Design and Modeling of Fluid Power Systems

ME 597/ABE 591 Lecture 8

Dr. Monika Ivantysynova
MAHA Professor Flud Power Systems

MAHA Fluid Power Research Center
Purdue University

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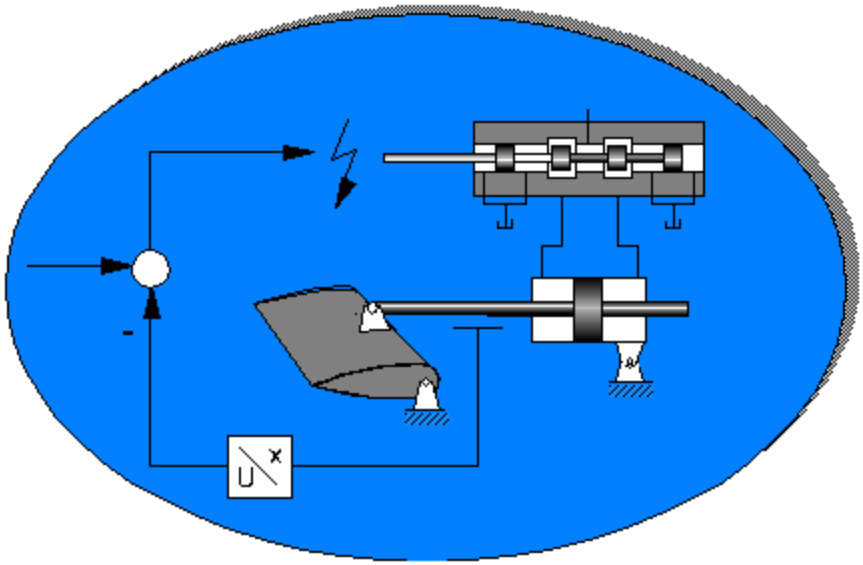
- Hydraulic Resistances
- Hydraulic Bridges, half bridge elements
- Flow gain, pressure gain
- Pressure – flow metering characteristics
- Flow forces
- Directional control valves
- Pressure control valves
- Flow control valves



Hydraulic Resistances

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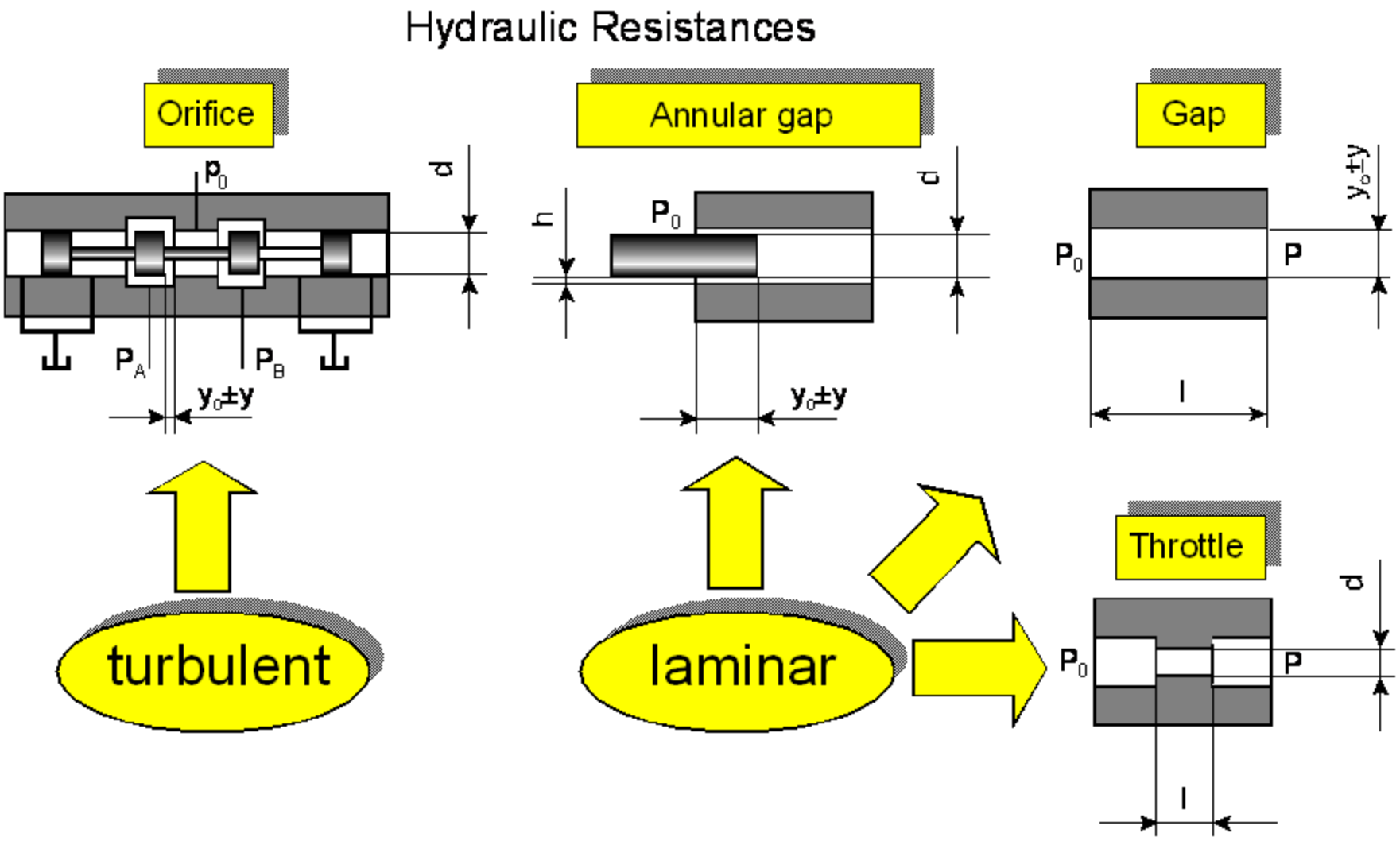
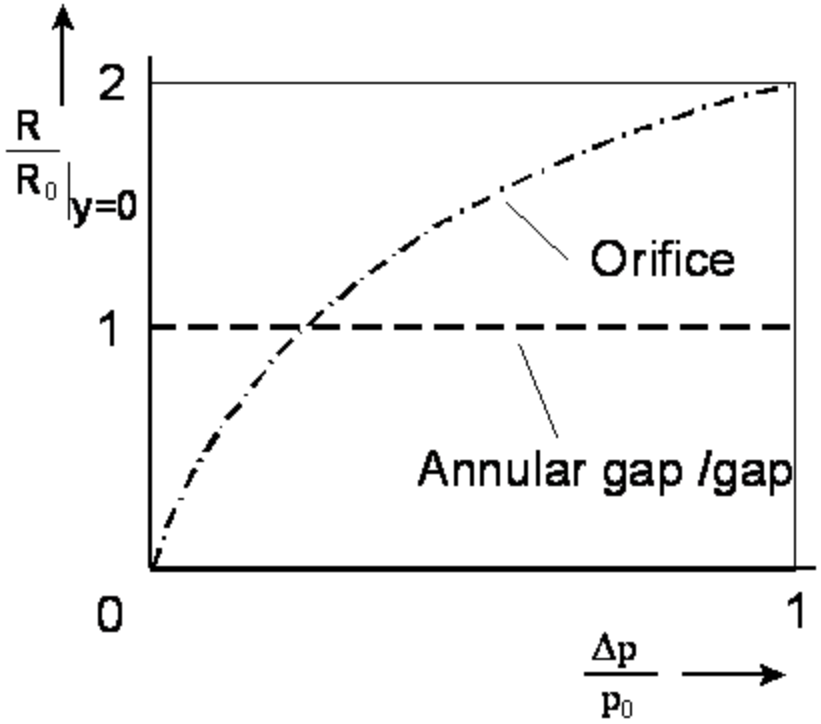
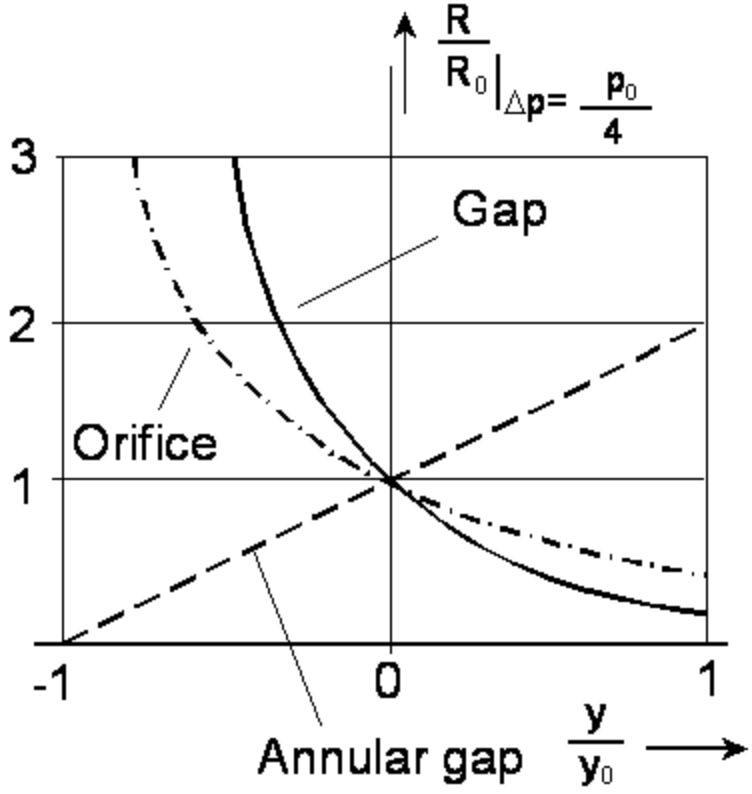


Hydraulic Resistances

Resistance dependent on:

- Pressure difference Δp
- Control variable y

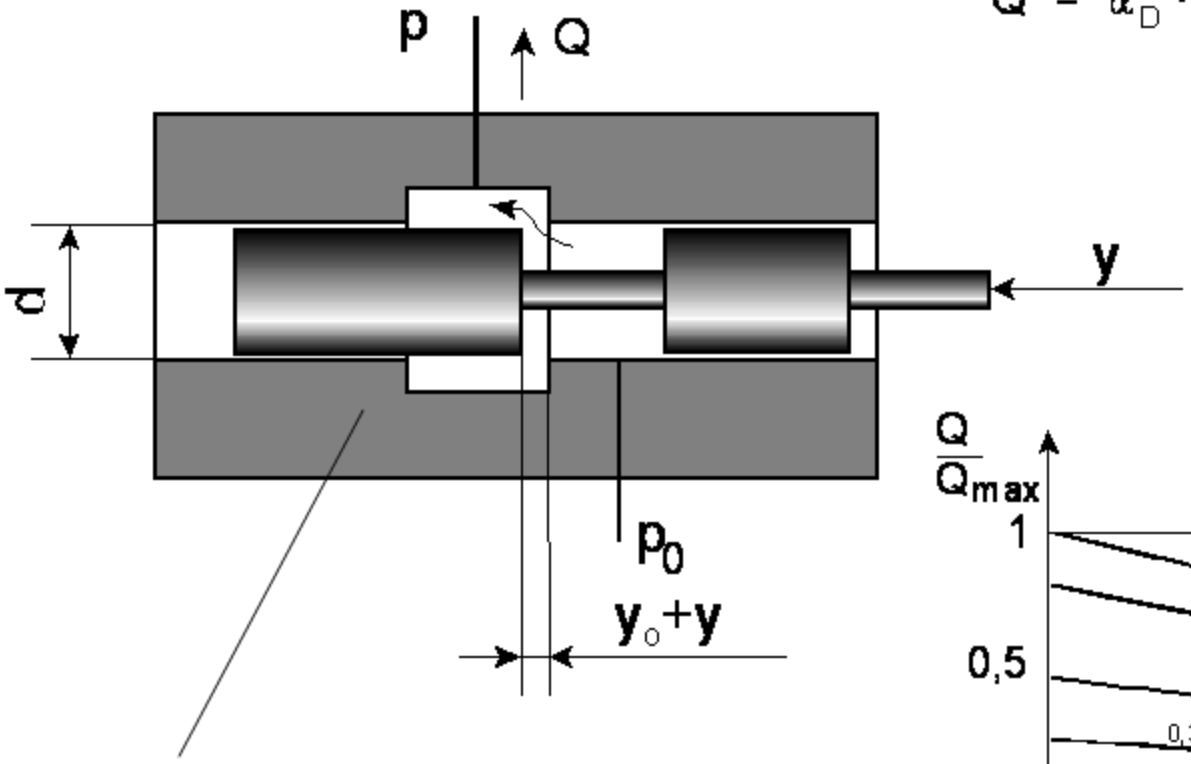




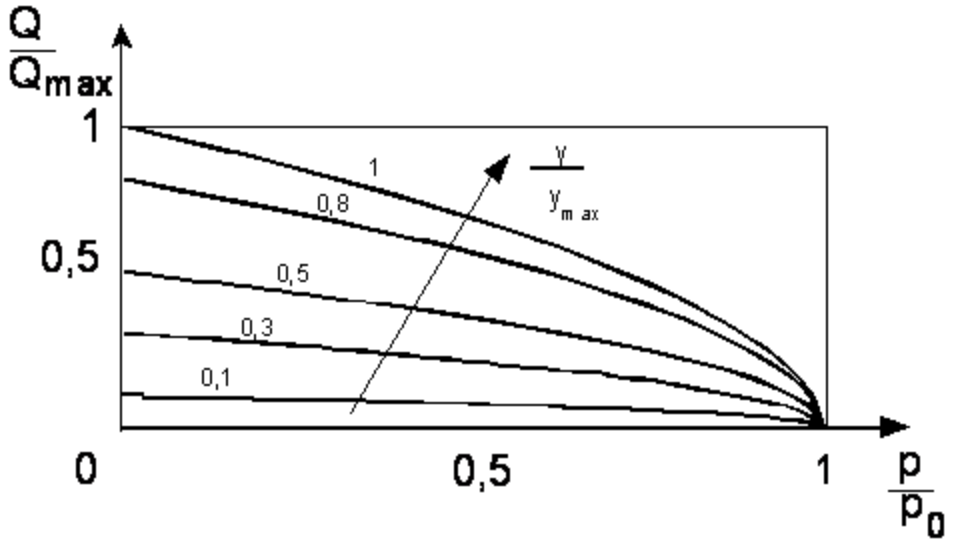
Hydraulic Resistances

Variable resistance (turbulent)

$$Q = \alpha_D \cdot \pi \cdot d\,(y_0 + y)\sqrt{\frac{2}{\varrho}}\sqrt{p_0 - p}$$



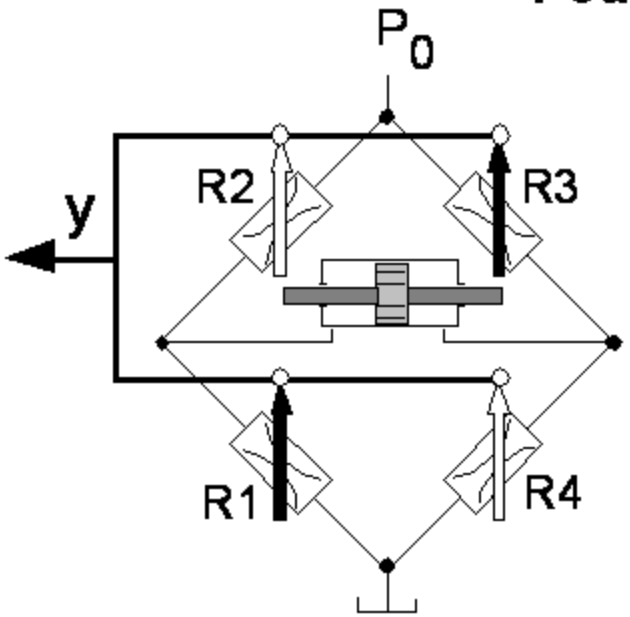
Spool valve

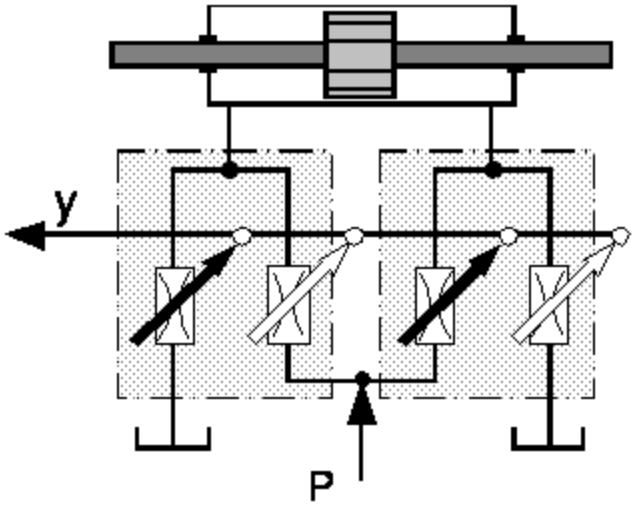


Hydraulic Resistances

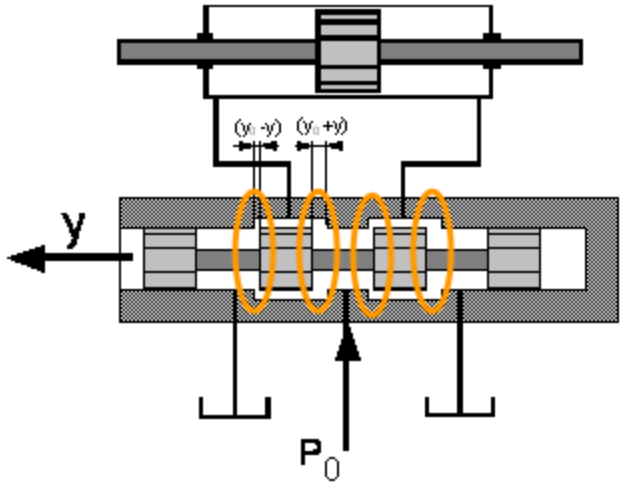
Hydraulic bridge

Four variable hydraulic resistances



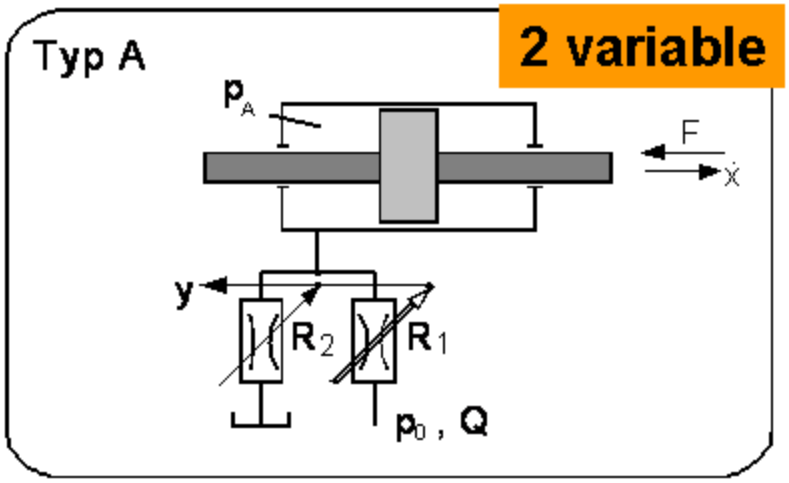


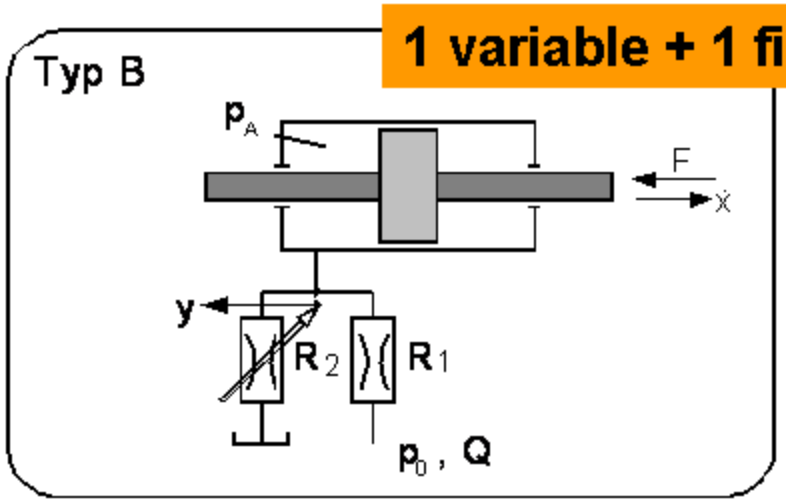
Four metering edges

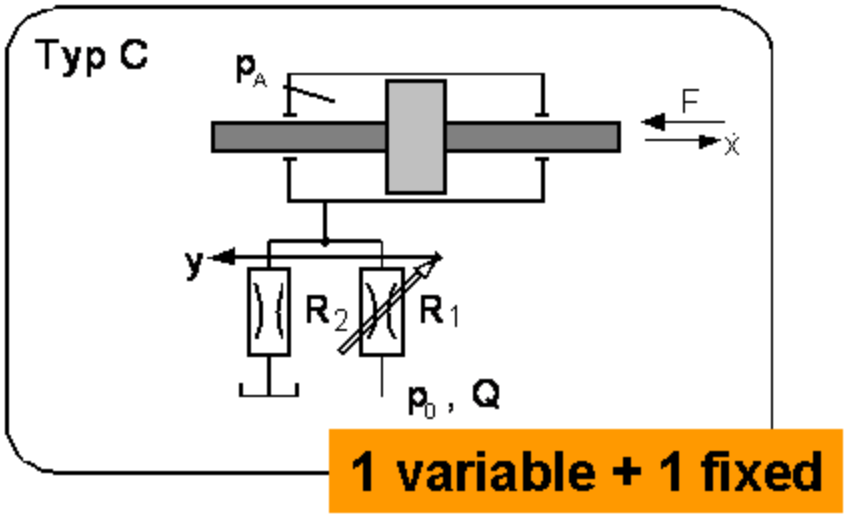


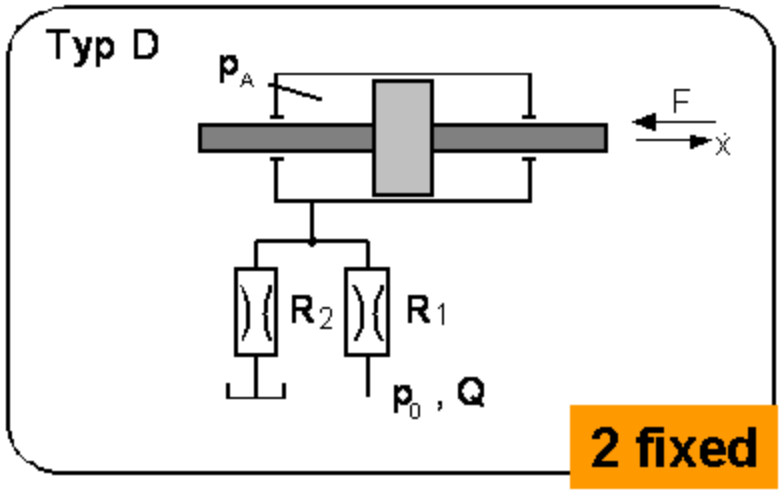
Hydraulic Resistances

Definition of hydraulic half bridge elements

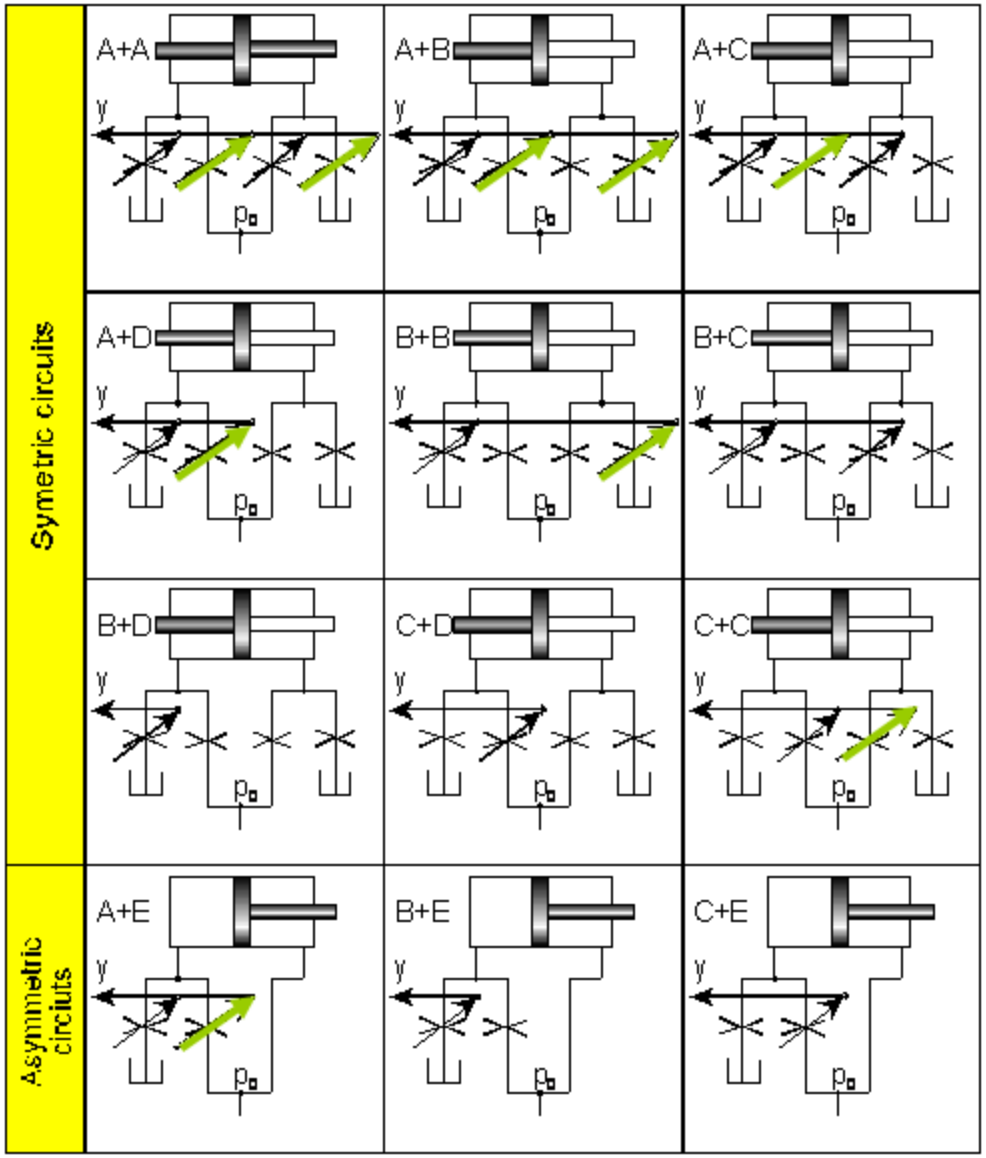








Matrix of hydraulic bridges



Resistance increase

Orifice diameter decrease
throttle valve closing

Resistance decrease

Orifice diameter increase
throttle valve opening

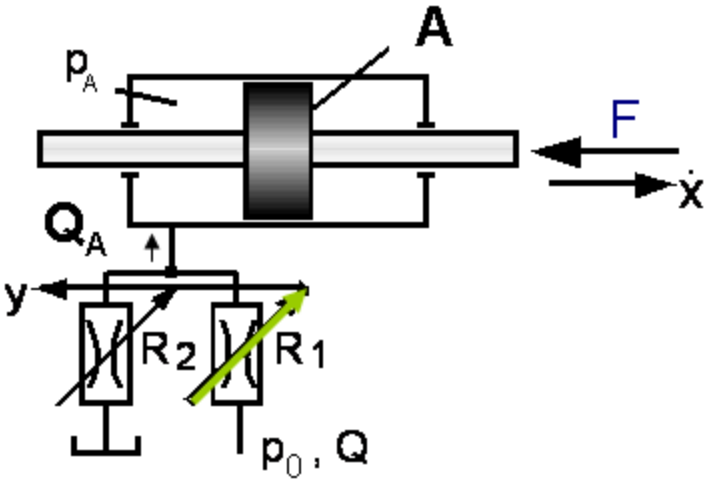
Characteristic values

of half bridge elements

Flow gain:

Defined under no load conditions

$$C_Q = \frac{\partial Q_A}{\partial y}\bigg|_{p_A = \frac{p_0}{2};\ y=0} = \text{tg}\,\alpha$$

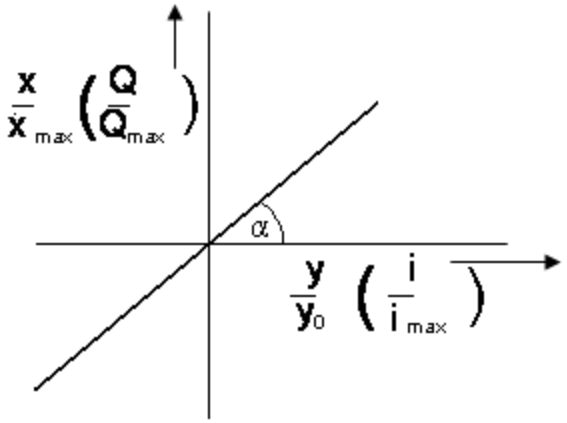


Flow gain in case of electric input

$$V_{Qi} = \frac{\partial Q_A}{\partial i}$$

Velocity gain:

$$C_V = \frac{\partial \dot{x}}{\partial y}\bigg|_{p_A = \frac{p_0}{2};\ y=0} = \frac{C_Q}{A}$$



Characteristic values

of half bridge elements

Pressure gain (sensitivity):

Defined at blocked port

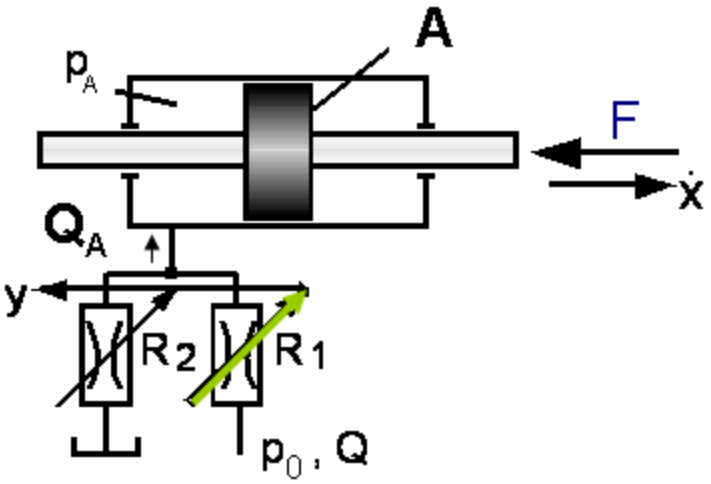
$$C_p = \frac{\partial p_A}{\partial y}\bigg|_{\dot{x} = 0 \; ; \; y = 0}$$

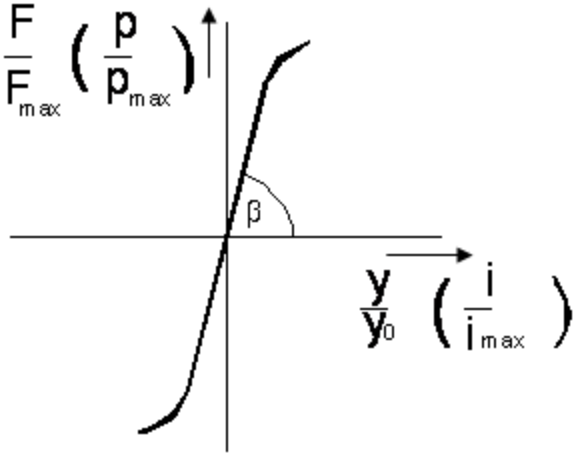
Pressure gain (sensitivity) in case of electrical input:

$$V_{pi} = \frac{\partial p}{\partial i}$$

Force gain:

$$C_F = \frac{\partial F}{\partial y}\bigg|_{\dot{x} = 0 \; ; \; y = 0} = c_p \cdot A$$





Spool Lap Configurations

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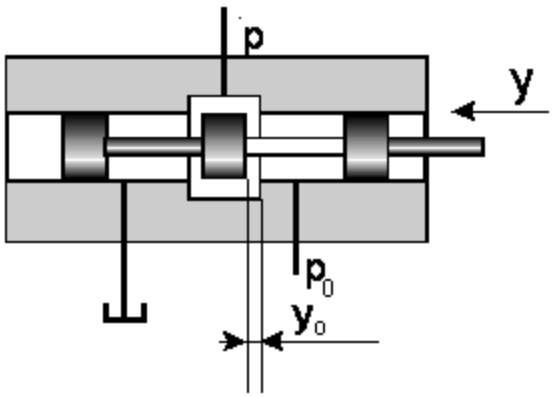
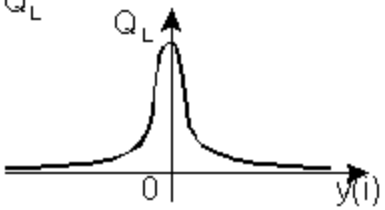
Underlapped

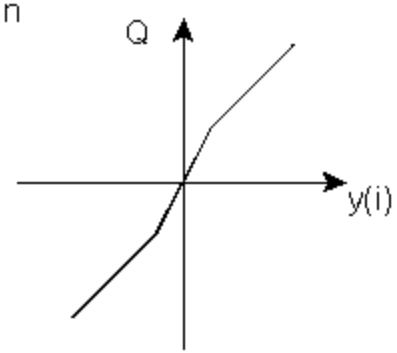


$Q(y) > 0$ für $y=0$

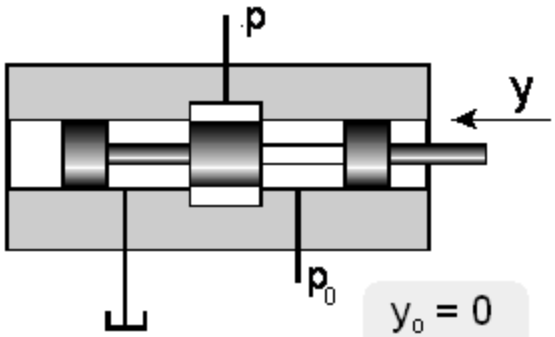
Leakage Q_L



Flow gain

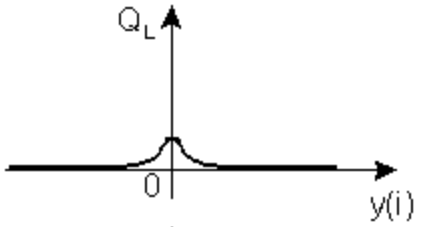


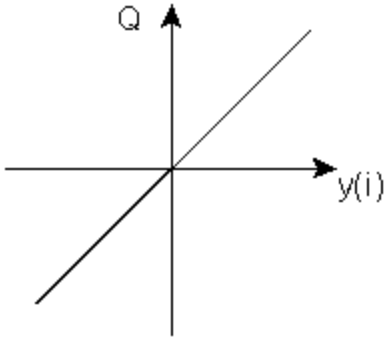
Zero lapped



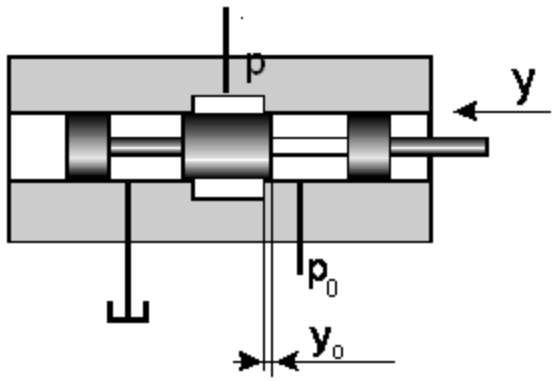
$y_0 = 0$

$Q(y) = 0$ für $y=0$

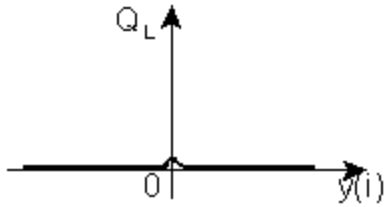


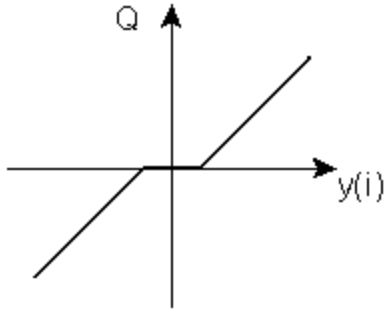


Overlapped



$Q(y) = 0$ für $|y| \leq y_0$





Pressure-Flow-Metering Characteristics

Half bridge element A

$$Q_1 = B \cdot (y_0 + y) \sqrt{p_0 - p_A}$$

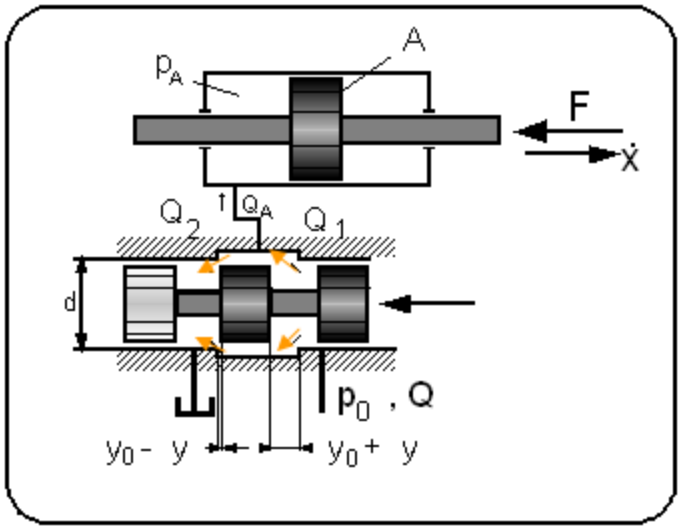
$$Q_2 = B \cdot (y_0 - y) \sqrt{p_A}$$

$$\text{with } B = \alpha_D \cdot \pi \cdot d \cdot \sqrt{\frac{2}{\rho}}$$

$$Q_A = Q_1 - Q_2 = A \cdot \dot{x}$$

$$F = p_A \cdot A$$

$$\dot{x} = \frac{B}{A} \left[(y_0 + y) \sqrt{p_0 - p_A} - (y_0 - y) \sqrt{p_A} \right]$$



Flow gain

$$C_Q = \frac{\partial Q_A}{\partial y}\bigg|_{p_A = \frac{p_0}{2};\ y = 0} = \sqrt{2}\ B \sqrt{p_0}$$

Velocity gain

$$C_V = \frac{\partial \dot{x}}{\partial y}\bigg|_{p_A = \frac{p_0}{2};\ y = 0} = \sqrt{2}\ \frac{B}{A} \sqrt{p_0}$$

Pressure gain

$$C_p = \frac{\partial p_A}{\partial y}\bigg|_{\dot{x} = 0;\ y = 0} = \frac{p_0}{y_0}$$

Force gain

$$C_F = \frac{\partial F}{\partial y}\bigg|_{\dot{x} = 0;\ y = 0} = \frac{p_0 \cdot A}{y_0}$$

Pressure-Flow-Metering Characteristics

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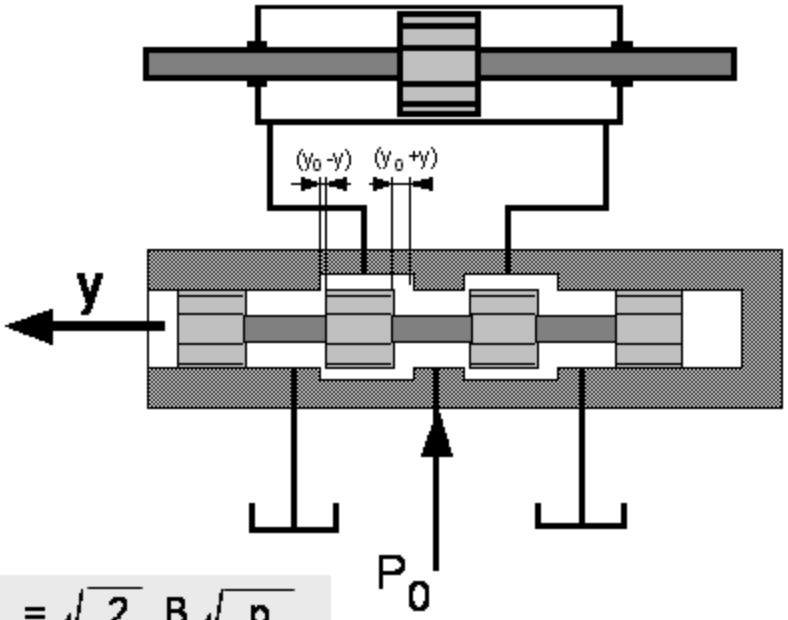
Hydraulic bridge **A+A**



Flow gain / velocity gain

- **Mean value of half bridges**

$$C_Q = \sqrt{2}\, B \sqrt{p_0}$$

Pressure gain:

- **Sum of half bridges**

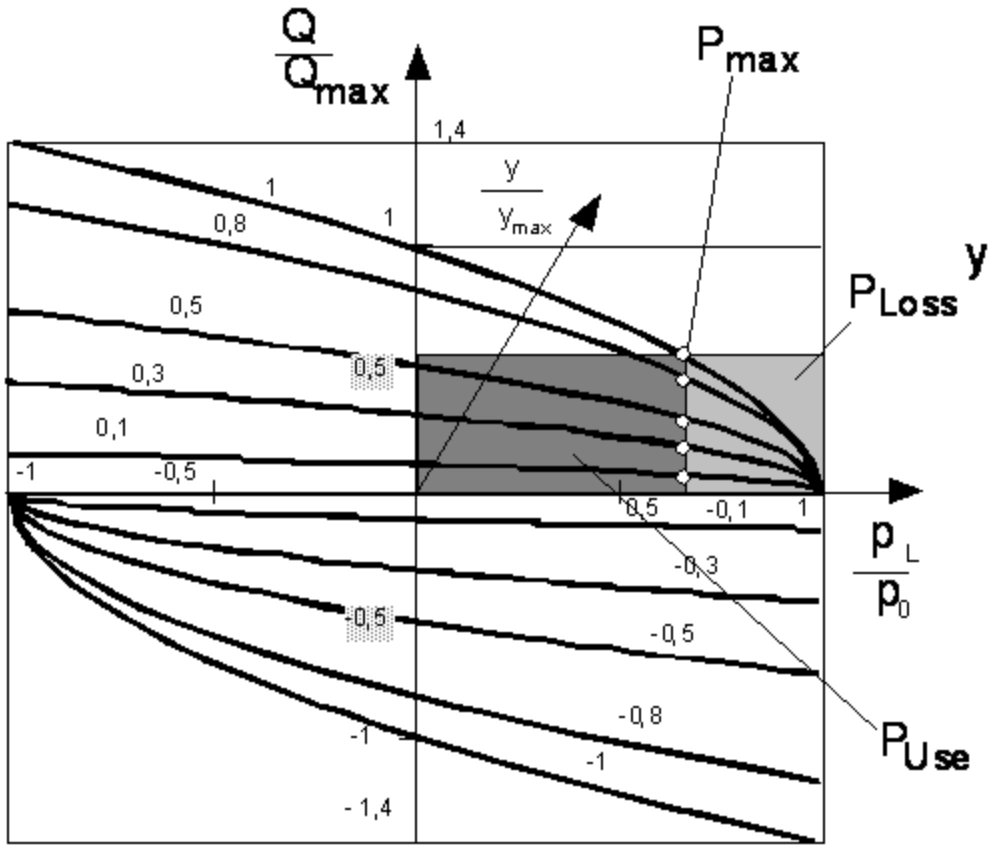
$$C_p = 2\,\frac{p}{y}$$

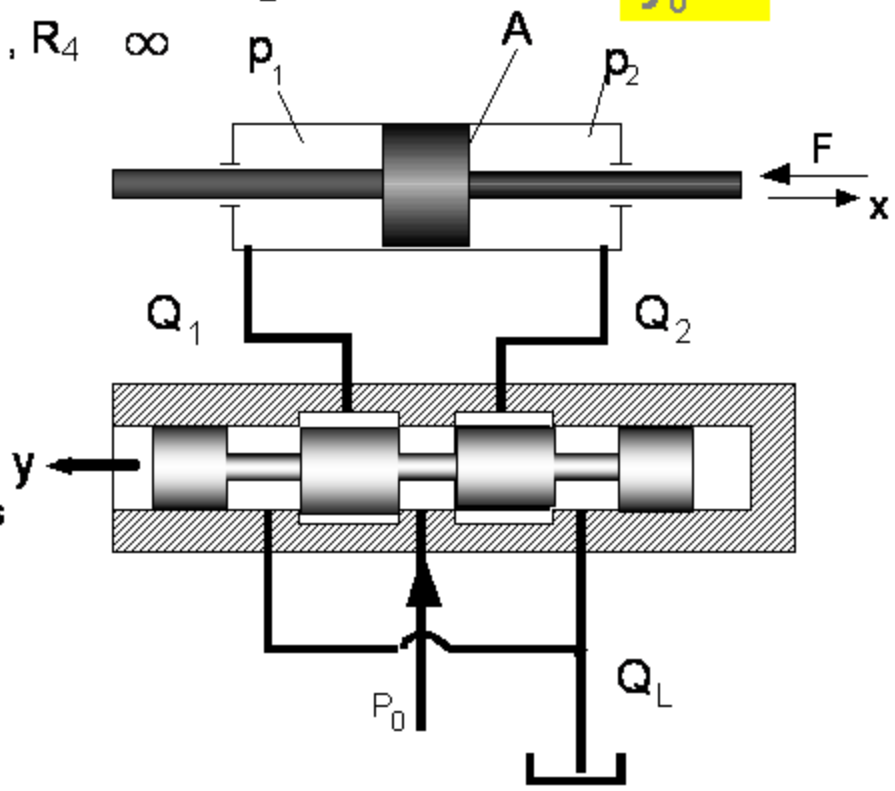
Zero Lap Configuration

$p_L = \Delta p = p_1 - p_2$; $F = A \cdot \Delta p = A \cdot p_L$

for $y > 0$ follows R_1 , R_3 variable and R_2 , R_4 ∞

$y_0=0$



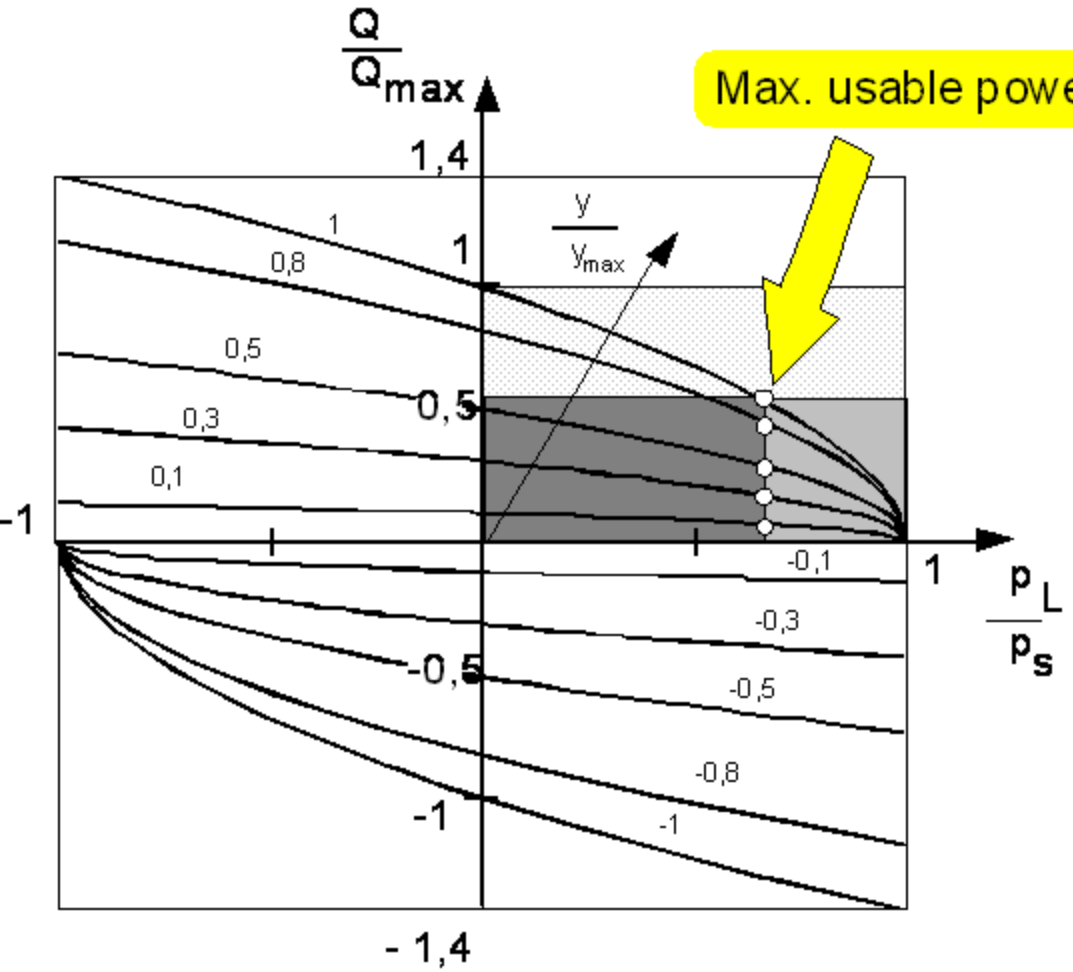


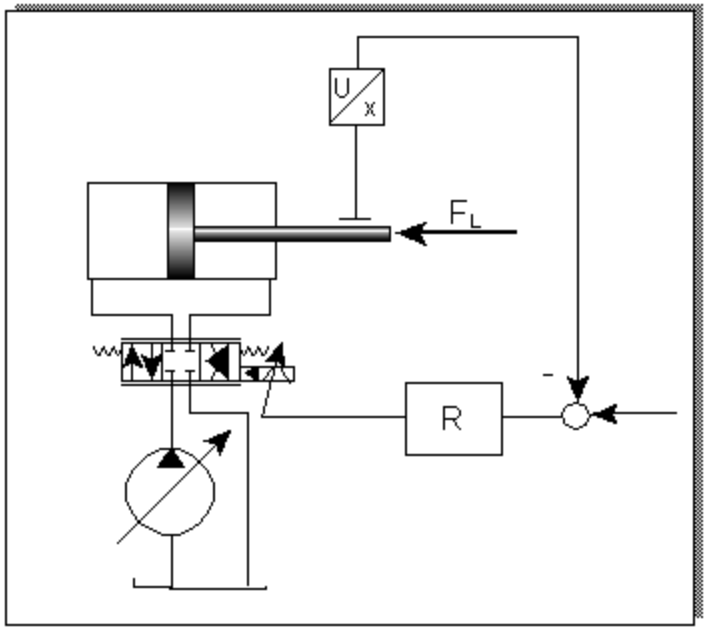
Normalized pressure p_L/p_0

Pressure-flow metering characteristics

Usable power

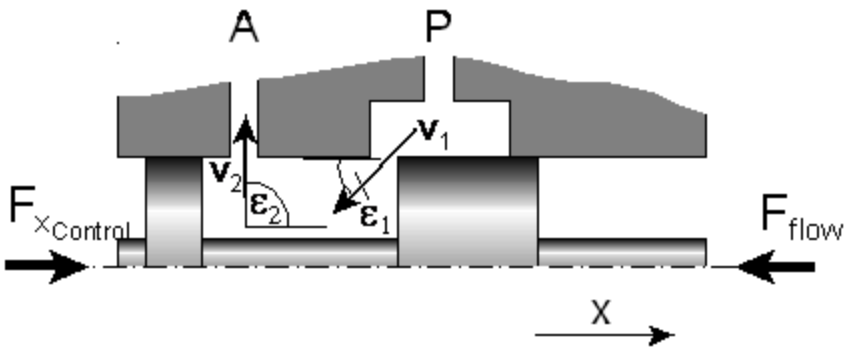
Power loss

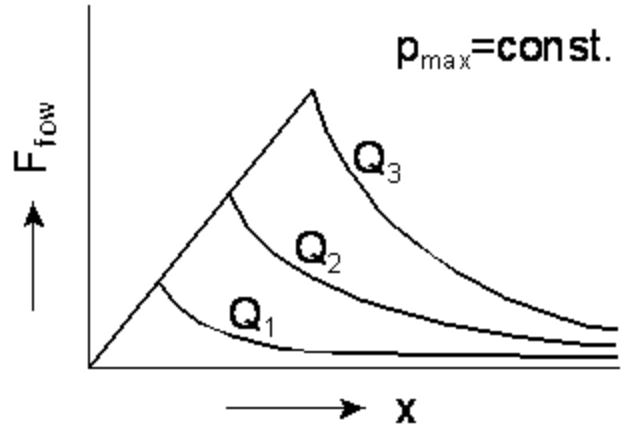


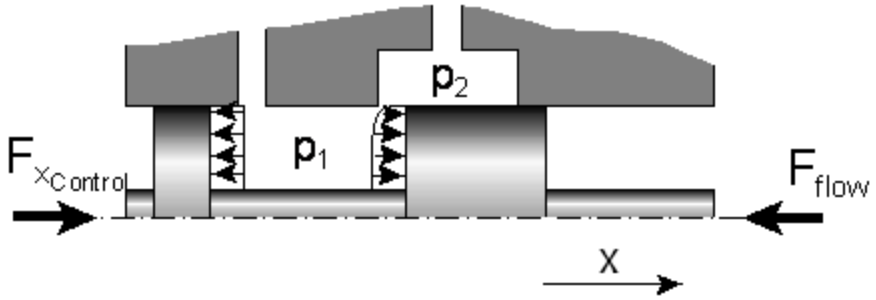


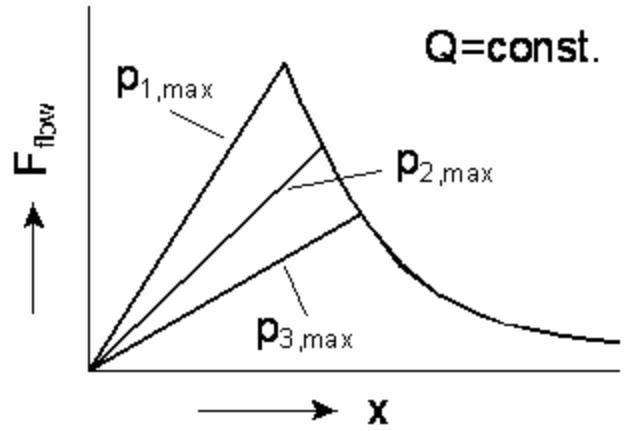
Flow Forces

Spool valve



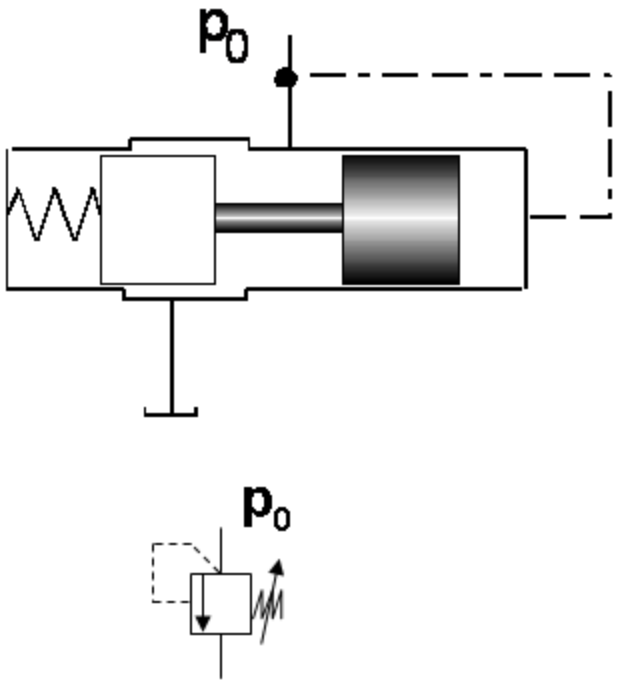


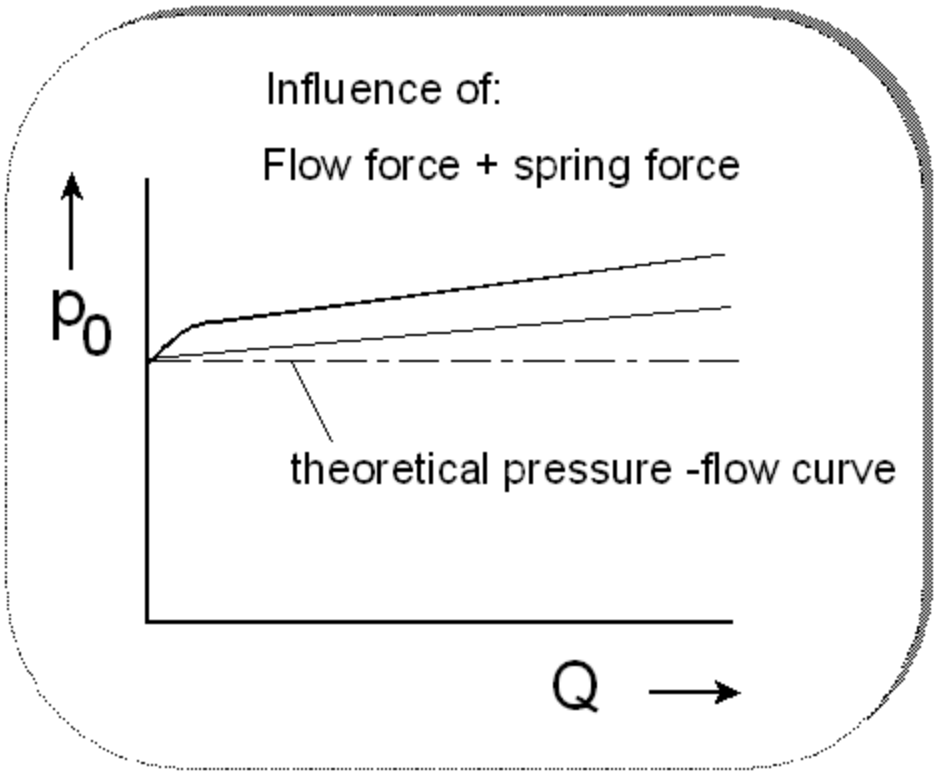




Pressure control

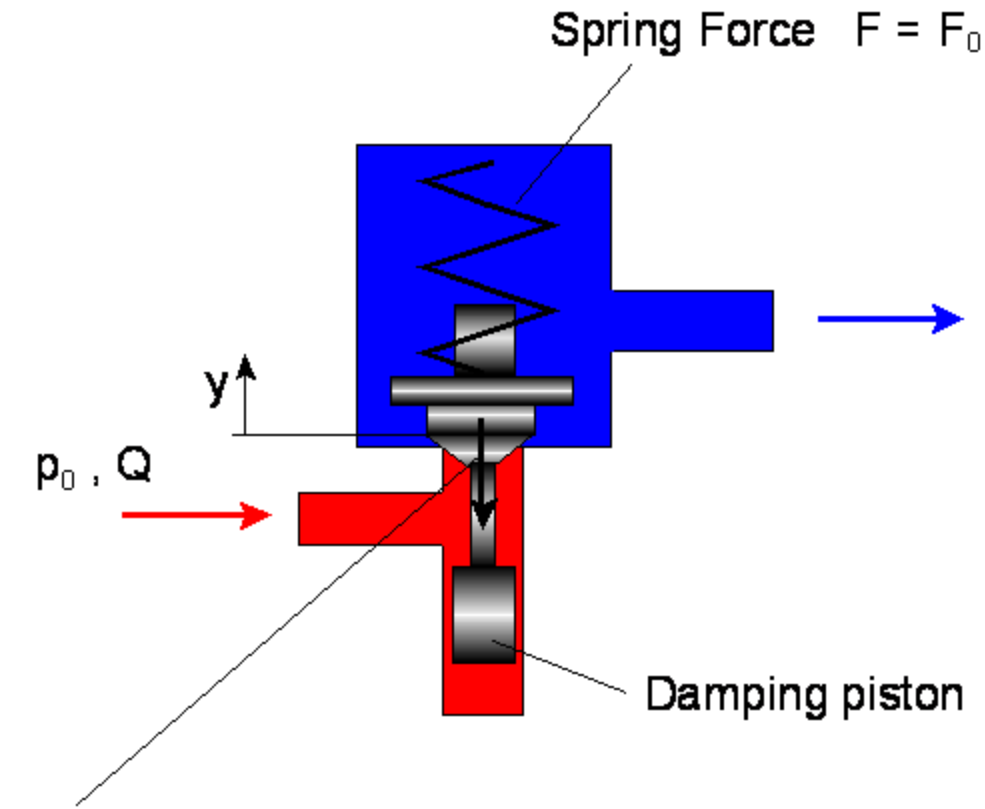
Pressure Relief Valve

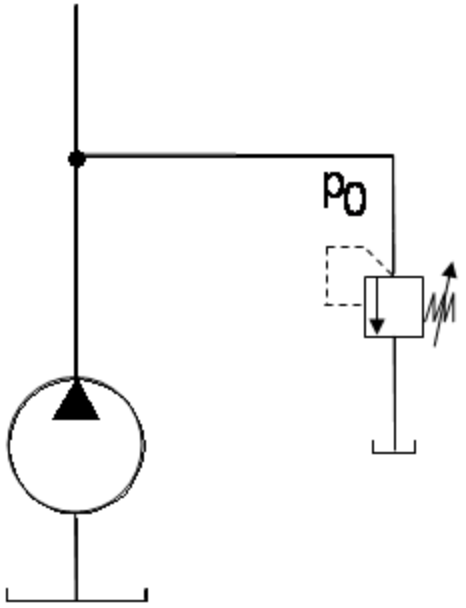




Pressure relief valve

Direct operated pressure relief valve (poppet type)



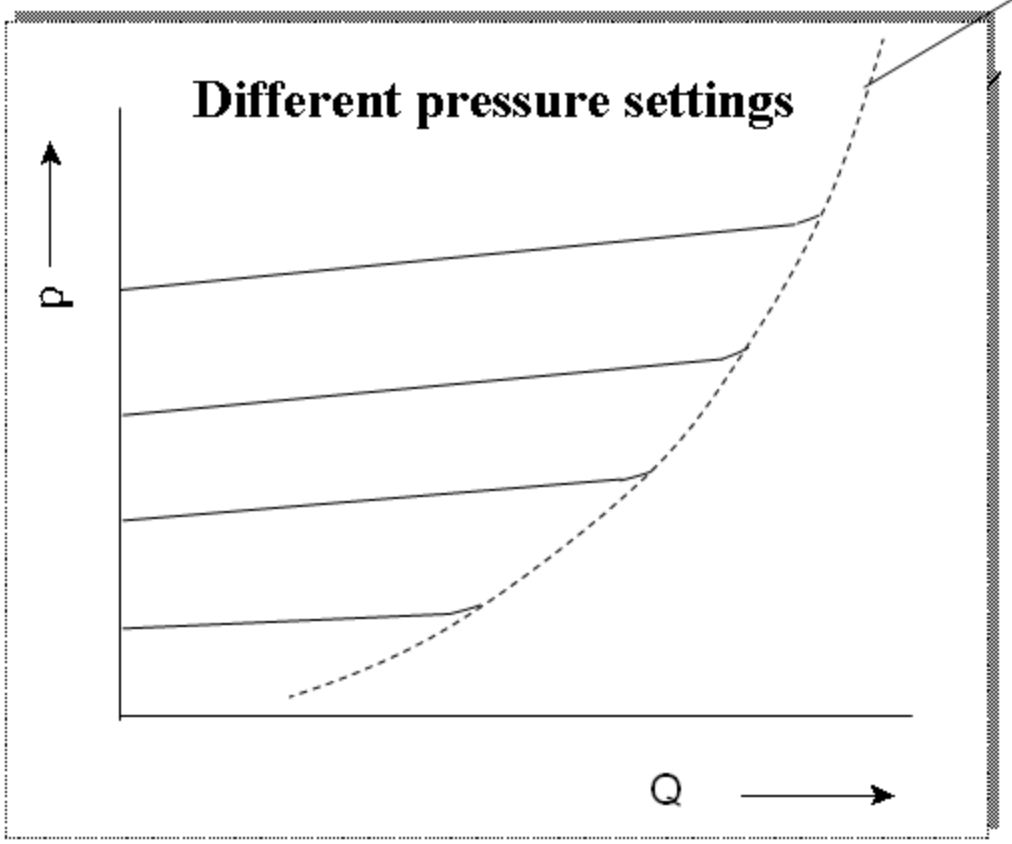


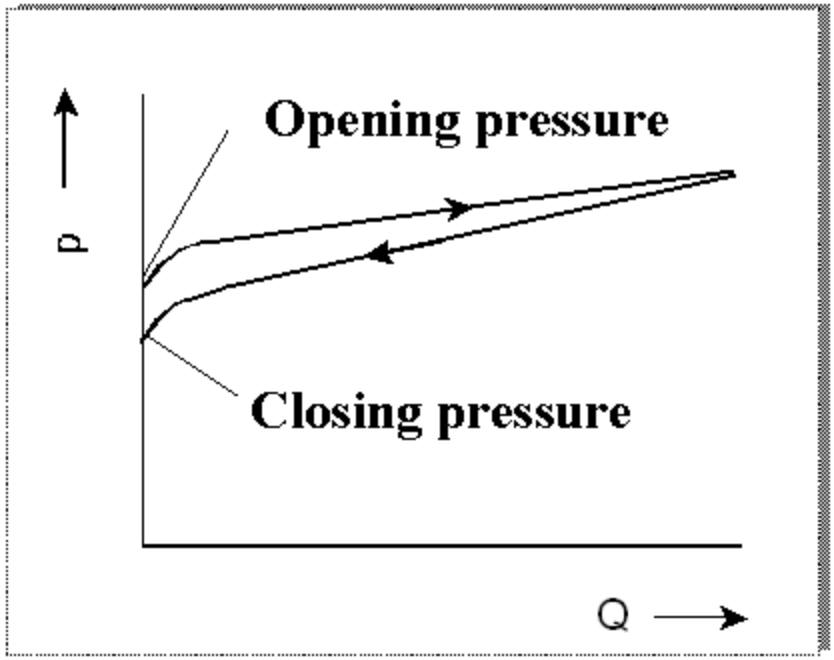
Pressure relief valve

Basic characteristics of pressure relief valves

Orifice flow

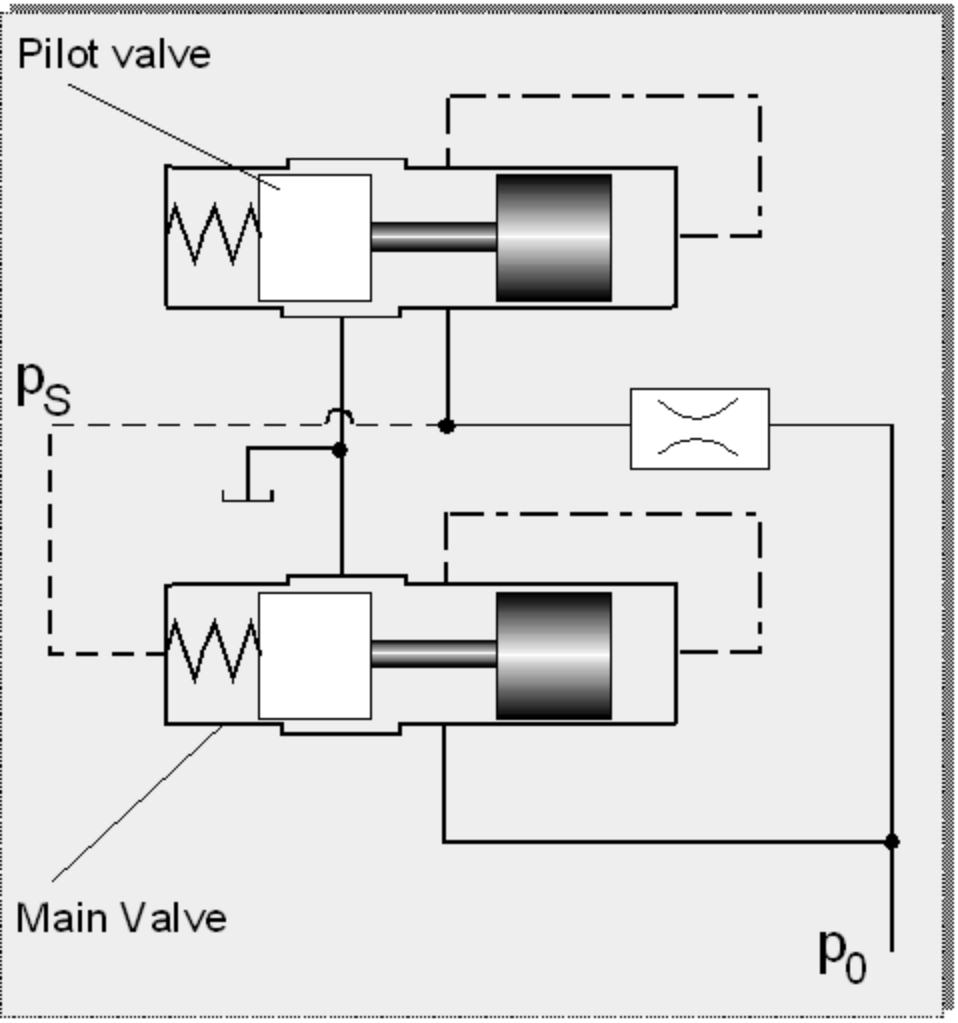
$$Q = \alpha_D \cdot A \cdot \sqrt{2/\rho} \cdot \sqrt{\Delta p}$$

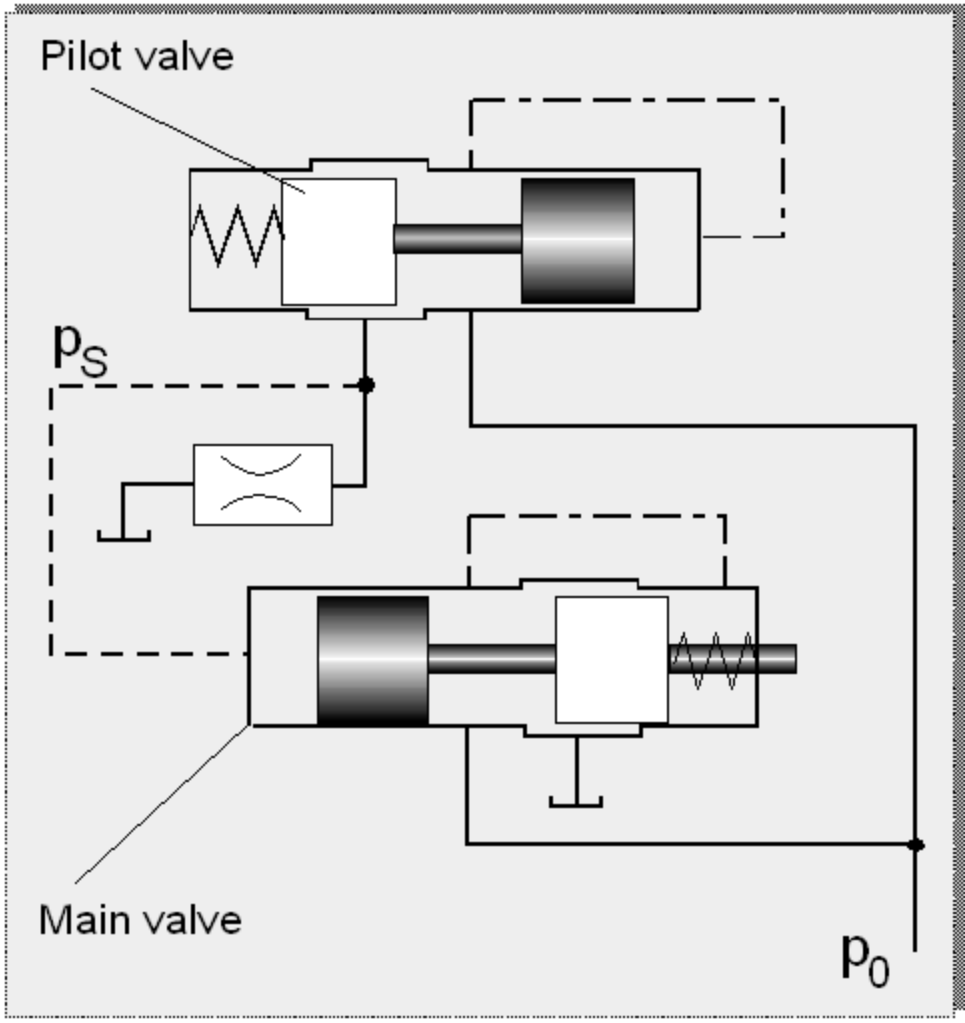




Pressure relief valve

Pilot operated pressure relief valve

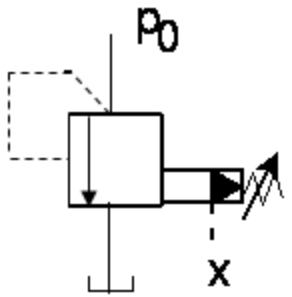


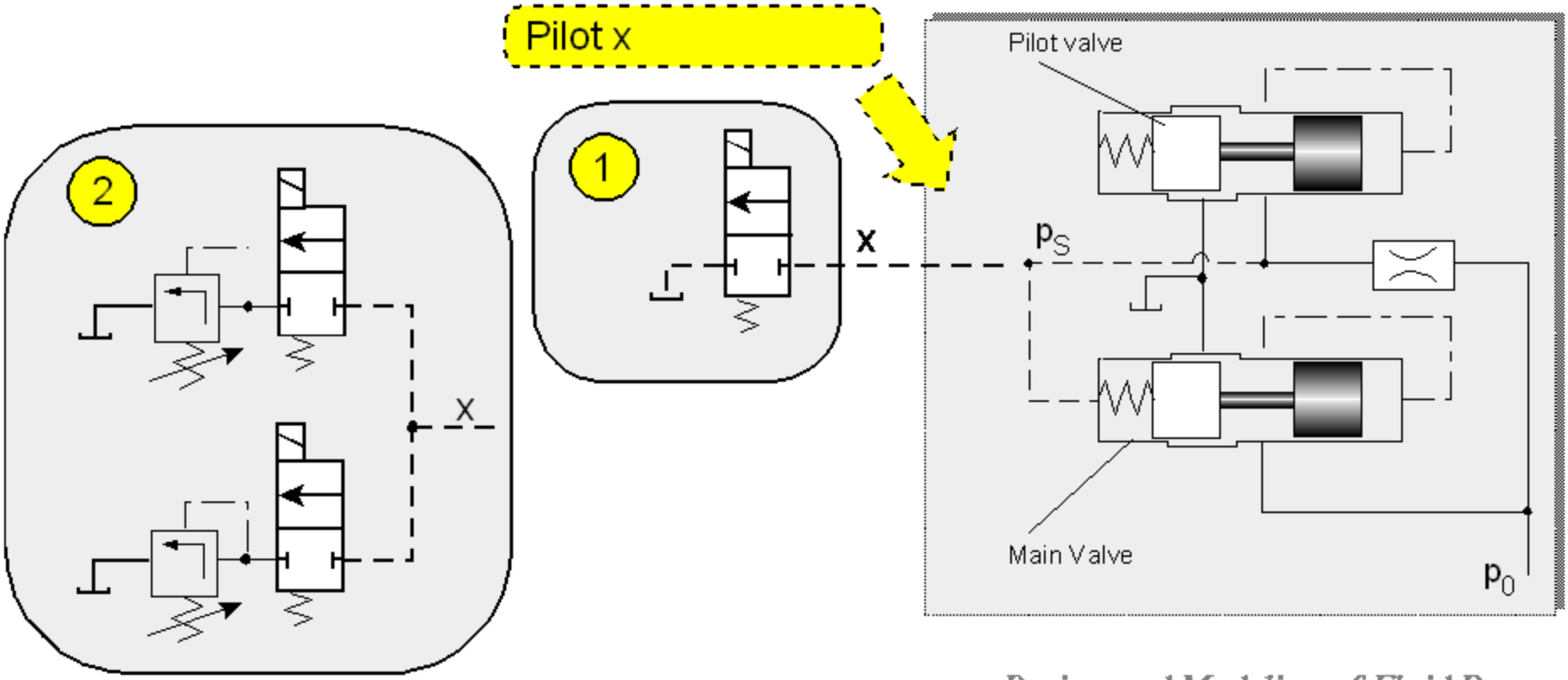


Pressure relief valve

Pressure relief valves with:

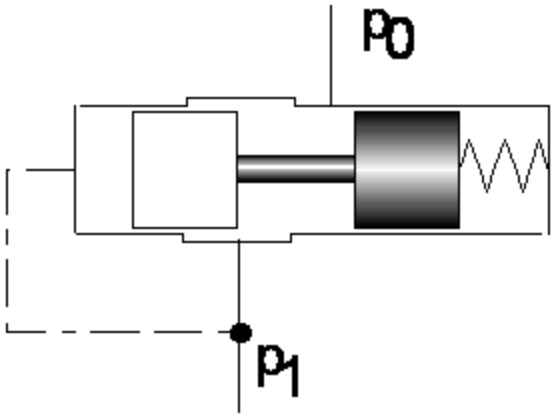
- electrical release (1)
- two pressure settings (2)



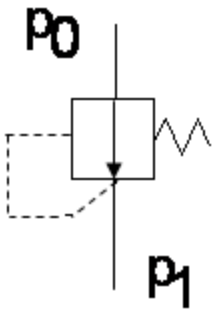


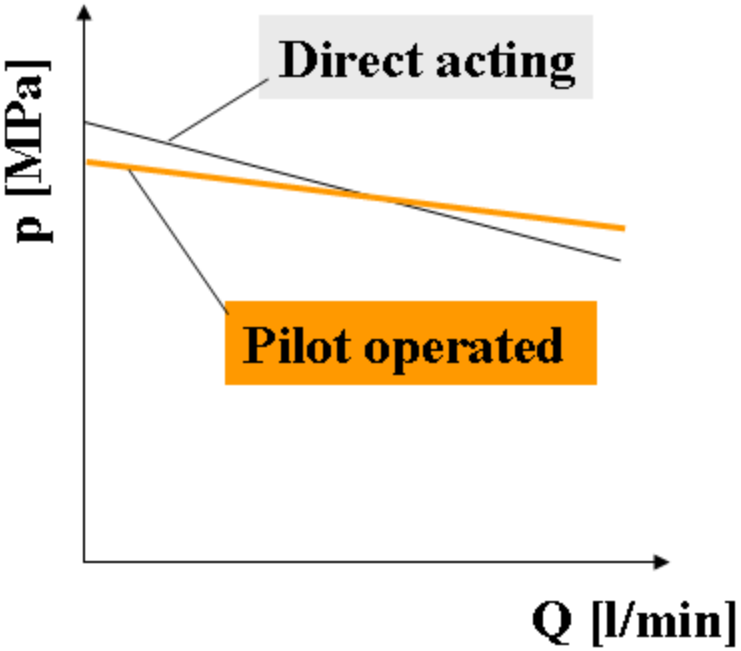
Pressure reducing valve

Pressure p_1 is controlled

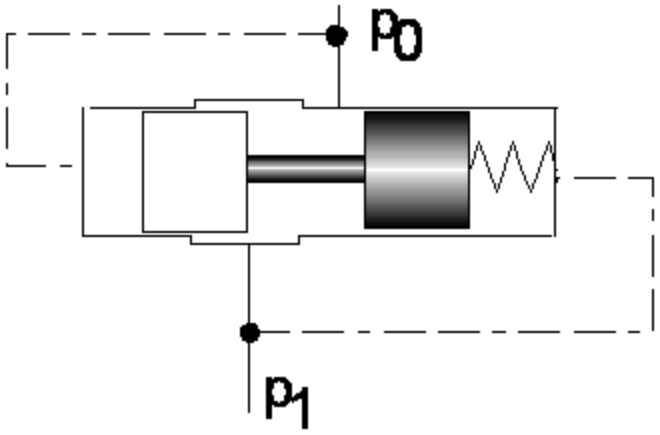


$p_0 > p_1$





Pressure difference is controlled

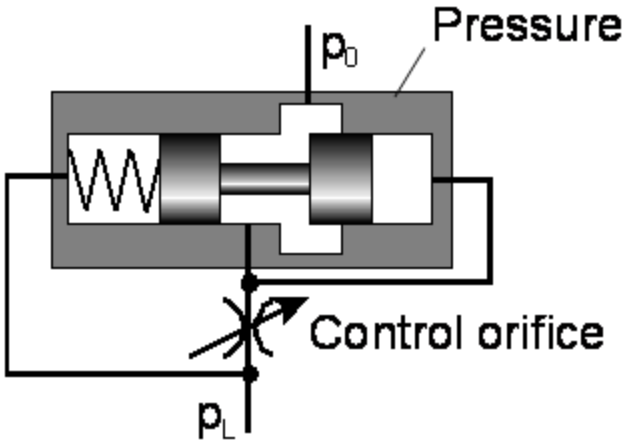


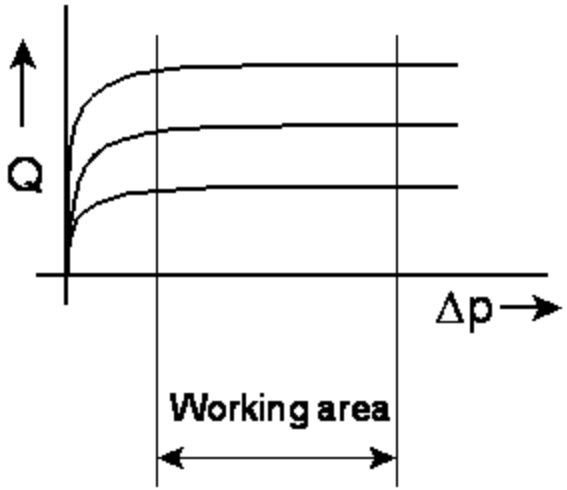
$\triangle p = p_0 - p_1 = F_F / A$

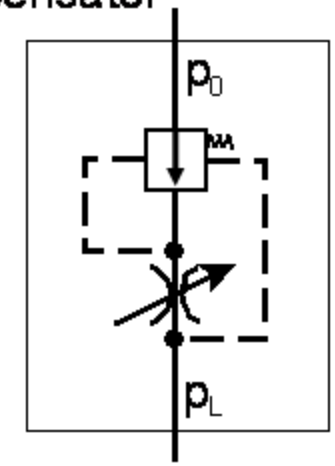
Flow control valve

Pressure compensated flow control

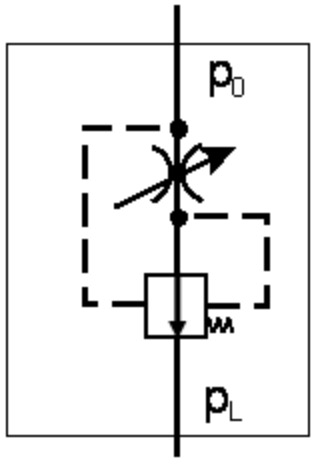
Pressure compensator in series with control orifice



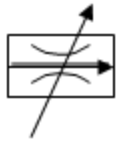




Inlet control type



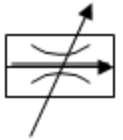
Outlet control type

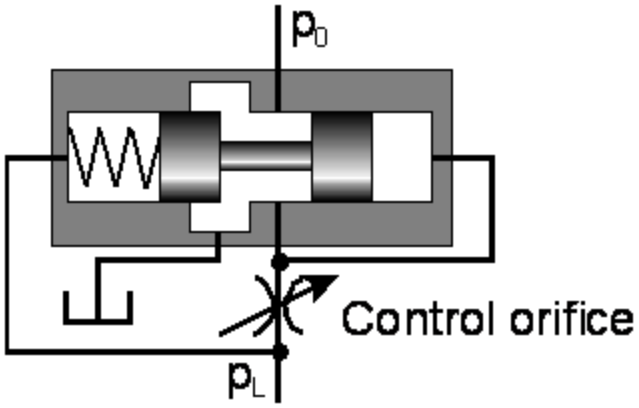


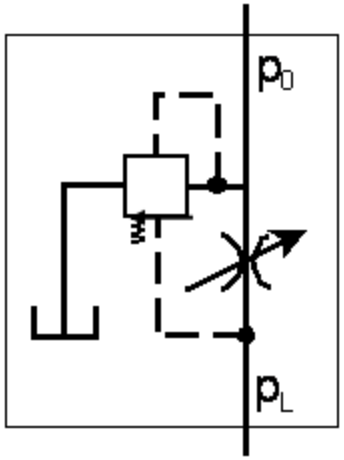
Flow control valve

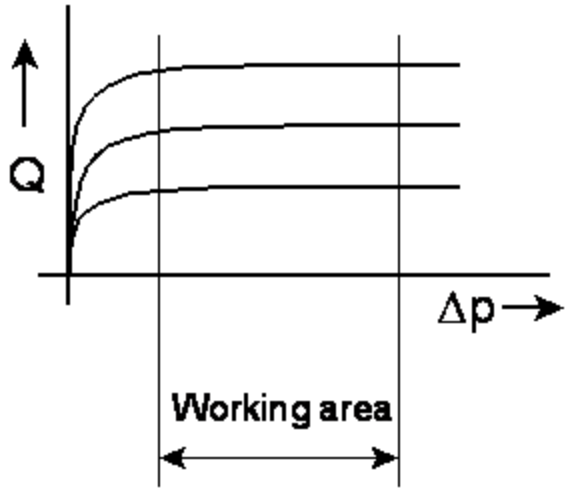
Pressure compensated flow bypass control valve

Relief valve parallel to control orifice









Cannot be used in parallel arrangement!