Exercise 5 Lifting

$p_P := 100 \cdot 10^5 \cdot Pa$ Pump pressure

$D := 0.032 \cdot m$ Cylinder diameter

$d := 0.020 \cdot m$ Rod diameter

$U := 2$ Valve command voltage [V]

$m := 100 \cdot 1 \cdot kg$ LOAD mass ON/OFF (0/1)

$$A_A := \frac{\pi}{4} \cdot D^2$$

$$A_A = \left(8.042 \cdot 10^{-4}\right)\ m^2$$

$$A_B := A_A - \frac{\pi}{4} \cdot d^2$$

$$A_B = \left(4.901 \cdot 10^{-4}\right)\ m^2$$

$$K_{MAX} := \frac{40 \cdot \frac{l}{min}}{\sqrt[2]{35 \cdot 10^5 \cdot Pa}}$$

$$K_{MAX} = \left(3.563 \cdot 10^{-7}\right)\ \frac{m^{\frac{7}{2}}}{kg^{\frac{1}{2}}}$$

$$K_{VALVE} := \frac{U}{10} \cdot K_{MAX}$$

$$K_{VALVE} = \left(7.127 \cdot 10^{-8}\right)\ \frac{m^{\frac{7}{2}}}{kg^{\frac{1}{2}}}$$

$$F := m \cdot g$$

$$p_P = \left(1 \cdot 10^7\right)\ Pa$$

Maximum lifting force - without movement -> pressure losses in valve

$$p_P \cdot A_A = \left(8.04248 \cdot 10^3\right)\ N$$

Piston velocity, method 1

$$v_{1.1} := \sqrt{\frac{p_P \cdot A_A - F}{\frac{1}{K_{VALVE}^2} \cdot A_A^3 + \frac{1}{K_{VALVE}^2} \cdot A_B^3}}$$

$$v_{1.1} = 0.237\ \frac{m}{s}$$

Piston velocity, method 2

$$v_{1.2} := \sqrt{\frac{\left(p_P \cdot A_A - F\right) \cdot K_{VALVE}^2}{A_A^3 + A_B^3}}$$

Piston velocity, method 2.1

$$v_1 := K_{VALVE} \cdot \sqrt[2]{\frac{\left(p_P \cdot A_A - F\right)}{A_A^3 + A_B^3}}$$

$$v_1 = 0.237\ \frac{m}{s}$$

$q_{vPA} := v_1 \cdot A_A$

$q_{vPA} = (1.907 \cdot 10^{-4}) \frac{m^3}{s}$

$q_{vPA} = 11.443 \frac{l}{min}$

$q_{vBT} := v_1 \cdot A_B$

$q_{vBT} = (1.162 \cdot 10^{-4}) \frac{m^3}{s}$

$q_{vBT} = 6.973 \frac{l}{min}$

$p_A := p_P - \frac{1}{K_{VALVE}^2} \cdot q_{vPA}^2$

$\Delta p_{PA} := \frac{1}{K_{VALVE}^2} \cdot q_{vPA}^2$

$p_B := \frac{1}{K_{VALVE}^2} \cdot q_{vBT}^2$

$p_A = 28.396$ bar

$p_B = 26.589$ bar

$P_{LIFT} := F \cdot v_1$

$P_{PA} := q_{vPA} \cdot \Delta p_{PA}$

$P_{BT} := q_{vBT} \cdot p_B$

$P_{LIFT} = 232.543$ W

$P_{PA} = 1.366$ kW

$P_{BT} = 309.002$ W

$P_{PUMP} := p_P \cdot q_{vPA}$

$P_{PUMP} = 1.907$ kW

$P_{LIFT} + P_{PA} + P_{BT} = 1.907$ kW

$K_{MAX} = (3.563 \cdot 10^{-7}) \frac{m^{\frac{7}{2}}}{kg^{\frac{1}{2}}}$

Exercise 6

$$v_2 := \sqrt{\frac{p_P \cdot A_B + F}{\frac{1}{K_{VALVE}^2} \cdot A_A^3 + \frac{1}{K_{VALVE}^2} \cdot A_B^3}}$$

$F = 980.665\ N$

$v_2 = 0.216\ \frac{m}{s}$ or with (-= sign)

$q_{vAT} := v_2 \cdot A_A$

$q_{vPB} := v_2 \cdot A_B$

$q_{vAT} = 10.443\ \frac{l}{min}$

$q_{vPB} = 6.363\ \frac{l}{min}$

$$p_A := \frac{1}{K_{VALVE}^2} \cdot q_{vAT}^2$$

$p_A = 59.636\ bar$

$$p_B := p_P - \frac{1}{K_{VALVE}^2} \cdot q_{vPB}^2$$

$p_B = 77.855\ bar$

Power usage

$P_{LOWER} := F \cdot v_2$

$P_{PUMP} := p_P \cdot q_{vPB}$

$$P_{PB} := q_{vPB} \cdot \frac{1}{K_{VALVE}^2} \cdot q_{vPB}^2$$

$P_{AT} := q_{vAT} \cdot p_A$ (with tank pressure 0)

$P_{AT} = 1.038\ kW$

$P_{PB} = 234.869\ W$

$P_{LOWER} = 212.222\ W$

$P_{PUMP} = 1.061\ kW$

$P_{PUMP} + P_{LOWER} = 1.273\ kW$

$P_{AT} + P_{PB} = 1.273\ kW$

Exercise 7

$$K := \frac{0.45 \cdot \frac{l}{min}}{50 \cdot 10^5 \cdot Pa}$$

$$K = \left(1.5 \cdot 10^{-12}\right) \frac{m^4 \cdot s}{kg}$$

$$p_A := \frac{p_P}{2} \qquad p_B := \frac{p_P}{2}$$

$$q_{vA} := K \cdot \left(p_P - p_A\right)$$

$$q_{vA} = 0.45 \frac{l}{min}$$

$$q_{vB} := q_{vA}$$

$$q_{vB} = 0.45 \frac{l}{min}$$

$$q_{vAT} := q_{vA}$$

$$q_{vAT} = 0.45 \frac{l}{min}$$

$$q_{vBT} := q_{vA}$$

$$q_{vBT} = 0.45 \frac{l}{min}$$

$$q_{vP} := q_{vA} + q_{vB}$$

$$q_{vP} = 0.9 \frac{l}{min}$$

$$p_A = 50 \ bar$$

$$p_B = 50 \ bar$$

$$P_{PA} := q_{vA} \cdot \left(p_P - p_A\right)$$

$$P_{PA} = 37.5 \ W$$

$$P_{PB} := q_{vB} \cdot \left(p_P - p_B\right)$$

$$P_{PB} = 37.5 \ W$$

$$P_{AT} := q_{vAT} \cdot \left(p_A - 0\right)$$

$$P_{AT} = 37.5 \ W$$

$$P_{BT} := q_{vBT} \cdot \left(p_B - 0\right)$$

$$P_{BT} = 37.5 \ W$$

$$P_P := q_{vP} \cdot p_P$$

$$P_P = 150 \ W$$

$$F := p_A \cdot A_A - p_B \cdot A_B$$

$$F = 1.571 \ kN$$

Exercise 8

$p_B = \frac{A_A}{A_B} \cdot p_A$ — cylinder force balance

$q_{v.PA} = v \cdot A_A + q_{v.AT}$ — A side continuity equation

$q_{v.PB} = -v \cdot A_B + q_{v.BT}$ — B side continuity equation

$K \cdot (p_P - p_A) = v \cdot A_A + K \cdot p_A$ — flow rates with orifice equations, A side

$K \cdot (p_P - p_B) = -v \cdot A_B + K \cdot p_B$ — flow rates with orifice equations, B side

$K \cdot p_P = v \cdot A_A + 2 \cdot K \cdot p_A$ — flow rates with orifice equations, A side

$K \cdot p_P = -v \cdot A_B + 2 \cdot K \cdot p_B$ — flow rates with orifice equations, B side

$v = \frac{K \cdot p_P}{A_A} - \frac{2 \cdot K \cdot p_A}{A_A}$ — velocity with A side pressure

$v = \frac{-K \cdot p_P}{A_B} + \frac{2 \cdot K \cdot p_B}{A_B}$ — velocity with B side pressure

$$\frac{K \cdot p_P}{A_A} - \frac{2 \cdot K \cdot p_A}{A_A} = \frac{-K \cdot p_P}{A_B} + \frac{2 \cdot K \cdot p_B}{A_B}$$

$$\left(\frac{2 \cdot K}{A_A} + \frac{2 \cdot K \cdot A_A}{A_B^{2}}\right) p_A = K \cdot \left(\frac{1}{A_A} + \frac{1}{A_B}\right) \cdot p_P$$

$$p_A = \frac{\frac{1}{A_A} + \frac{1}{A_B}}{2\left(\frac{1}{A_A} + \frac{A_A}{A_B^{2}}\right)} \cdot p_P$$

$$p_{B2} := \frac{1}{2} \cdot \frac{A_A^{2} + A_A \cdot A_B}{A_A^{2} + A_B^{2}} \cdot p_P$$

$$p_A := \frac{1}{2} \cdot \frac{A_B^{2} + A_A \cdot A_B}{A_A^{2} + A_B^{2}} \cdot p_P$$

$p_{B2} = 58.679$ bar

$$p_B := \frac{A_A}{A_B} \cdot p_A$$

$p_A = 35.758$ bar

$p_B = 58.679$ bar

$q_{vBT} := K \cdot p_B$

$q_{vBT} = \left(8.802 \cdot 10^{-6}\right) \frac{m^3}{s}$

$q_{vAT} := K \cdot p_A$

$q_{vAT} = \left(5.364 \cdot 10^{-6}\right) \frac{m^3}{s}$

$q_{vPA} := K \cdot \left(p_P - p_A\right)$

$q_{vPB} := K \cdot \left(p_P - p_B\right)$

$q_{vA} := q_{vPA} - q_{vAT}$

$v_A := \frac{q_{vA}}{A_A}$

$v_A = 0.005 \frac{m}{s}$

$q_{vB} := q_{vBT} - q_{vPB}$

$v_B := \frac{q_{vB}}{A_B}$

$q_{vP} := q_{vPA} + q_{vPB}$

$q_{vP} \cdot 60000 = 0.95 \frac{m^3}{s}$

$q_{vPA} = 0.578 \frac{l}{min}$

$q_{vPB} = 0.372 \frac{l}{min}$

$q_{vAT} = 0.322 \frac{l}{min}$

$q_{vBT} = 0.528 \frac{l}{min}$

$q_{vP} = 0.95 \frac{l}{min}$

$p_A = 35.758\ bar$

$p_B = 58.679\ bar$

$P_{PA} := q_{vPA} \cdot \left(p_P - p_A\right)$

$P_{PA} = 61.906\ W$

$P_{PB} := q_{vPB} \cdot \left(p_P - p_B\right)$

$P_{PB} = 25.611\ W$

$p_T := 0 \cdot Pa$

$P_{AT} := q_{vAT} \cdot \left(p_A - p_T\right)$

$P_{AT} = 19.179\ W$

$P_{BT} := q_{vBT} \cdot \left(p_B - p_T\right)$

$P_{BT} = 51.648\ W$

$P_P := q_{vP} \cdot \left(p_P - p_T\right)$

$P_P = 158.345\ W$

$v_B = 0.00531 \frac{m}{s}$

Check! What if the cylinder areas are the same

$A_B := A_A$

$$p_A := \frac{1}{2} \cdot \frac{A_B^2 + A_A \cdot A_B}{A_A^2 + A_B^2} \cdot p_P$$

$$p_B := \frac{A_A}{A_B} \cdot p_A$$

$p_A = 50\ \mathrm{bar}$

$p_B = 50\ \mathrm{bar}$

$q_{vBT} := K \cdot p_B$

$q_{vBT} = \left(7.5 \cdot 10^{-6}\right) \frac{m^3}{s}$

$q_{vAT} := K \cdot p_A$

$q_{vAT} = \left(7.5 \cdot 10^{-6}\right) \frac{m^3}{s}$

$q_{vPA} := K \cdot \left(p_P - p_A\right)$

$q_{vPB} := K \cdot \left(p_P - p_B\right)$

$q_{vA} := q_{vPA} - q_{vAT}$

$v_A := \frac{q_{vA}}{A_A}$

$v_A = 0\ \frac{m}{s}$

$q_{vB} := q_{vBT} - q_{vPB}$

$v_B := \frac{q_{vB}}{A_B}$

$q_{vP} := q_{vPA} + q_{vPB}$

$q_{vP} \cdot 60000 = 0.9\ \frac{m^3}{s}$

$q_{vPA} = 0.45\ \frac{l}{min}$

$q_{vPB} = 0.45\ \frac{l}{min}$

$q_{vAT} = 0.45\ \frac{l}{min}$

$q_{vBT} = 0.45\ \frac{l}{min}$

$q_{vP} = 0.9\ \frac{l}{min}$

$p_A = 50\ \mathrm{bar}$

$p_B = 50\ \mathrm{bar}$

$P_{PA} := q_{vPA} \cdot \left(p_P - p_A\right)$

$P_{PA} = 37.5\ W$

$P_{PB} := q_{vPB} \cdot \left(p_P - p_B\right)$

$P_{PB} = 37.5\ W$

$p_T := 0 \cdot Pa$

$P_{AT} := q_{vAT} \cdot (p_A - p_T)$

$P_{AT} = 37.5\ W$

$P_{BT} := q_{vBT} \cdot (p_B - p_T)$

$P_{BT} = 37.5\ W$

$P_P := q_{vP} \cdot (p_P - p_T)$

$P_P = 150\ W$ 1

$v_B = 0\ \frac{m}{s}$