SOLUTION 4

The required output power of the hydraulic motor

$$P_{\mathrm{m}} = T_2 \cdot \omega_2 = T_2 \cdot 2 \cdot \pi \cdot n_2 = 300\,\mathrm{Nm} \cdot 2 \cdot \pi \cdot 400/60\mathrm{s} = 12.6\,\mathrm{kW}$$

Due to losses, the input power to the motor has to be larger than the output power. From the input power, flow requirement can be calculated.

$$P_{\mathrm{m,hydr}} = \frac{P_{\mathrm{m}}}{\eta_{t2}} = \frac{12.6\,\mathrm{kW}}{0.83} = 15.1\,\mathrm{kW}$$

$$P_{\mathrm{m,hydr}} = \Delta p \cdot q_{\mathrm{v,m}}$$

$$\Rightarrow \quad q_{\mathrm{V,m}} = \frac{P_{\mathrm{m,hydr}}}{\Delta p} = \frac{15.1\mathrm{kW}}{14 \cdot 10^6\ \mathrm{Pa}} = 1.08 \cdot 10^{-3}\ \mathrm{m}^3/\mathrm{s} \quad (= 64.9\,\mathrm{l/min})$$

With non-ideal pump, its output flow is lesser than with ideal one; which is expressed with volumetric efficiency factor η_{V}.

$$q_{\mathrm{V,p}} = \eta_{\mathrm{V}} \cdot V_{\mathrm{g}} \cdot n_1 = \eta_{\mathrm{V}} \cdot V_{\mathrm{rad}} \cdot \omega_1$$

The inlet flow to the hydraulic motor is equal to pump's outlet flow

$$q_{\mathrm{V,p}} = q_{\mathrm{V,m}}$$

$$\Rightarrow \quad V_{\mathrm{g}} = \frac{q_{\mathrm{V,p}}}{\eta_{\mathrm{V}} \cdot n_1} = \frac{1.08 \cdot 10^{-3}\ \mathrm{m}^3/\mathrm{s}}{0.95 \cdot 1000/60\mathrm{s}} = 68.3 \cdot 10^{-6}\ \frac{\mathrm{m}^3}{\mathrm{r}} = 68.3 \frac{\mathrm{cm}^3}{\mathrm{r}}$$

Pump's hydraulic power (outlet power)

$$P_1 = q_{\mathrm{V,p}} \cdot \Delta p = 1.08 \cdot 10^{-3} \cdot 14 \cdot 10^6 = 15\,\mathrm{kW}$$

Which can be seen being equal to (calculated above) motors inlet power (Pipes assumed to be lossless)

Pumps mechanical inlet power (electric motors output power)

$$P_{\mathrm{pm}} = \frac{P_{\mathrm{m,hydr}}}{\eta_{t1}} = \frac{15.1\mathrm{kW}}{0.82} = 18.4\,\mathrm{kW}$$

SOLUTION 5

a) Flow requirement to cylinder $q_{V,s}$

$$q_{V,s} = \frac{v \cdot A_1}{\eta_{v,s}} = \frac{0.02 \cdot 20 \cdot 10^{-4}}{1} = 40 \cdot 10^{-6}\ \frac{\mathrm{m}^3}{\mathrm{s}}$$

Flow produced by pump $q_{V,p}$.

$$q_{V,p} = \varepsilon \cdot \omega \cdot V_{rad,max} \cdot \eta_{v,p} \Rightarrow \varepsilon = \frac{q_{V,p}}{\omega \cdot V_{rad,max} \cdot \eta_{v,p}}$$

Flows have to be equal $q_{V,p} = q_{V,s}$ (assuming that the pressure relief valve remains closed).

$$\Rightarrow \varepsilon = \frac{q_{V,s}}{\omega \cdot V_{rad,max} \cdot \eta_{v,p}} = \frac{40 \cdot 10^{-6}}{1460 \cdot \frac{2\pi}{60} \cdot 0.6 \cdot 10^{-6} \cdot 0.87} = 0.5$$

Pumps displacement has to be set to 50% of its maximum value.

b) Let's calculate the pressure in the piston side chamber of cylinder while assuming the pressure in rod side chamber being zero.

$$p_P = \frac{F}{A_1 \cdot \eta_{hm,s}} = \frac{18600}{20 \cdot 10^{-4} \cdot 0.93} = 10\ \mathrm{MPa}$$

Calculating the driving torque of the pump T_P

$$T_P = p_P \cdot \frac{\varepsilon \cdot V_{rad,max}}{\eta_{hm,p}} = 10 \cdot 10^6 \cdot \frac{0.5 \cdot 0.6 \cdot 10^{-6}}{0.94} = 3.2\mathrm{Nm}$$

The power required to drive the pump P_{in}

$$P_{in} = T_P \cdot \omega = 3.2 \cdot 1460 \cdot \frac{2\pi}{60} = 489\ \mathrm{W}$$

Mechanical output power of cylinder P_{out}

$$P_{out} = F \cdot v = 18600 \cdot 0.02 = 372\ \mathrm{W}$$

Overall system efficiency η_t

$$\eta_t = \frac{P_{out}}{P_{in}} = \frac{372}{489} = 0.76$$

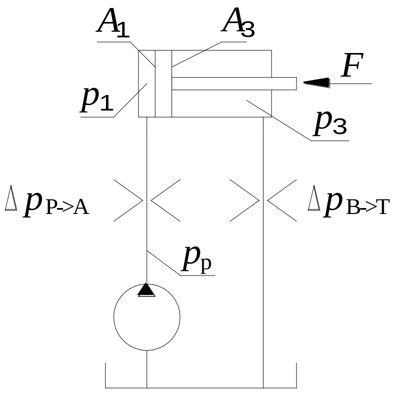
SOLUTION 6

a) Magnet a is energized

$$\left.\begin{aligned} q_{V3} &= v \cdot A_3 \\ q_{V,p} &= v \cdot A_1 \end{aligned}\right. \Rightarrow q_{V3} = \frac{q_{V,p} \cdot A_3}{A_1} = \frac{42\,\mathrm{l/min} \cdot 25\,\mathrm{cm}^2}{31.2\,\mathrm{cm}^2} = 33.7\,\mathrm{l/min}$$

The pressure losses in both control edges (from chart)

$$q_{V3} = 33.7\,\mathrm{l/min} \Rightarrow \Delta p_{B\to T} \approx 4\,\mathrm{bar}$$
$$q_{V,p} = 42\,\mathrm{l/min} \Rightarrow \Delta p_{P\to A} \approx 8\,\mathrm{bar}$$



Resolving p_1 (from force balance equation)

$$p_1 \cdot A_1 - p_3 \cdot A_3 = F$$
$$p_1 = \frac{p_3 \cdot A_3 + F}{A_1}$$
$$p_1 = \frac{30\mathrm{kN} + 4 \cdot 10^5\,\mathrm{N/m^2} \cdot 25 \cdot 10^{-4}\,\mathrm{m^2}}{31.2 \cdot 10^{-4}\,\mathrm{m^2}} = 9.9\,\mathrm{MPa}$$

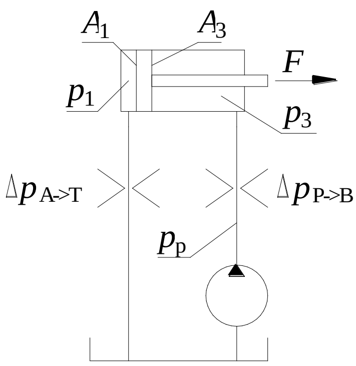
$$p_p = p_1 + \Delta p_{P\to A} = 9.9\,\mathrm{MPa} + 0.8\,\mathrm{MPa} = 10.7\,\mathrm{MPa}$$

b)

$$\left.\begin{aligned} q_{V,p} &= v \cdot A_3 \\ q_{V1} &= v \cdot A_1 \end{aligned}\right. \Rightarrow q_{V1} = \frac{q_{V,p} \cdot A_1}{A_3} = \frac{42\,\mathrm{l/min} \cdot 31.2\,\mathrm{cm}^2}{25\,\mathrm{cm}^2} = 52.4\,\mathrm{l/min}$$

The pressure losses (from chart)

$$q_{V1} = 52.4\,\mathrm{l/min} \Rightarrow \Delta p_{A\to T} \approx 10\,\mathrm{bar}$$
$$q_{V,p} = 42\,\mathrm{l/min} \Rightarrow \Delta p_{P\to B} \approx 8\,\mathrm{bar}$$



Resolving p_3 (from force balance equation)

$$p_3 = \frac{F + p_1 \cdot A_1}{A_3}$$
$$p_3 = \frac{30\mathrm{kN} + 10 \cdot 10^5\,\mathrm{N/m^2} \cdot 31.2 \cdot 10^{-4}\,\mathrm{m^2}}{25 \cdot 10^{-4}\,\mathrm{m^2}} = 13.2\,\mathrm{MPa}$$

$$p_p = p_3 + \Delta p_{P\to B} = 13.2\,\mathrm{MPa} + 0.8\,\mathrm{MPa} = 14\,\mathrm{MPa}$$

Additional information 1:

Should all the losses in the transfer line be included, one method for solving the pumps output ports pressure would is to:

Solve volume flows in pipes

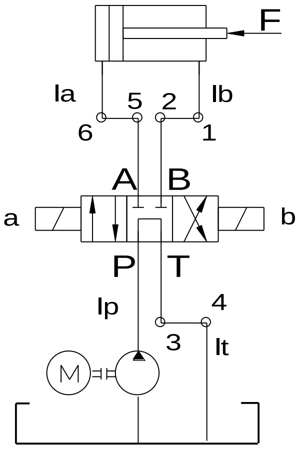
↓

Find out the (inside) diameters of pipes

↓

Calculate the flow velocities in the pipes

↓



Find out loss coefficients of pipe bendings (see literature)

↓

$$\Delta p_{\text{bend}} = \xi_{90°} \cdot \frac{\rho \cdot v^2}{2}$$

↓

Calculate losses in each bending

↓

Calculate *Re* at each pipe

↓

Find out the surface roughness of the pipes

↓

Find out friction factor λ , e.g. Moody's chart

↓

$$\Delta p_{\text{pipe}} = \lambda \cdot \frac{l}{d} \cdot \frac{\rho \cdot v^2}{2}$$

↓

Calculate pressure loss at each pipe

↓

Sum the pressure losses starting from tank and return line and ending to the rod side chamber of the cylinder

↓

$$\Delta p_{\text{lT}} + \Delta p_{\text{bends3,4}} + \Delta p_{\text{B}\to\text{T}} + \Delta p_{\text{lB}} + \Delta p_{\text{bends1,2}}$$

↓

Resolve the pressure in the piston side chamber of the cylinder by using the force equilibrium equation of the cylinder

↓

To this value add the remaining pressure losses between the piston side chamber and pump output port (pipe bendings, valve, pipes)

↓

$$\Delta p_{\text{lA}} + \Delta p_{\text{bends5,6}} + \Delta p_{\text{P}\to\text{A}} + \Delta p_{\text{lP}}$$

↓

The pressure at the pump outlet port p_p is resolved!

Additional information 2:

Sometimes flow loss curves are not given, but only a flow rate value with a given pressure loss. In such cases, the losses with any other given flow rate can be estimated as in the following example.

EXAMPLE ASSIGNMENT

Let's assume that pressure loss-curves are not available. The pressure loss (P→B) with flow of q_V = 40 l/min is known to be Δp = 4 bar. Calculate the pressure loss, when the flow is q_V = 30 l/min and the opening of the valve (and therefore the flow cross section area) remains constant.

SOLUTION

Flow through a turbulent choke (as in the case of a flow control valve) is

$$q_V = C_q \cdot A \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

where

$C_q =$ flow coefficient (depends on flow velocity and of the geometry of the choke orifice)

$A = \pi \cdot d \cdot h$

$h =$ opening of the slide

$d =$ diameter of the slide

$\Delta p =$ pressure difference over a control edge

$\rho =$ density of the fluid

Using previous

$$\frac{q_{V1}}{q_{V2}} = \frac{C_q \cdot A_1 \cdot \sqrt{\frac{2 \cdot \Delta p_1}{\rho}}}{C_q \cdot A_2 \cdot \sqrt{\frac{2 \cdot \Delta p_2}{\rho}}} = \frac{\sqrt{\Delta p_1}}{\sqrt{\Delta p_2}} \quad \text{when } A_1 = A_2 \text{ ja } \rho = \text{constant}$$

$$\Rightarrow \quad \Delta p_2 = \Delta p_1 \cdot \left(\frac{q_{V2}}{q_{V1}}\right)^2 = 4\,\text{bar} \cdot \left(\frac{30\,\text{l/min}}{40\,\text{l/min}}\right)^2 = 2.25\,\text{bar}$$

This derived equation can be found in the equation collection-document.