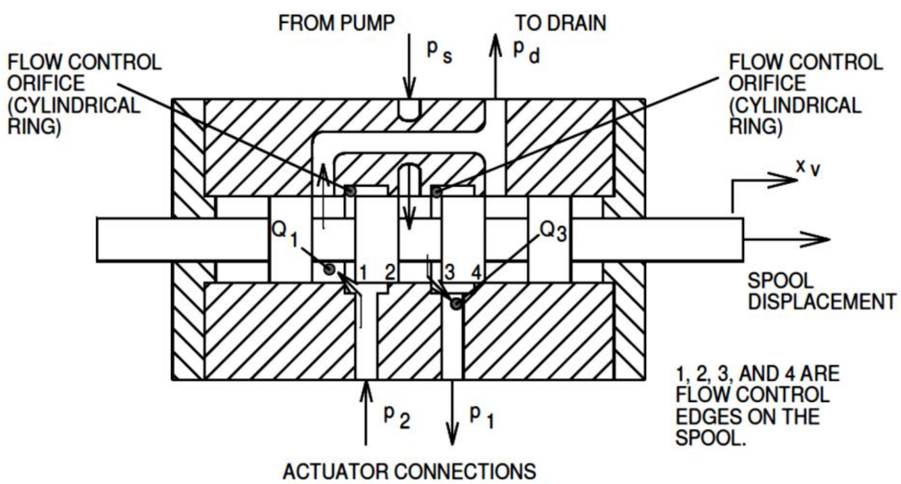
LECTURE 15 TO 17– DIRECTION CONTROL VAVLES

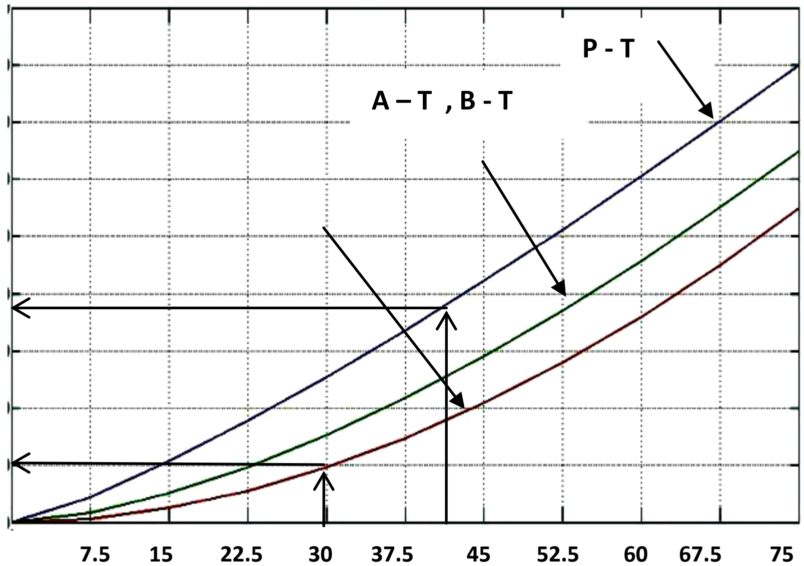
SELF EVALUATION QUESTIONS AND ANSWERS

1. A spool valve is controlling an ideal motor. The system characteristics are given in the following table. Calculate the following (a) Load pressure (b) Load flow (c) Power delivered by the motor (d) Motor displacement

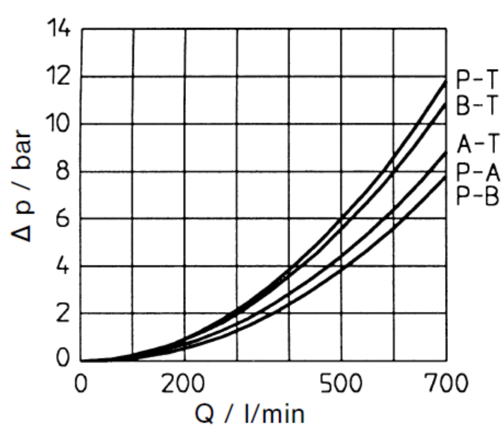


Parameters	Value
Orifice discharge constant (C_d)	0.62
Valve area gradient (w)	0.01 m
Valve opening (x_v)	0.25mm
Supply side pressure (p_s)	20 MPa
Drain side pressure (p_d)	0
Upstream pressure to motor(p_1)	12 MPa
Fluid density	855 $\frac{kg}{m^3}$
Motor speed (n)	1000 RPM

2. A cylinder with bore diameter of 8 cm and a rod diameter of 4 cm is to be used in a system with a 30 LPM pump. Use the graph in the figure to determine the pressure drops across the DCV when the cylinder is retracting (P->B,A->T).



3. A cylinder with bore diameter of 10 cm and a rod diameter of 6 cm is to be used in a system with a 200 LPM pump. Use the graph in the figure to determine the pressure drops across the DCV when the cylinder is retracting (P->B,A->T).



Q1 Solution

First calculate certain properties associated with the initial conditions. Calculate the load pressure. The valve was indicated to be ideal with no leakage and the motor is also ideal. Thus:

$$\mathrm{p_2 = p_s - p_1 = 20 \text{ x } 10^6 - 12 \text{ x } 10^6 = 8x10^6 \text{ Pa} = 8 \text{ MPa}}$$

So the load pressure can be determined:

$$\mathrm{p_L = p_1 - p_2 = 12 \text{ x } 10^6 - 8 \text{ x } 10^6 = 4x10^6 \text{ Pa} = 4MPa}$$

Calculate the initial load flow:

$$\mathrm{Q_L = C_d w x_v \sqrt{\frac{(p_s - p_L)}{\rho}}}$$

$$= 0.62 \text{ x } 0.01 \text{ x } 0.25 \text{ x } 10^{-3} \sqrt{\frac{(20x\,10^6 - 4\,x\,10^6)}{855}}$$

$$= 0.212x10^{-3} m^3 /s$$

Now we shall evaluate $\mathrm{K_q}$ $\mathrm{K_c}$ and $\mathrm{K_p}$ at initial operating point. The flow gain coefficent, $\mathrm{K_q}$

$$\mathrm{K_q} = C_d w \sqrt{\frac{(p_s - p_L)}{\rho}}$$

$$= 0.62 \text{ x } 0.01 \sqrt{\frac{(20\text{x } 10^6 - 4 \text{ x } 10^6)}{855}}$$

$$= 0.8481 \;\; m^2 \;/s$$

The flow pressure coefficeint , $\mathrm{K_c}$

$$\mathrm{K_c} \;\; = \;\; \mathrm{K_q} \; \frac{x_v}{2(p_s - p_L)}$$

$$= 0.8481 \; \frac{0.25x10^{-3}}{2(20\text{x } 10^6 - 4 \text{ x } 10^6)}$$

$$= 6.626 \; x10^{-12}\mathrm{m^3/s \,.\, Pa}$$

The pressure sensitivity coefficeint ,

$$\mathrm{K_p} = \frac{K_q}{K_c} = \frac{0.8481}{6.626 \; x \; 10^{-12}} = 0.128x10^{12} \; Pa/m$$

Calculate the power delivered by the motor

$$P = \mathrm{p_L Q_L} = 4\text{x } 10^6\text{x } 0.212 \text{ x } 10^{-3} = 848.1 \text{ watts}$$

Calcute the motor shaft speed , ω:

$$\omega: \frac{2\pi n}{60} = \frac{2x\pi x1000}{60} = 104.7\ rad/s$$

Calculate the power coefficeint $K_{pwr} = \frac{P}{\omega^2} = \frac{848.1}{104.7^2} = 77.34 \text{ x } 10^{-3} W/rad^2$

Calculate th motor displacement D_m

$$D_m = \frac{Q_L}{\omega} = \frac{0.212x10^{-3}}{104.7^2} = 2.025x10^{-6}m^{-3}/rad$$

Now we shall develop a relationship that will allow the calculation of load pressure p_L, when the load follows $P = K_{pwr}\omega^2 = K_{pwr}\left(\frac{Q_L}{D_m}\right)^2$

Which leads to an expression for Q_L

$$Q_L = \left(\frac{{D_m}^2}{K_{pwr}}\right) p_L$$

Noting that Q_L may also be expressed as

$$Q_L = w x_v C_d \sqrt{\frac{(p_s - p_L)}{\rho}}$$

Thus Q_L can be eliminated leaving

$$Q_L = \left(\frac{{D_m}^2}{K_{pwr}}\right) p_L = w x_v C_d \sqrt{\frac{(p_s - p_L)}{\rho}}$$

This expression can be rearranged as a quadratic equation to calucalte $\mathrm{p_L}$

$$\mathrm{p_L^2} + \left(\frac{w x_{\mathrm{v}} C_d \mathrm{K_{pwr}}}{\mathrm{D_m}^2}\right)\frac{1}{\rho}p_L - \left(\frac{w x_{\mathrm{v}} C_d \mathrm{K_{pwr}}}{\mathrm{D_m}^2}\right)\frac{1}{\rho}p_s = 0$$

Let

$$\mathrm{C} = \left(\frac{w x_{\mathrm{v}} C_d \mathrm{K_{pwr}}}{\mathrm{D_m}^2}\right)^2 \frac{1}{\rho}$$

For the new operating condition where

$$x_{\mathrm{v}} = 1.05 x_{\mathrm{v}} = 1.05x0.25x10^{-3} = 0.2625x10^{-3}\ m$$

$$\mathrm{C} = \left(\frac{0.62x\ 0.01x0.2625x10^{-3}x\ 77.34x10^{-3}}{(2.025x10^{-6})^2}\right)^2 \frac{1}{855} = 1.103x10^6$$

Now solve the quadratic in $\mathrm{p_L}$:

$$\mathrm{p_L}^2 + C\ \mathrm{p_L} - C\mathrm{p_s} = 0$$

Only the positive root has meaning in this context, so substituting C= $11.103x10^6$

$$\mathrm{p_L} = \frac{-1.103\mathrm{x}10^6 \pm \sqrt{(1.103\mathrm{x}10^6)^2 + 4\mathrm{x}1.103\mathrm{x}10^6\mathrm{x}\ 20\mathrm{x}10^6}}{2} = 4.177\mathrm{x}10^6\ \mathrm{Pa} = 4.177\ \mathrm{MPa}$$

Calcute the load flow, $\mathrm{Q_L}$ under the new conditions:

$$Q_L = w x_v C_d \sqrt{\frac{(p_s - p_L)}{\rho}} = 0.62x0.01x\ 0.2625x10^{-3}\sqrt{\frac{(20x\ 10^6 - 4.177\ x\ 10^6)}{855}} = 0.2214x\ 10^{-3} m^3/s$$

Now caluclate ω and verify that the predicted p_L is correct by calculating the power under the new conditons in two separate ways:

$$\omega = \frac{Q_L}{D_m} = \frac{0.2214x10^{-3}}{2.025\ x\ 10^{-6}} = 109.4\ rad/s$$

calculate the power from

$$P = p_L Q_L = 4.177x\ 10^6 x\ 0.221\ x\ 10^{-3} = 924.8\ \text{watts}$$

and from:

$$P = K_{pwr}\omega^2 = K_{pwr}\left(\frac{Q_L}{D_m}\right)^2 = 77.34\ x10^{-3} x\ 109.4^2 = 924.8\ \text{watts}$$

Both the power expressions yield the same result. Calculate the increment in valve opening

$$\Delta x_v = 0.05x0.25x10^{-3} = 0.0125x10^{-3} m$$

Now calculate the approximate value of the load flow, Q_L, using K_q from the linearisation appraoch:

$$Q_L \approx Q_L(\text{old}) + \Delta x_v K_q = 0.2120x10^{-3} + 0.0125x10^{-3} x\ 0.8481 = 0.2214x10^{-3} m^3/s$$

and the approximate value of the load pressure $\mathrm{p_L}$, using K_q

$$\mathrm{p_L} \approx \mathrm{p_L(old)} + \Delta x_v K_\mathrm{p} = 4x10^6 + 0.0125x0.128\,x10^{12} = 5.6x10^6\ \mathrm{Pa}$$

Q2 Solution:

The flow from P to B is the pump flow into the rod end, so this can be read from the graph

Δp =1.5 bar (approx.)

The flow from A->T is the return flow out of the blind end. This flow rate is greater than the pump flow and must be determined by the following method

a. Calculate the piston area

$$A_{p=}\,\frac{\pi}{4}\left({D_P}^2\right) = \frac{\pi}{4}(8^2) = 50.264cm^2$$

b. Calculate the rod area

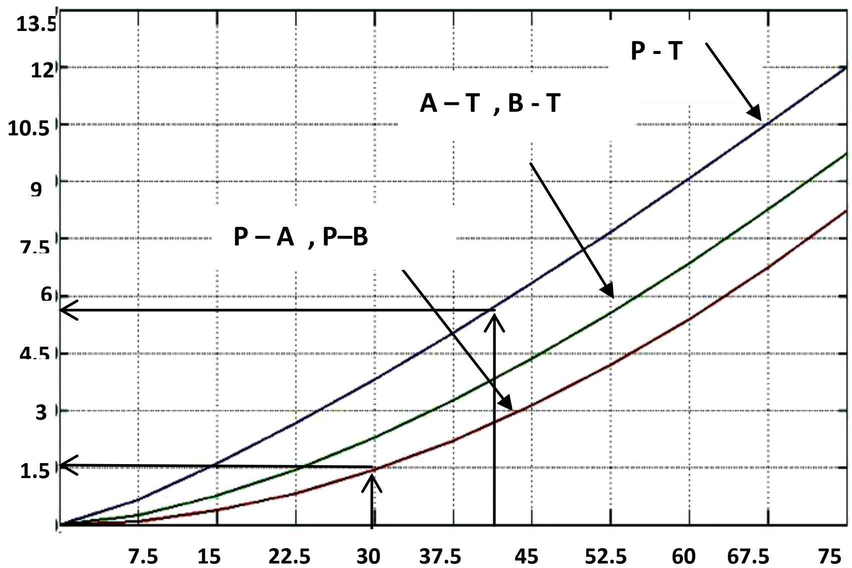
$$A_R = \frac{\pi}{4}\left({D_R}^2\right) = \frac{\pi}{4}(4^2) = 12.566cm^2$$

c. Calculate the return flow

$$Q_{return,R} = \frac{Q_{pump}}{A_p - A_R} x\,A_p = \frac{Q_{pump}}{50.264 - 12.566} x50.264 = 1.33x30 = 40\ LPM$$

The flow from A to T can now be read from the graph

Δp =5.8 (approx.)



Q3 Solution:

The flow from P to B is the pump flow into the rod end, so this can be read from the graph

Δp =1.5 bar (approx.)

The flow from A->T is the return flow out of the blind end. This flow rate is greater than the pump flow and must be determined by the following method

a. Calculate the piston area

$$A_{p=}\frac{\pi}{4}\left({D_P}^2\right)=\frac{\pi}{4}(10^2)=78.73cm^2$$

b. Calculate the rod area

$$A_R=\frac{\pi}{4}\left({D_R}^2\right)=\frac{\pi}{4}(6^2)=28.3cm^2$$

c. Calculate the return flow

$$Q_{return,R}=\frac{Q_{pump}}{A_p-A_R}x\,A_p=\frac{Q_{pump}}{78.73-28.3}x78.73=1.576\times 200=315.36\,LPM$$

The flow from A to T can now be read from the graph Δp =1.9 bar (approx.)