SOLUTION 9

Initial values:

Pump:

$V_{g,p} = 75 cm^3 / r$	Displacement
$\eta_{hm,p} = 0{,}95$	Hydromechanical efficiency
$\eta_{v,p} = 0{,}90$	Volumetric efficiency
$\eta_{t,p} = \eta_{v,p} \cdot \eta_{hm,p} = 0{,}86$	Total efficiency

Electric motor:

$n_p = 1500 r / \min$	Rotational speed

Cylinders:

$d_{c1} = 80mm$	Cylinder1: piston diameter
$d_{c2} = 63mm$	Cylinder2: piston diameter
$d_{cr1} = 50mm$	Cylinder1: piston rod diameter
$d_{cr2} = 45mm$	Cylinder2: piston rod diameter
$m_1 = 5000kg$	Load mass on cylinder 1
$m_2 = 3000kg$	Load mass on cylinder 2
$\eta_{hm,c1} = 1{,}0$	Cylinder1: hydromechanical efficiency
$\eta_{v,c1} = 1{,}0$	Cylinder1: volumetric efficiency
$\eta_{hm,c2} = 1{,}0$	Cylinder2: hydromechanical efficiency
$\eta_{v,c2} = 1{,}0$	Cylinder2: volumetric efficiency

Throttle:

$d_t = 3mm$	diameter

Additional:

$C_q = 0{,}7$

$\rho = 860 kg / m^3$

$g = 9{,}82 m / s^2$

Let us start with Cylinder1: the pressure needed to overcome the load:

$$p_{c1} = \frac{m_1 \cdot g}{\pi \cdot \frac{d_{c1}^{\ 2}}{4} \cdot \eta_{hm,c1}} \approx 97{,}68 bar$$

and next Cylinder2: the pressure needed to overcome the load:

$$p_{c2} = \frac{m_2 \cdot g}{\pi \cdot \frac{\left(d_{c2}^{\ 2} - d_{cr2}^{\ 2}\right)}{4} \cdot \eta_{hm,c2}} \approx 192{,}95 bar$$

Based on these pressures we'll have to assume that the sequence of the cylinders is: first cylinder C1, then cylinder C2.

When the cylinder C1 moves the exiting flow is

$$q_{V,c1m} = \frac{\pi \cdot \frac{\left(d_{c1}^{\ 2} - d_{cr1}^{\ 2}\right)}{4}}{\pi \cdot \frac{d_{c1}^{\ 2}}{4}} \cdot V_{g,p} \cdot n_p \cdot \eta_{v,p} = 1{,}03 \cdot 10^{-3} m^3 / s = 61{,}70 l / \min$$

In throttle this would induce a pressure loss of

$$\Delta p_t = \frac{\rho}{2} \cdot \left(\frac{4 \cdot q_{V,c1m}}{C_q \cdot \pi \cdot d_k^{\ 2}} \right)^2 \approx 185{,}72 bar$$

Which is reduced into pressure in the piston side using the piston area ratio (in form of diameters). This results into pressure difference:

$$\Delta p_{t,red} = \frac{\pi \cdot \frac{\left(d_{c1}^{\ 2} - d_{cr1}^{\ 2}\right)}{4}}{\pi \cdot \frac{d_{c1}^{\ 2}}{4}} \cdot \Delta p_t = 113{,}17 bar$$

This would mean that the pressure for operating C1 alone would be

$$p = p_{c1} + p_{t,red} = 210{,}86 bar$$

This pressure would be sufficient to also operate Cylinder C2, and hence we can deduce that the cylinders operate simultaneously and the maximum system pressure is roughly 193 bar (= p_{c2}). Therefore the setting pressure of pressure relief valve should be at least p_{prv} = 193 bar

The velocities of cylinders can be solved with the help of pressures; the pressure at the piston side chamber of Cylinder C1 is 193 bar, of which about 97,7, bar is needed to overcome the load, and therefore (193-97.7 bar =) 95.3 bar is left for the throttle induced internal load. When this pressure is reduced to the piston rod side pressure of Cylinder C1, this reduced pressure is also the pressure difference across the throttle, since after the throttle valve there are no other pressure loss inducing components.

$$\Delta p_{t,red} = p_{c2} - p_{c1} = 95{,}3 bar$$

$$\Delta p_t = \frac{\pi \cdot \frac{d_{c1}{}^2}{4}}{\pi \cdot \frac{\left(d_{c1}{}^2 - d_{cr1}{}^2\right)}{4}} \cdot \Delta p_t = 156{,}34\, bar$$

This pressure loss in throttle yields to flow of

$$q_{V,t} = C_q \cdot A_t \sqrt{\frac{2 \cdot \Delta p_t}{\rho}} \approx 56{,}61\, l / \min$$

Resulting Cylinder S1 velocity

$$v_{c1} = \frac{4 \cdot q_{V,c1m}}{\pi\left(d_{c1}{}^2 - d_{cr1}{}^2\right)} = 0{,}31 m / s$$

Flow entering Cylinder C1 (reduced from known output flow = flow through throttle)

$$q_{V,c1p} = \frac{\pi \cdot \frac{d_{c1}{}^2}{4}}{\pi \cdot \frac{\left(d_{c1}{}^2 - d_{cr1}{}^2\right)}{4}} \cdot q_{V,c1m} = 92{,}90\, l / \min$$

Flow entering Cylinder C2 $q_{V,c2m} = q_{V,p} - q_{V,c1p}$ (pumps output flow minus flow to Cylinder S1)

$$q_{V,c2m} = V_{g,p} \cdot n_p \cdot \eta_{v,p} - q_{V,c1p} = 1{,}39 \cdot 10^{-4} m^3 / s = 8{,}35\, l / \min$$

Resulting Cylinder C2 velocity

$$v_{c2} = \frac{4 \cdot q_{V,c2m}}{\pi\left(d_{c2}{}^2 - d_{cr2}{}^2\right)} = 0{,}09 m / s$$

SOLUTION 10

Initial values

Motors:

$V_{g,m1} = 1000 cm^3 / r$

$\eta_{hm,m1} = 0,85$

$\eta_{v,m1} = 0,90$ Leakage totally internal

$T_{m1} = 1500 Nm$

$V_{g,m2} = 1000 cm^3 / r$

$\eta_{hm,m2} = 0,85$

$\eta_{v,m2} = 0,90$ Leakage totally external

$T_{m2} = 700 Nm$

$V_{g,m3} = 500 cm^3 / r$

$\eta_{hm,m3} = 0,85$

$\eta_{v,m3} = 0,90$ Leakage totally internal

$T_{m3} = 300 Nm$

Pump:

$q_{V,p} = 8 l / \mathrm{min}$

Additional:

$d_t = 0,5 mm$

$C_q = 0,7$

$\rho = 860 kg / m^3$

Cracking pressure of pressure relief valve:

Required pressure differencies across motors:

$$\Delta p_m = \frac{2 \cdot \pi \cdot T_m}{V_{g,m} \cdot \eta_{hm,m}}$$

Motor 1:

$$\Delta p_{m1} = \frac{2 \cdot \pi \cdot T_{m1}}{V_{g,m1} \cdot \eta_{hm,m1}} \approx 110,9 bar$$

Motor 2:

$$\Delta p_{m2} = \frac{2 \cdot \pi \cdot T_{m2}}{V_{g,m2} \cdot \eta_{hm,m2}} \approx 51{,}7 bar$$

Motor 3:

$$\Delta p_{m3} = \frac{2 \cdot \pi \cdot T_{m3}}{V_{g,m3} \cdot \eta_{hm,m3}} \approx 44{,}4 bar$$

Cracking pressure of pressure relief valve:

$$p_{PRV} = \Delta p_{m1} + \Delta p_{m2} + \Delta p_{m3} \approx 207 bar$$

Rotational speed of motors:

Part of the flow rate is diverted to tank before entering motors 2 and 3, so the flow through them is lesser than through motor 1. Let us calculate the flow through the bypass route (through the throttle valve):

Pressure difference across the throttle:

$$\Delta p_t = \Delta p_{m3} + \Delta p_{m2}$$

Flow through the throttle:

$$q_{V,t} = C_q \cdot A_t \sqrt{\frac{2 \cdot \Delta p_t}{\rho}} = 0{,}7 \cdot \frac{\pi \cdot (0{,}0005m)^2}{4} \sqrt{\frac{2 \cdot 96{,}1 \cdot 10^5 Pa}{860 kg/m^3}} \approx 1{,}23 l/\min$$

Rotational speeds of motors:

$$n_m = \left(\frac{q_{V,m}}{V_{g,m}} \right) \cdot \eta_{v,m}$$

- Motor 1 receives the total pump flow

$$n_{m1} = \left(\frac{q_{V,p}}{V_{g,m1}} \right) \cdot \eta_{v,m1} = \left(\frac{\frac{8}{60000}}{0{,}001} \right) r/s \cdot 0{,}9 = 0{,}12 r/s = 7{,}2 r/\min$$

- Motor 2 receives pump flow – throttle flow

$$n_{m2} = \left(\frac{q_{V,p} - q_{V,t}}{V_{g,m2}} \right) \cdot \eta_{v,m2} = 6{,}09 r/\min$$

- Motor 3 receives pump flow - throttle flow – external leakage of motor 2

$$n_{m3} = \left(\frac{q_{V,m3}}{V_{g,m3}}\right) \cdot \eta_{v,m3} = 10{,}96 \text{ r/min}$$

OR

$$n_{m3} = \left(\frac{q_{V,P} - q_{V,t} - (1 - \eta_{v,m2})(q_{V,P} - q_{V,t})}{V_{g,m3}}\right) \cdot \eta_{v,m3}$$