Example 3.10

We are designing a hydraulic system. We want to use a single rod hydraulic cylinder to drive a 10,000 kg mass horizontally. The maximum desired acceleration is 2 m/s^2, the maximum desired velocity is 0.5 m/s and the density of the hydraulic oil is 900 kg/m^3. If the supply pressure is 1.5×10^7 Pa absolute (≈2,200 psi) and a 2000 kPa pressure drop across the valve is acceptable then determine an appropriate bore size for the cylinder and the minimum required flow coefficient. Assume that the pressure drop across the valve is the same for the return flow as for the intake flow and that the sump is open to the atmosphere. Also assume the available bore sizes for the cylinder only come in 5 mm increments, and that the area of its rod can be neglected.

Solution

The required force is: $F = ma = (10{,}000\ kg)(2\ m/s^2) = 2 \times 10^4\ N$

Because the rod's area can be neglected and the pressure drops for the intake flow and the return flow are the same, the pressure/force equation (3.42) will be the same for the extend and retract directions. For the extend case, the gauge pressures are:

$$P_{extend} = P_{\text{supply}} - \Delta P = (1.5\times10^7 - 1.01\times10^5 - 2.0\times10^6)Pa = 1.29\times10^7\,Pa$$

$$P_{retract} = P_{\text{sump}} + \Delta P = (0 + 2.0\times10^6)Pa = 2.0\times10^6\,Pa$$ (**Note:** sump pressure = 0 gauge)

Force eq'n is:

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

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

So the minimum required area is:

$$A = \frac{F_{extend}}{P_{extend} - P_{retract}} = \frac{2\times10^4\ N}{(1.29\times10^7 - 2.0\times10^6)Pa} = 1.835\times10^{-3}\ m^2$$

and the minimum required bore diameter is:

$$D_{bore} = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(1.835\times10^{-3}\ m^2)}{\pi}} = 4.83\times10^{-2}\ m = 48.3\,mm$$

But we are limited to 5 mm increments so the acceptable bore size is:

$$D_{bore} = 50\ mm = 5\times10^{-2}\,m$$

and the corresponding area is:

$$A = \frac{\pi}{4}D_{bore}^2 = \frac{\pi}{4}(5\times10^{-2}\,m)^2 = 1.96\times10^{-3}\,m^2$$

Maximum required volume flow rate is:

$$Q = v_{\max}A = (0.5m/s)(1.96\times10^{-3}\,m^2) = 9.82\times10^{-4}\,m^3/s$$

Finally, the minimum required flow coefficient is:

$$C_V = 4.22\times10^4 Q\sqrt{\frac{\rho}{\Delta P}} = 4.22\times10^4(9.82\times10^{-4}\,m^3/s)\sqrt{\frac{900\ kg/m^3}{2.0\times10^6\,Pa}} = 0.88$$