt{\frac{2\Delta p}{\rho}}$$

In turbulent region flow coefficient C_q is often considered as constant (circa 0.6 … 0.7).

Thus orifice equation can be ewxpressed in more compact form if

C_q flow coefficient

ρ density

remain the same.

$$q_v = KA\sqrt{\Delta p}$$

Where parameter

$$K = C_{\mathrm{q}} \sqrt{\frac{2}{\rho}}$$

Pressure loss is

$$\Delta p = \frac{1}{K^2 A^2} q_v^2$$

In the exercise

- the pressure drop are the same through flow paths
- orifices 2 and 3
    - $\Delta p_2 + \Delta p_3$
- and orifice 1
    - Δp_1

Thus

- $\Delta p_2 + \Delta p_3 = \Delta p_1$

Also we try to arrange so that flow rates are the same through these flow paths 2-3 and 1.

Thus

- $q_{v1} = q_{v2} = q_{v3}$

Now

$$\Delta p_{\mathbf{AB}} = \frac{1}{K^2 A_2^2} q_v^2 + \frac{1}{K^2 A_3^2} q_v^2 = \frac{1}{K^2 A_1^2} q_v^2$$

As parameter K is comon and flow rate q_v through the orifices is the same the relation below exists.

$$\frac{1}{A_2^2}+\frac{1}{A_3^2}=\frac{1}{A_1^2}$$

$$\frac{1}{A_3^2}=\frac{1}{A_1^2}-\frac{1}{A_2^2}$$

$$A_3^2=\frac{A_1^2A_2^2}{A_2^2-A_1^2}$$

Equation for the orifice area

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

$$d_3^4=\frac{d_1^4d_2^4}{d_2^4-d_1^4}$$

$$d_3=\sqrt[4]{\frac{d_1^4d_2^4}{d_2^4-d_1^4}}$$

As

d_1= 0.004 m

d_2= 0.008 m

Thus the proper diameter for the orifice t3 would be:

d_3= $4.0651 \cdot 10^{-3}$ m