Hydraulic Component Modeling Example: Simulink Modeling of a Pressure Compensated Flow Control (PCFC) Valve

1 Principles

Refer to figure from handout.

- The resistor type PCFC valve consists of two orifices, a fixed orifice and a variable orifice, in series.
- Since orifices are in series, flow rates through both of them are the same.
- By maintaining the pressure across the fixed orifice, the flow rate is fixed.
- The variable orifice is adjusted based on the pressure difference ($\Delta P$) across the fixed orifice
  - if $\Delta P = P_c - P_b$ is greater than desired, the variable orifice is closed
  - if $\Delta P = P_c - P_b$ is smaller than desired, the variable orifice is opened.
- Internal portings and a spring sprung spool achieves this feedback.

2 Orifice modeling

Suppose the fixed orifice is described by:

$$Q = C_2 \sqrt{P_c - P_b} \quad (1)$$

and the variable orifice is described by:

$$Q = c_1(x) \sqrt{P_a - P_b} \quad (2)$$

where $P_a$ is the inlet pressure, $P_b$ is the outlet pressure, $P_c$ is the pressure in between the two orifices.

From several lectures ago, we found for 2 needle valves in series:

$$Q = C(x) \sqrt{P_a - P_b}$$

where

$$\frac{1}{C^2(x)} = \frac{1}{c_1^2(x)} + \frac{1}{c_2^2}$$

From this, we can determine $P_c$ also:

$$P_c = P_a - Q^2/c_1^2(x) = P_a - \frac{C^2(x)}{c_1^2} (P_a - P_b).$$
3 Spool displacement

The orifice opening for the variable orifice is determined by the pressure difference \( \Delta P = P_c - P_b \).

Let \( x \) be the displacement of the spool when the spring is uncompressed. If the spool has mass \( m \), damping coefficient \( b \), the spring constant is \( K \), and the area on which the pressure acts is \( A \), then by considering the free body diagram for the spool, and by applying Newton’s second law:

\[
m\ddot{x} = -b\dot{x} - Kx + A(P_b - P_c)
\]

Note the directions of these forces.

In Laplace domain, we have the transfer function:

\[
\frac{X(s)}{P_b(s) - P_c(s)} = \frac{A}{ms^2 + bs + K}
\]

4 Orifice area modeling

Finally, we need to determine the actual orifice opening. For simplicity, we consider

\[
A_1(x) = A_0 + w \cdot x
\]

and the actual area is given by \( A(x) = A_1(x) \) if \( 0 \leq A_1(x) \leq A_{max} \), otherwise \( A(x) = 0 \) if \( A_1(x) \leq 0 \) and \( A(x) = A_{max} \) if \( A_1(x) \geq A_{max} \). This saturation limits can easily be implement using simulink’s (saturation block).

The orifice coefficient \( c_1(x) = C_d A(x) \), \( C_d \) is some discharge coefficient.