LECTURE 22 TO 23 – PROPORTIAONAL VALVES

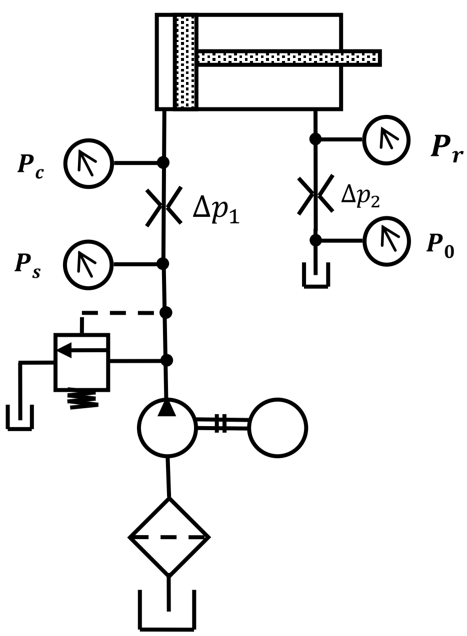
SELF EVALUATION QUESTIONS AND ANSWERS

1 Consider the hydraulic system shown in the Figure below. The cylinder ratio is 2:1, Pressure $P_s = 120$ bar, $A_c = 0.002\text{m}^2$, $A_r = 0.001\text{m}^2$, $F_f = 290$ N.

i) Find the load which will cause negative pressure at the cap end of the cylinder & corresponding pressure at the rod end & pressure drop across port P to A and port B to T

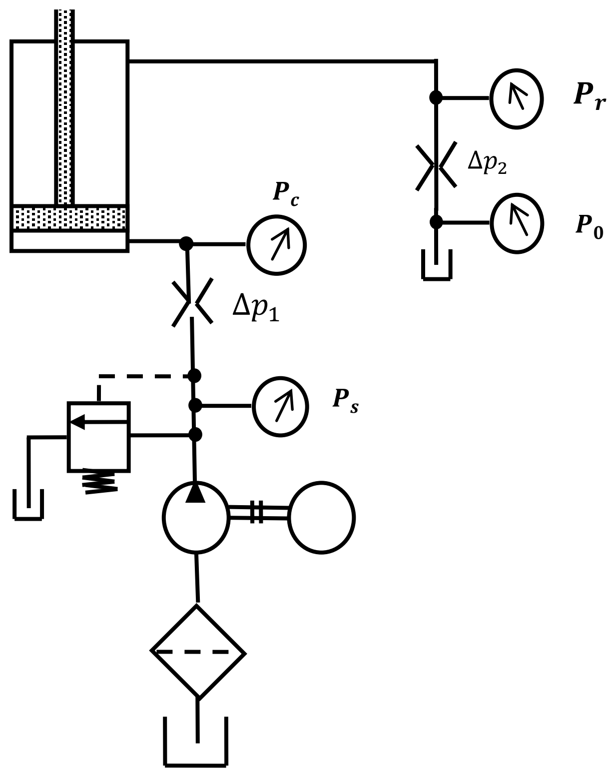
ii) If the load is 5000 N, find the pressure drop across port P to port A & corresponding pressure at the rod end. Is it possible to obtain this pressure drop valve area ratio 1:1

iv) If the valve area ratio is 2:1 what is the overrunning load. Comment on result



2: Consider the hydraulic circuit with resistive load shown in the Figure below. The cylinder ratio is 2:1, Pressure $P_s = 120$ bar, $A_c = 0.002\ m^2$, $A_r = 0.001 m^2$, $F_f = 500$ N. $F_L = 5000$ N. If the valve has 2:1 area ratio,

Determine, P_r P_c and total pressure drop



Q1 Solution

Since the cylinder area is 2:1

$$Q_2 = \frac{Q_1}{2}\, or \left[\frac{Q_1^2}{Q_2^2}\right] = 0.25$$

To find the load which causes the negative pressure on cap end set P_c=0

$$P_c = \frac{P_s\left[\frac{Q_2^2}{Q_1^2}\right] - [\,F_f - \,F_L]/A_r}{\left[\frac{A_c}{A_r}\right] + \left[\frac{Q_2^2}{Q_1^2}\right]}$$

$$0 = P_s\left[\frac{Q_1^2}{Q_2^2}\right] - [\,F_f - \,F_L]/A_r$$

$$F_L = P_s\left[\frac{Q_1^2}{Q_2^2}\right]A_r + [\,F_f]$$

$$F_L = 120 \times 10^5[0.25] \times 0.001 + [500] = 3500\ N$$

Any load greater than 3500 N will cause a negative pressure at the cap end of the cylinder. If the overrunning load is 3500 N, the pressure at the rod end is given by

$$P_r = \frac{P_c A_c - \,F_f + \,F_L}{A_r}$$

$$P_r = \frac{0 - 500 + 5000}{0.001} = 40\ bar$$

The pressure drop across the port P to port A orifice is

$$\Delta p_1 = p_s - \,p_c = 120 - 0 = 120\ bar$$

$$\Delta p_2 = p_r - \,p_o = p_r = 40\ bar$$

For any overrunning load greater than 3500N , the valve will not create enough pressure drop across the port B to port A orifice to maintain control of load. Suppose the load $F_L = 5000\ N$ then we can calculate

$$P_c = \frac{P_s\left[\frac{Q_2^2}{Q_1^2}\right] - \frac{[F_f - F_L]}{A_r}}{\left[\frac{A_c}{A_r}\right] + \left[\frac{Q_2^2}{Q_1^2}\right]} = \frac{120 \times 10^5[0.25] - \frac{[500-5000]}{0.001}}{\left[\frac{0.002}{0.001}\right] + [0.25]}$$

$$= -\frac{75 \times 10^5}{2.25} = -33.33 \times 10^5 = -33.33\ bar$$

To create P_c =-33.33bar , the pressure drop across the port P to port A orifice must be

$\Delta p_1 = p_s - p_c = 120 - (-33.33) = 153.33\ bar$, which is not possible.

The required pressure at the rod end is

$$P_r = \frac{P_c A_c - F_f + F_L}{A_r}$$

$$P_r = \frac{-33.33 \times 10^5 \times 0.002 - 500 + 5000}{0.001} = 11.23\ bar$$

Let the use the valve with the area ratio of 2:1

$$Q_1 = C_d A_1 \sqrt{\Delta p_1}$$

$$Q_2 = C_d A_2 \sqrt{\Delta p_2} = C_d \frac{A_1}{2} \sqrt{\Delta p_2}$$

Solving we get

$$\frac{Q_1^2}{4Q_2^2} = \frac{\Delta p_1}{\Delta p_2}$$

$$\Delta p_1 = \frac{Q_1^2}{4Q_2^2} \Delta p_2$$

Using in the equation

$$equation\ \Delta p_1 = p_s - p_c\ becomes$$

$$p_r = \{p_s - p_c\} \times \frac{Q_1^2}{Q_2^2}$$

Solving for the pressure at the end of the cylinder we can get

$$P_r = \frac{P_c A_c - F_f + F_L}{A_r}$$

$$p_r = \{p_s - p_c\} \times \frac{4Q_2^2}{Q_1^2}$$

$$P_c = \frac{P_s\left[\frac{4Q_2^2}{Q_1^2}\right] - \left[F_f - F_L\right]/A_r}{\left[\frac{A_c}{A_r}\right] + \left[\frac{4Q_2^2}{Q_1^2}\right]}$$

Setting $P_c = 0\ we\ get$

$$F_L = P_s A_r \left[\frac{4Q_2^2}{Q_1^2}\right] + \left[F_f\right]$$

For 2:1 area ratio $Q_2 = \frac{Q_1}{2}\ therefore \left[\frac{4Q_2^2}{Q_1^2}\right] = 1$

$$F_L = P_s A_r \left[\frac{4Q_2^2}{Q_1^2}\right] + \left[F_f\right] = 120 \times 10^5 \times 0.001 + 500 = 12500\ N$$

Therefore 2:1 area ratio valve can control the overrunning load more than 2.5 times the size load controlled with a 1:1 area ratio valve.

Now the cap end pressure can be calculated using the equation

$$P_c = \frac{P_s\left[\frac{4Q_2^2}{Q_1^2}\right] - \left[F_f - F_L\right]/A_r}{\left[\frac{A_c}{A_r}\right] + \left[\frac{4Q_2^2}{Q_1^2}\right]}$$

$$P_c = \frac{120 \times 10^5[1] - \frac{[500-5000]}{0.001}}{\left[\frac{0.002}{0.001}\right] + [1]} = \frac{165 \times 10^5}{3} = 55\ bar$$

$$P_r = \frac{P_c A_c - F_f + F_L}{A_r}$$

$$P_r = \frac{55 \times 10^5[0.002] - 500 + 5000}{0.001} = 155\ bar$$

The pressure drop across the valve is

$\Delta p_1 = p_s - p_c = 120 - (55) = 65\ bar,$

$\Delta p_2 = p_r - 0 = 155\ bar$

Total pressure drop across the valve is $65 + 155 = 220\ bar$

Q2- solution

We can write the force balance on the cylinder as

$P_c A_c = F_f + F_L + P_r A_r$

Where

$F_L = W = load\ on\ the\ cylinder\ (N)$

$F_f = frictional\ force\ (N)$

solving for P_c

$$P_c = \frac{P_r A_r + F_f + F_L}{A_r}$$

If the area ratio is unity (i.e. $A_1 = A_2 = A$) and the orifice equation becomes

$Q_1 = C_d\, A\ \sqrt{\Delta p_1}$

$Q_2 = C_d\, A\ \sqrt{\Delta p_2}$

Solving we get

$$\frac{Q_1^2}{Q_2^2} = \frac{\Delta p_1}{\Delta p_2}$$

$$\Delta p_1 = \frac{Q_1^2}{Q_2^2} \Delta p_2$$

Also $\Delta p_1 = p_s - p_c$

$$\Delta p_2 = p_r$$

Solving we get

$$p_c = \{p_s - p_r\} \times \frac{Q_1^2}{Q_2^2}$$

$$P_r = \frac{P_s - \left[F_f + F_L \right] / A_c}{\left[\frac{A_r}{A_1}\right] + \left[\frac{Q_1^2}{Q_2^2}\right]}$$

If $F_L = 5000\ N$ and other parameters as same as previous example

$$P_r = \frac{P_s - \left[F_f + F_L \right] / A_c}{\left[\frac{A_r}{A_1}\right] + \left[\frac{Q_1^2}{Q_2^2}\right]}$$

$$P_r = \frac{120 \times 10^5 - \frac{[500+5000]}{0.0020}}{\left[\frac{0.001}{0.002}\right] + [4]} = 15.41\ bar$$

Using

$$P_c = \frac{P_r A_r + F_f + F_L}{A_c}$$

$$P_c = \frac{15.41 \times 10^5 \times 0.001 + 500 + 5000}{0.002} = 38.52\ bar$$

The pressure drop across the valve is

Also $\Delta p_1 = 100 - 38.52 = 61.48\ bar$

$\Delta p_2 = p_r = 15.41\ bar$

$\Delta p_{total} = \Delta p_1 + \Delta p_2 = 61.48 + 15.41 = 76.89\ bar$

If the valve has a 2:1 area ratio.

$$\Delta p_1 = \frac{Q_1^2}{Q_2^2} \Delta p_2$$

$$P_r = \frac{P_s - \left[F_f + F_L \right] / A_c}{\left[\frac{A_r}{A_1}\right] + \left[\frac{Q_1^2}{4Q_2^2}\right]}$$

$$P_r = \frac{120 \times 10^5 - \frac{[500+5000]}{0.002}}{\left[\frac{0.001}{0.002}\right] + [1]} = 30.83\ bar$$

$$P_c = \frac{P_r A_r + F_f + F_L}{A_c}$$

$$P_c = \frac{30.83 \times 10^5 \times 0.001 + 500 + 5000}{0.002} = 42.92\ bar$$

The pressure drop across the valve

Also $\Delta p_1 = 100 - 42.92 = 77.08\ bar$

$\Delta p_2 = p_r = 30.83\ bar$

$\Delta p_{total} = \Delta p_1 + \Delta p_2 = 77.08 + 30.83 = 107.91\ bar$