LECTURE 21

FLOW AND FORCE ANALYSIS OF VALVES

FREQUENTLY ASKED QUESTIONS

1. Discuss in detail the flow displacement relationship of the critical centre spool valves, giving their possible applications in the hydraulic control valves.

Critical Centre Valve

In critical centre valves, the land of the spool are exactly the same width as the annual ports of the valve body in the central or null position the lands exactly cover the ports. (Figure 16.1)

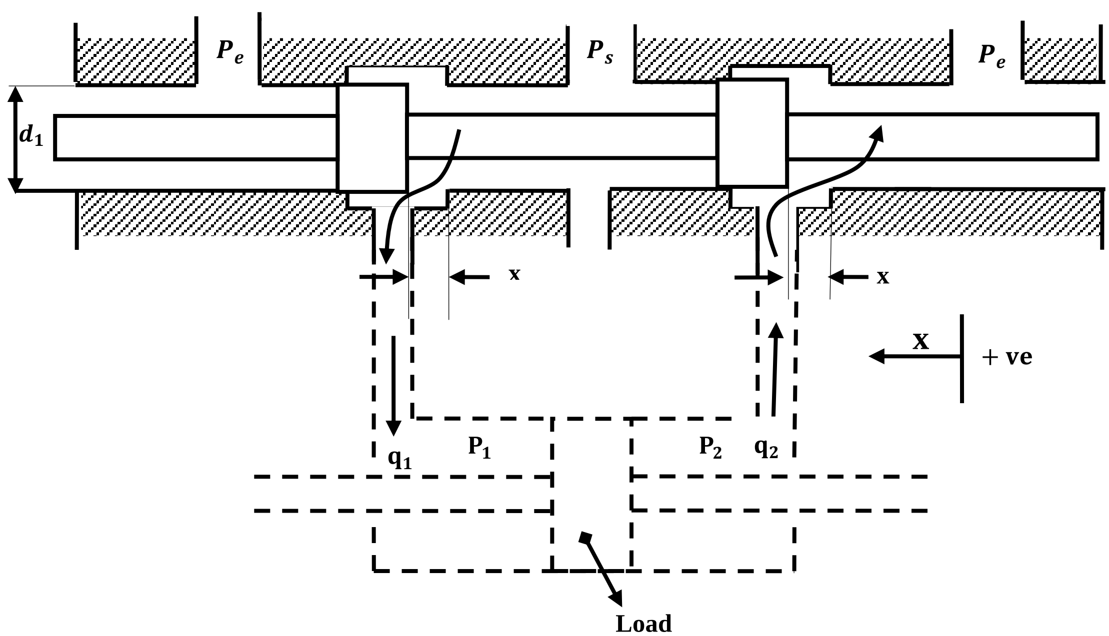


Figure 15.1 Four way valve

Flow rate prediction

Flow through sharp edged orifices is predicted by applying the ‘square root law’.

Treating the annular orifices formed within the valve in this way gives

$$q_1 = C_d \pi d_1 x (P_s - P_1)^{1/2} (2/\rho)^{1/2}$$

$$q_2 = C_d \pi d_1 x (P_2 - P_e)^{1/2} (2/\rho)^{1/2}$$

The above equations can be simplified by making certain assumptions or approximations to the actual situation with real valves.

Let q_1=q_2 , $P_s - P_1$=$P_2 - P_e$

Supply pressure , P_s is a constant and P_e is negligible.

By introducing the term P_m=$P_1 - P_2$, we have $s - P_m$= $2P_2$ and P_s+P_m=$2P_1$

Then the equation can be written

$q = C_d \pi d_1 x (P_s - P_m)^{1/2} (1/\rho)^{1/2}$ (=q_1=q_2)

When

C_d =5/8 and ρ =870 Kg/m^3

$q = 6.7\pi d_1 x (P_s - P_m)^{1/2}$

Using binomial approximation,

$(P_s - P_m)^{\frac{1}{2}}$=$P_s^{1/2}$(1-$P_m/2P_s$)

Equation becomes,

$q = 6.7\pi d_1 x P_s^{1/2} - 6.7\pi d_1 x P_s^{1/2} P_m/2P_s$)

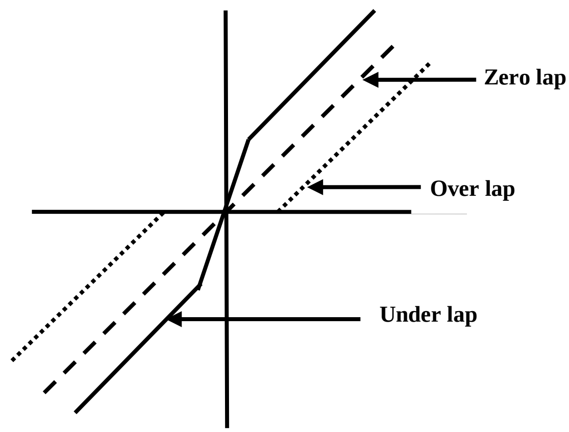
Then $K_{q=}6.7\pi d_1 P_s^{1/2}$

$K_{c=}6.7\pi d_1 x P_s^{1/2}/2P_s$

The above analysis predicts that the flow gain K_q can be treated as constant for a particular valve and supply pressure but the pressure flow coefficient K_c will vary with valve opening x. the variation of K_c are of minor significance for linear analysis.

In reality, spool lands will never exactly match the annular ports in valve body. Actual test results with a constant pressure drop across the valve ports would show variations, particularly near the central or null position of the spool as those illustrated in the Figure 15.3

The flow gainK_q is the slope of the approximate line in Figure. Which can double its valve near null with negative lap. The magnitude of K_q is most important parameter of a valve and often also of any system incorporating the valve.



Flow rates versus valve displacement for constant pressure drop

2. Discuss in detail the flow forces acting on :Pressure compensated flow control valveForces

The steady state balance of forces for some equilibrium operating position with the poppet stationary and open distancex_0, for a supply pressure P_s outlet pressure P_{Lo} and consequent chamber pressure P_{co} is given by

$(P_{co} - P_{Lo})\, A_p = F - \lambda\, (P_s + - P_{Co}+)x_o$--------------(3)

Under dynamic conditions with the spool in motion for outlet pressure $P_{L0} + P_L$, with the instantaneous spool position distance x to the left of its initial position, noting that $P_{C0} + P_C$ is the instantaneous chamber pressure, the balance of forces is given by

$\{(P_{co} + P_c) - (P_{Lo} + P_L\}\, A_p = F - k_s x - \lambda\, \{P_s - (P_{Co} + + P_C)\}(x + x_o) - f\, Dx - mD^2x$------------(4)

Assuming P_C, P_L, and x are small and terms $P_C x$ may be neglected, then (4)-(3) gives

$- P_C = \frac{k_s + \lambda\,(P_s - P_{Co})}{Ap - \lambda x_o}\, x + \frac{f}{Ap - \lambda x_o}\, Dx + \frac{m}{Ap - \lambda x_o}\, D^2x - \frac{Ap}{Ap - \lambda x_o}\, P_L$ ------------------(

3. Derive an expression for the flow displacement relations of the under lapped four way valve.

Open centre type (under lapped four way valve)

A valve in which the land of the spool never completely covers the ports of the valve body is said to be under lapped. (Figure 16.2)

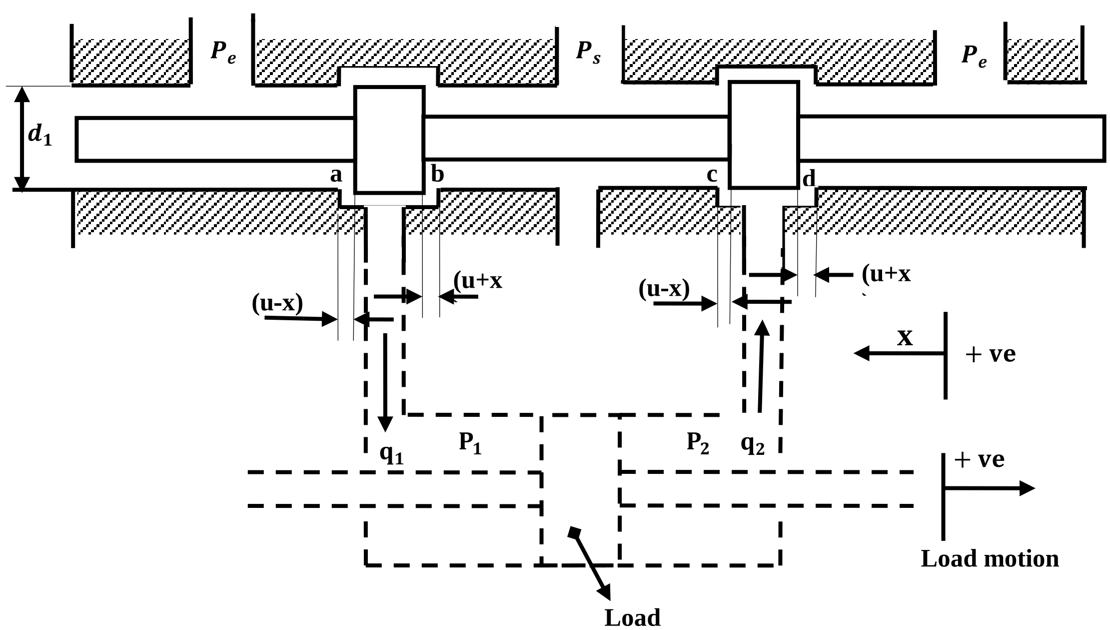


Figure 15.2 Open centre –four way valve

Referring to the figure 15.2 ,a displacement of x unbalances the symmetry of the ports. Two of the annular orifices increase in width from u to u+x and two decrease from u to u-x.

The flow rates is estimated as follows

$$q_1 = C_d\pi d_1(u + x)(P_s - P_1)^{\frac{1}{2}}\left(\frac{2}{\rho}\right)^{\frac{1}{2}} - C_d\pi d_1(u - x)(P_1 - P_e)^{\frac{1}{2}}\left(\frac{2}{\rho}\right)^{\frac{1}{2}}$$

$$q_2 = C_d\pi d_1(u + x)(P_2 - P_e)^{\frac{1}{2}}\left(\frac{2}{\rho}\right)^{\frac{1}{2}} - C_d\pi d_1(u - x)(P_s - P_2)^{\frac{1}{2}}\left(\frac{2}{\rho}\right)^{\frac{1}{2}}$$

Assuming $q_1 = q_2$ and P_s remains constant and $P_e = 0$, sothat $P_s = P_1 + P_2$ and writing

$P_m = P_1 - P_2$, we obtain

$$q = C_d\pi d_1\{(u + x)(P_s - P_m)^{\frac{1}{2}} - (u - x)(P_s + P_m)^{\frac{1}{2}}\}\left(\frac{1}{\rho}\right)^{\frac{1}{2}}$$

Which may be approximated as

$$q = C_d\pi d_1\left(\frac{1}{\rho}\right)^{\frac{1}{2}} P_s^{\frac{1}{2}}2x - C_d\pi d_1 u\left(\frac{1}{\rho}\right)^{\frac{1}{2}} P_s^{\frac{1}{2}}P_m/P_s$$

$$K_{q=}13.4\pi d_1 P_s^{1/2}$$

$K_{c=}6.7\pi d_1 x P_s^{1/2}/P_s$

4. Derive an expression for the flow for a flapper nozzle valve.

We assume the valve has a balanced condition such that x=0 and p_m=0 when q=0.

That is q_1 (steady state) = q_3 (steady state) = $C_{d_0}A_0(P_s - P_s/2)^{1/2}(2/\rho)^{1/2}$

q_2(steady state) = q_4 (steady state) =$C_{d_n}\pi d_n x_0(P_s/2)^{1/2}(2/\rho)^{1/2}$

And $q_1 = q_2 = q_3 = q_4$

Which also implies that the orifice size and the curtain area in the null position are approximately equal.

$C_{d_0}A_0$=$C_{d_n}\pi d_n x_0$

Implies d_n=8x_0

Consider the valve is not in balance, that is x has some value as does P_m , we have

$q = q_1 - q_2$

$= K_n\{P_s - (P_s/2 + P_m/2)\}^{1/2} - K_n((x_0 - x)/x_0)(P_s/2 + P_m/2)\}^{1/2}$

Where $K_n = C_{d_0} A_0 (2/\rho)^{1/2} = C_{d_n} \pi d_n x_0 (2/\rho)^{1/2}$

$q = -q_3 + q_4$

$= -K_n\{P_s - (P_s/2 - P_m/2)\}^{1/2} -+ K_n((x_0 + x)/x_0)(P_s/2 - P_m/2)\}^{1/2}$

And using binomial approximations

$q = K_n(P_s/2)^{1/2}(1 - P_m/2P_s) - K_n(P_s/2)^{1/2}(1 + P_m/2P_s) + K_n(P_s/2)^{1/2}((x_0 + x)/x_0)(P_s/2 + P_m/2)$

$q = -K_n(P_s/2)^{1/2}(1 + P_m/2P_s) + K_n(P_s/2)^{1/2}(1 - P_m/2P_s) + K_n(P_s/2)^{1/2}((x_0 + x)/x_0)(P_s/2 - P_m/2)$

adding and dividing by 2

$q = -K_n(P_s/2)^{1/2} P_m/P_s + K_n(x/x_0)(P_s/2)^{1/2}$

which is in the form of $q = K_q x - K_c P_m$

$K_q = K_n/x_0 (P_s/2)^{1/2} = C_{d_n} \pi d_n (2/\rho)^{1/2} (P_s/2)^{1/2}$

$K_c = K_n/P_s (P_s/2)^{1/2} = (C_{d_n} \pi d_n/P_s)(2/\rho)^{1/2}(P_s/2)^{1/2}$

$= (C_{d_0} A_0/P_s)(2/\rho)^{1/2}(P_s/2)^{1/2}$

5. What is the major limitation of a flapper nozzle amplifier and how you can overcome it?

The major limitation of a flapper nozzle amplifier is its limited air handling capacity. The variation of air pressure obtained cannot be used for any useful application, unless the air handling capacity is increased. An air relay serves the similar purpose as a power amplifier. It is used after the flapper nozzle amplifier to enhance the volume of air. (The situation can be compared with an operational amplifier in an electronic circuit. Though the operational amplifier is useful in amplifying small voltage signals, the output current delivered by the operational amplifier is limited and a power amplifier is used at the output stage in order to drive any device)

6. Why is feedback system used in a multi stage servo valve?

A small flapper motion creates an imbalanced pressure in one direction or the other on the ends of the spool of the second stage. Hence the spool will tend to move in response to this imbalance and allow flow to the actuator. Since continued imbalance in pressure would quickly move the spool to its limits of travel, a form of feedback connects the motion of the spool to the effective displacement of the flapper