Example 3.11

We are designing a hydraulic system for moving a 2,000 kg payload mass vertically. A single rod cylinder will be used, mounted above the payload. The bore diameter is 100 mm and the rod diameter is 40 mm. The desired acceleration is 1 m/s^2 upwards and the desired maximum velocity is 0.1 m/s. If the supply pressure is 7×10^6 Pa gauge and the density of the oil is 900 kg/m^3 then determine the minimum valve flow coefficient required.

Solution

The required force is:

$$F = ma + mg = (2{,}000\ kg)(1\ m/s^2) + (2{,}000\ kg)(9.81\ m/s^2) = 2.16\times10^4\ N$$

Extend side area $A_{extend} = \frac{\pi}{4} D_{bore}^2 = \frac{\pi}{4}(0.1\,m)^2 = 7.85\times10^{-3}\,m^2$

Retract side area

$$A_{retract} = \frac{\pi}{4}(D_{bore}^2 - D_{rod}^2) = \frac{\pi}{4}((0.1\,m)^2 - (0.04\,m)^2) = 6.60\times10^{-3}\,m^2$$

Since the cylinder is above the payload the retract direction will create upwards motion, so the pressure/force equation is:

$$F_{retract} = P_{retract} A_{retract} - P_{extend} A_{extend}$$

Assuming the pressure drops across the valve is the same for the return flow as for the intake flow

$$F_{retract} = (P_{\text{supply}} - \Delta P) A_{retract} - (P_{sump} + \Delta P) A_{extend}$$

Rearranging, and assuming that the sump is open to the atmosphere (i.e. $P_{sump} = 0$ gauge), gives:

$$F_{retract} - P_{\text{supply}} A_{retract} = \Delta P(-A_{extend} - A_{retract})$$

$$\begin{aligned}
\Delta P &= \frac{-F_{retract} + P_{\text{supply}} A_{retract}}{A_{extend} + A_{retract}} \\
&= \frac{-2.16\times10^4\ N + (7\times10^6\ Pa)(6.60\times10^{-3}\ m^2)}{7.85\times10^{-3}\ m^2 + 6.60\times10^{-3}\ m^2} \\
&= 1.70\times10^6\ Pa
\end{aligned}$$

Since $A_{extend} > A_{retract}$ the maximum required flow rate is:

$$Q = v_{\max} A_{extend} = (0.1\,m/s)(7.85\times10^{-3}\,m^2) = 7.85\times10^{-4}\,m^3/s$$

Note: When lifting the mass this is the return flow to the sump.