Design and Modeling of Fluid Power Systems ME 597/ABE 591 Lecture 12

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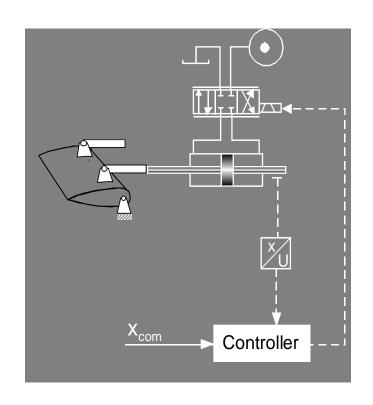


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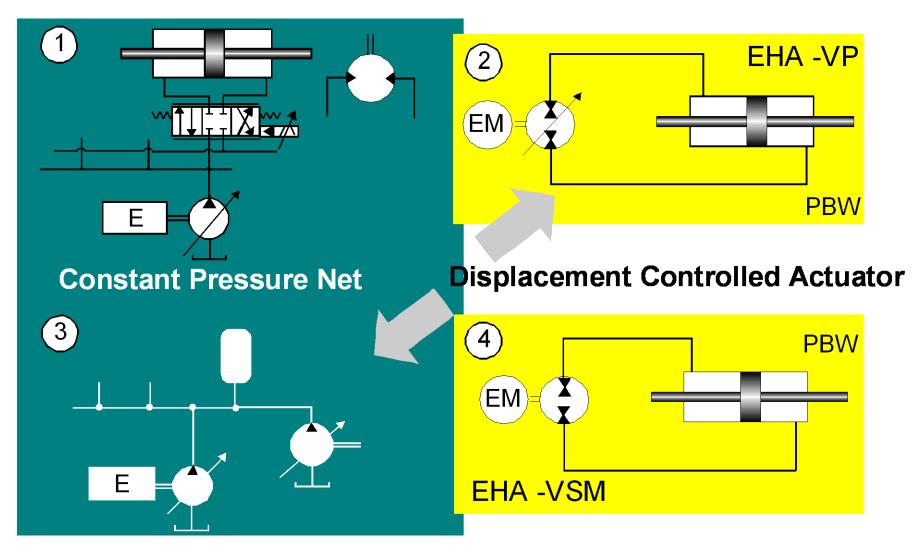
- Classification of power supply systems
- Pump control systems
- Modeling of pump control
- Load sensing systems



Classification of hydraulic actuators



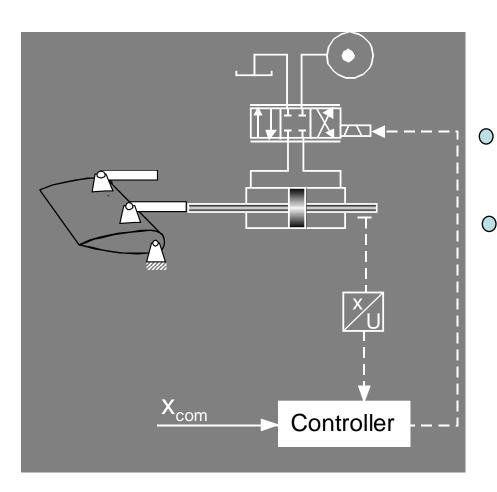




Overview pressure supply systems







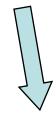
Fixed displacement pumps

Flow source

Pressure source



Pressure controlled systems



Variable displacement pumps

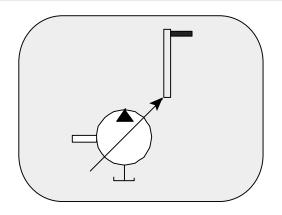
Classification pump control systems



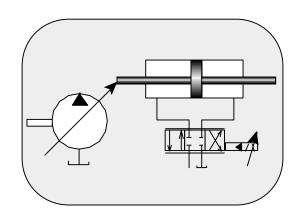


Open and closed loop control

Manual actuation

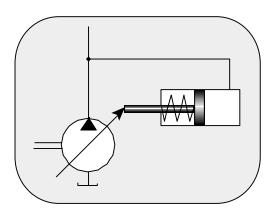


Electro-hydraulic actuation

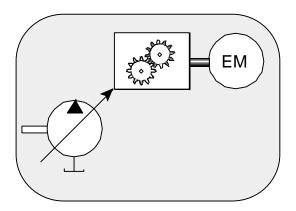


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Hydraulic control



Electro-mechanical actuation



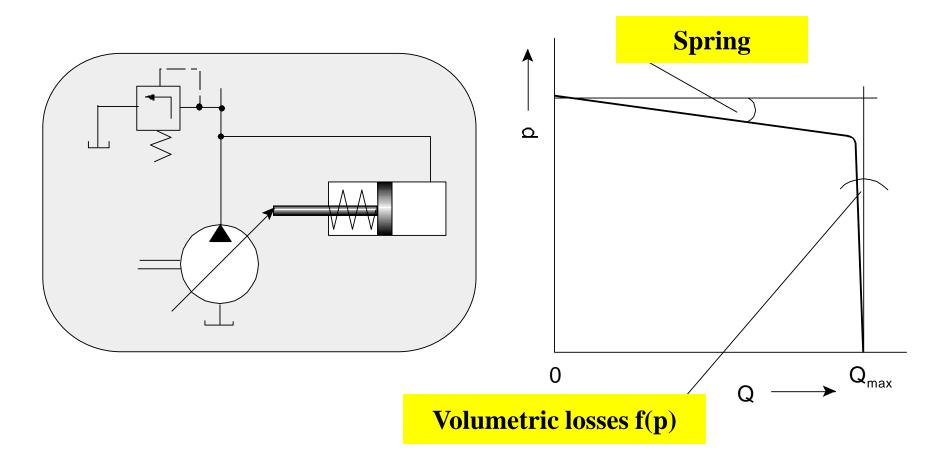
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Pump control





Pressure compensated pump – direct hydraulically operated & controlled

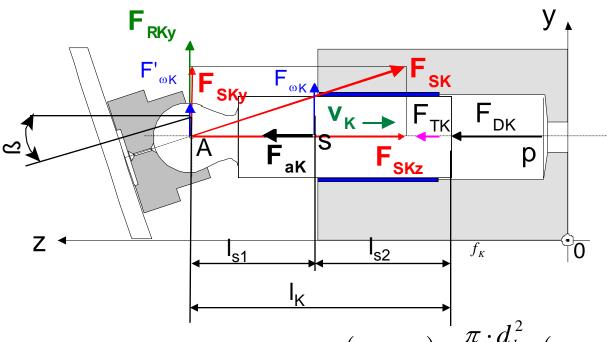


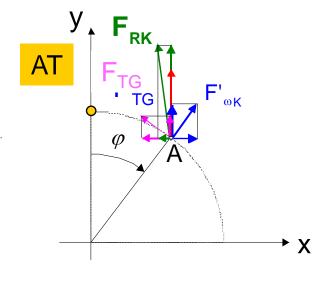
Axial piston pump – force analysis





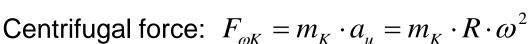
 F_{SK} ... reaction force of swash plate





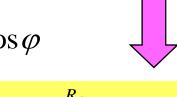
Slipper friction force:

Pressure force: $F_{DK} = A_K \cdot (p - p_e) = \frac{\pi \cdot d_k^2}{4} \cdot (p - p_e)$ Inertia force: $F_{aK} = -m_K \cdot a_K = m_K \cdot \omega^2 \cdot R \cdot \tan \beta \cdot \cos \varphi$



Piston friction force:
$$F_{TK} = f_K \cdot F_{RK} \cdot sign(-v_K)$$

with f_K friction coefficient



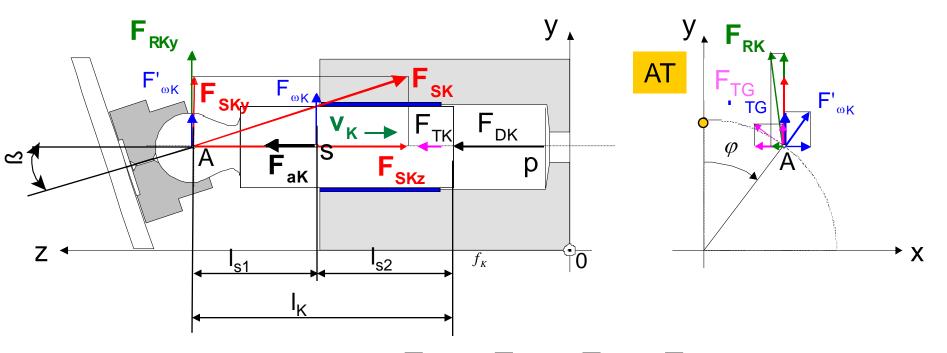
$$F_{TG} = \int_{r_G}^{R_G} \tau \cdot 2 \cdot \pi \cdot r \cdot dr$$

Forces applied on the piston





F_{SK} ... reaction force of swash plate



Resultant axial piston force:

$$F_{AK} = F_{DK} + F_{aK} + F_{TK}$$

Reaction force of swash plate:

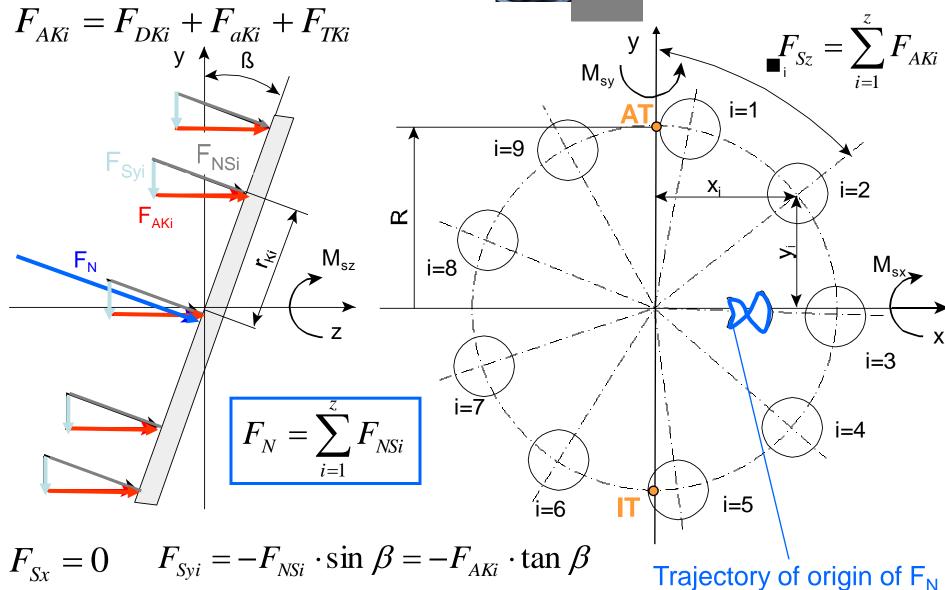
$$F_{SK} = -\frac{F_{AK}}{\cos \beta}$$

Resultant radial force:
$$F_{RK} = \sqrt{\left(F_{SKy} + F'_{\omega Ky} + F_{TGy}\right)^2 + \left(F'_{\omega Kx} + F_{TGx}\right)^2}$$

Forces exerted on swash plate







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Pressure forces dependent on cylinder pressure



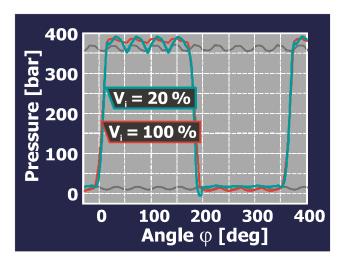


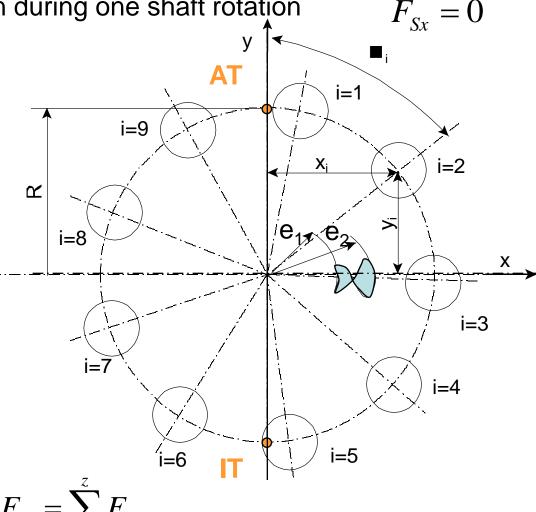
Normal force F_N changes its origin during one shaft rotation

$$F_{AKi} = F_{DKi} + F_{aKi} + F_{TKi}$$

Pressure force F_{DKi} depends on instantaneous cylinder pressure p_i

$$F_{Sy} = \sum_{i=1}^{z} F_{Syi} = -\tan \beta \cdot \sum_{i=1}^{z} F_{AKi}$$





$$F_{Sz} = \sum_{i=1}^{z} F_{AKi}$$

Moments acting on swash plate



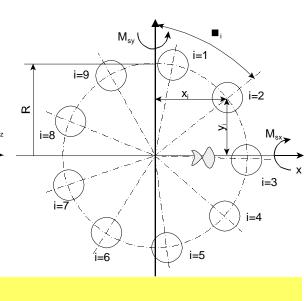
$$F_{Sx} = 0 \quad F_{Sy} = \sum_{i=1}^{z} F_{Syi} = -\tan \beta \cdot \sum_{i=1}^{z} F_{AKi}$$

$$F_{Sz} = \sum_{i=1}^{z} F_{AKi}$$

$$M_{Sx} = \sum_{i=1}^{z} \left(F_{Szi} \cdot y_{Si} - F_{Syi} \cdot z_{Si}\right)$$

$$M_{Sx} = \sum^{z} R \cdot F_{AKi} \cdot \cos \varphi_{i} \cdot (1 + \tan^{2} \beta)$$

$$n^2 \beta$$



$$M_{Sx} = \frac{R}{\cos^2 \beta} \cdot \sum_{i=1}^{z} F_{AKi} \cdot \cos \varphi_i$$

$$M_{Sy} = -\sum_{i=1}^{z} F_{Szi} \cdot x_{Si} = -R \cdot \sum_{i=1}^{z} F_{AKi} \cdot \sin \varphi_{i}$$

$$x_{Si} = R \cdot \sin \varphi_i$$

$$y_{Si} = R \cdot \cos \varphi_i$$

$$z_{Si} = y_{Si} \tan \beta = R \cdot \tan \beta \cdot \cos \varphi_i$$

 $\overline{i=1}$ Moment due to friction force of slipper F_{TG}

$$M_{Sz} = \sum_{i=1}^{z} F_{Syi} \cdot x_{Si} + M_{TSz} = -R \cdot \tan \beta \cdot \sum_{i=1}^{z} F_{AKi} \cdot \sin \varphi_i + M_{TSz}$$

Moments acting on swash plate

Friction forces F_{TS} exerted on swash plate due to slipper slipper

movement:

$$F_{TSi} = -F_{TGi}$$

$$F_{TSxi} = F_{TSi} \cdot \cos \varphi_i$$

$$F_{TSyi} = -F_{TSi} \cdot \sin \varphi_i$$

$$F_{TSzi} = 0$$

$$M_{TSz} = \sum_{i=1}^{z} \left(F_{TSyi} \cdot x_{TSi} - F_{TSxi} \cdot y_{TSi} \right)$$

$$M_{TSz} = -R \cdot \sum_{i=1}^{z} F_{TSi} \left(\sin^2 \varphi_i + \cos^2 \varphi_i \right) = -R \cdot \sum_{i=1}^{z} F_{TSi}$$



$$x$$

$$x_{Si} = R \cdot \sin \varphi_i$$

$$y_{Si} = R \cdot \cos \varphi_i$$

$$z_{Si} = R \cdot \tan \beta \cdot \cos \varphi_i$$

$$M_{Sz} = \sum_{i=1}^{z} F_{Syi} \cdot x_{Si} + M_{TSz} = -R \cdot \left(\sum_{i=1}^{z} F_{TSi} + \tan \beta \cdot \sum_{i=1}^{z} F_{AKi} \cdot \sin \varphi_i \right)$$

F_{TG} **↑**F_{TGy}

Forces exerted on swash plate





Resulting force F_S exerted on swash plate:

$$F_{S} = \sqrt{F_{Sy}^2 + F_{Sz}^2}$$

and moments about y- and z-axis:

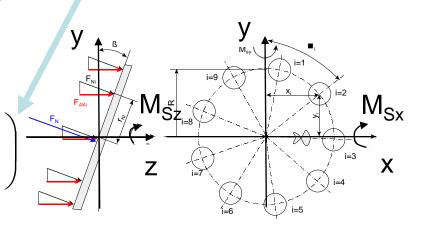
$$M_{Sy} = -\sum_{i=1}^{z} F_{Szi} \cdot x_{Si} = -R \cdot \sum_{i=1}^{z} F_{AKi} \cdot \sin \varphi_i$$

$$M_{Sz} = -R \cdot \left(\sum_{i=1}^{z} F_{TSi} + \tan \beta \cdot \sum_{i=1}^{z} F_{AKi} \cdot \sin \varphi_i \right)$$

Moment M_{Sx}

$$M_{Sx} = \frac{R}{\cos^2 \beta} \cdot \sum_{i=1}^{z} F_{AKi} \cdot \cos \varphi_i$$

must be carried by swash plate bearing



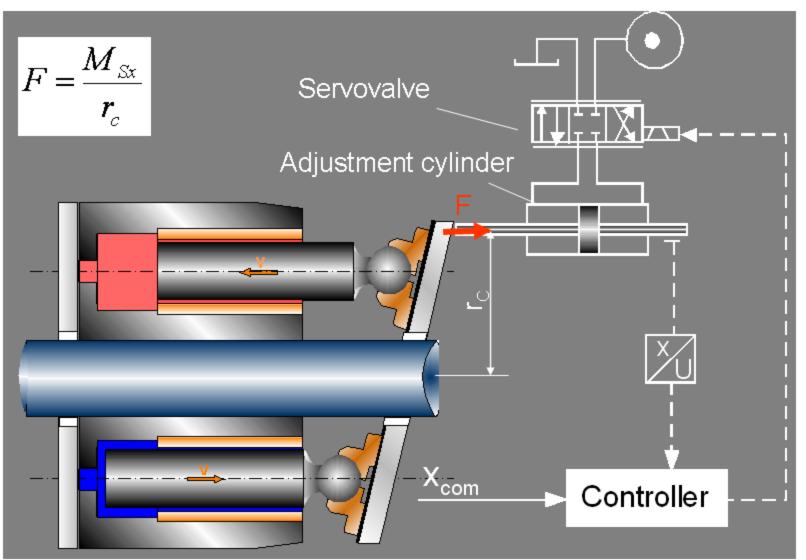
In case of variable displacement pumps $M_{Sx} = \frac{K}{\cos^2 \beta} \cdot \sum_{i=1}^{\infty} F_{AKi} \cdot \cos \varphi_i$ M_{Sx} must be overcome by the swash plate control system

Swash plate control system





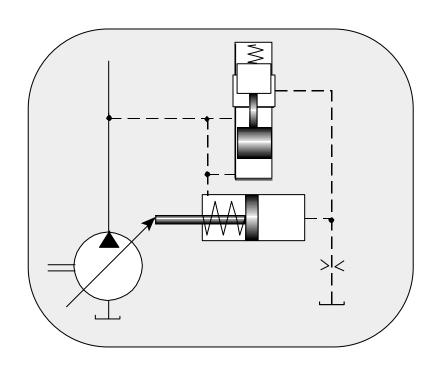
Electrohydraulic swash plate control system

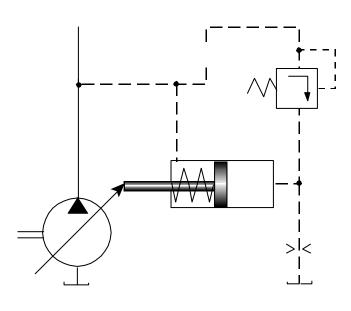






Pressure compensated pump using one variable hydraulic resistance

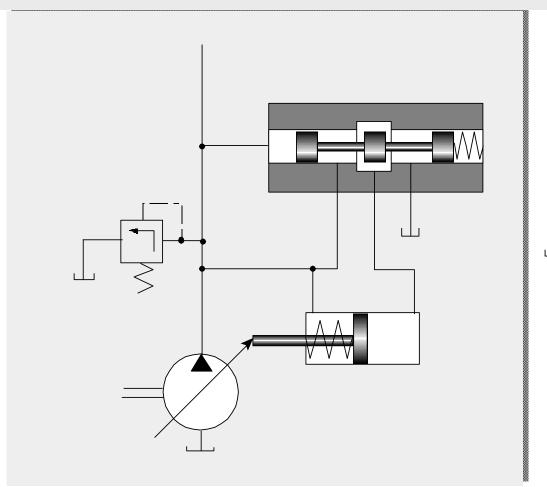


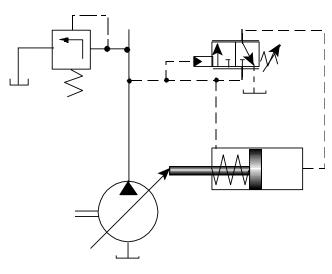






Pressure compensated pump using two variable hydraulic resistances





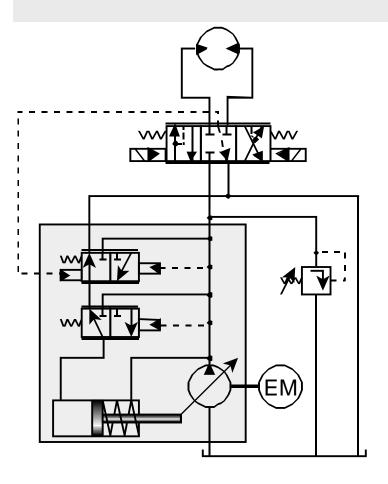
Load sensing

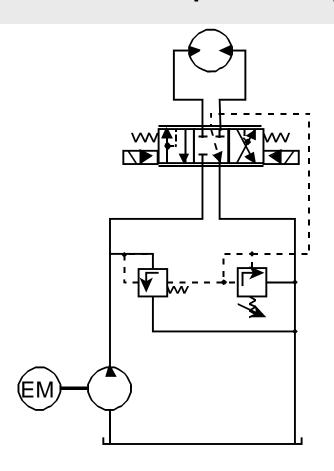




with variable displacement pump

with fixed displacement pump



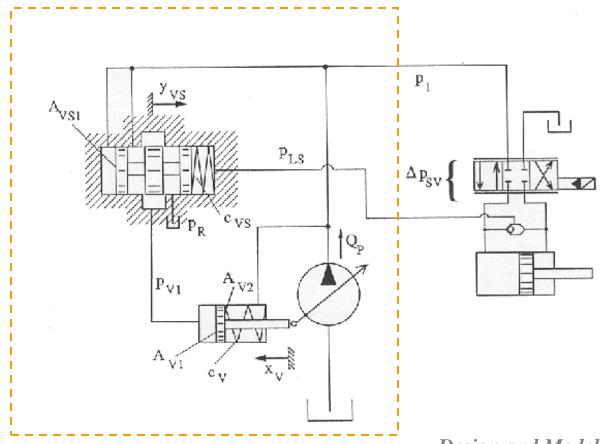


Load sensing





Hydraulic-mechanical LS – pump control



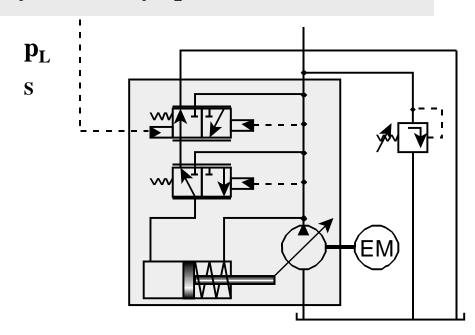
Load Sensing Pump Control

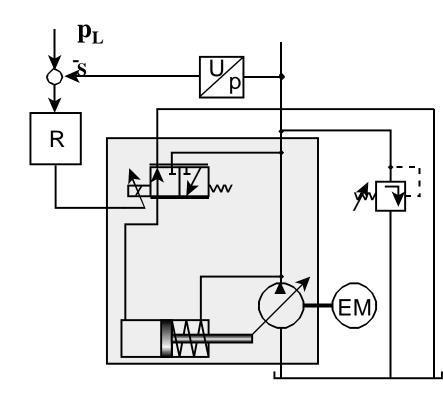




Electric closed loop control & hydraulically operated

Hydraulically operated and controlled



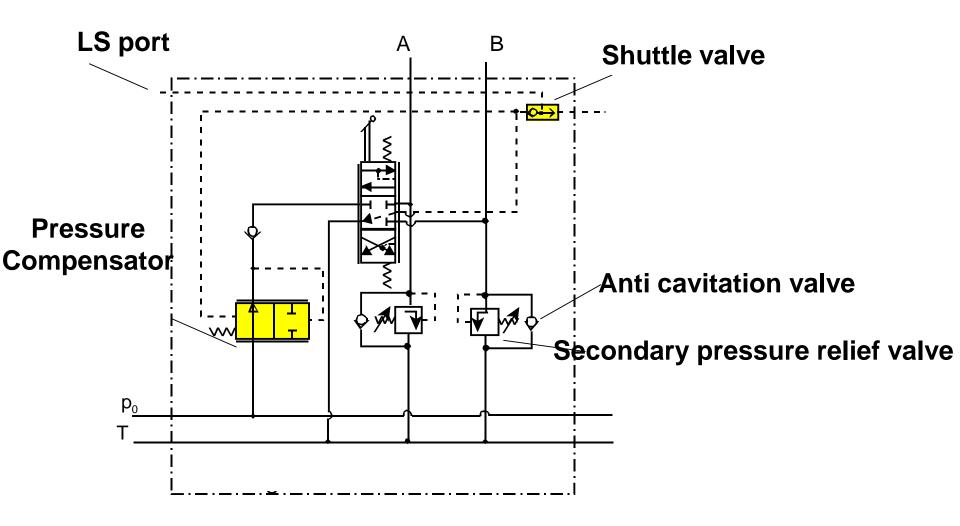


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LS-Valve





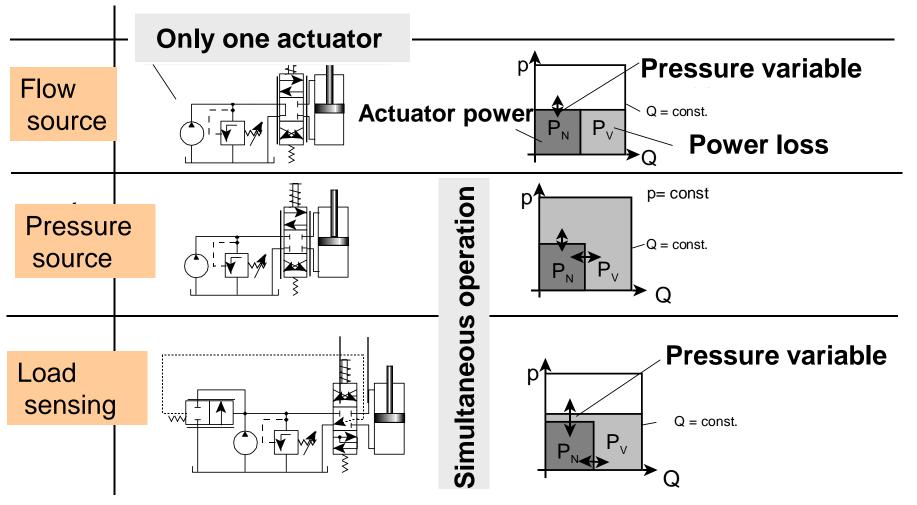


Classification power supply





Systems with fixed displacement pump



Classification power supply





Systems with variable pumps

