Advanced Control of the Hydraulic Asymmetric Actuator

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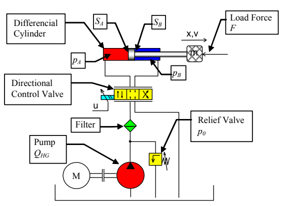
- Introduction
- Valve controlled actuator with linear differential cylinder
- Controller for position closed loop control
- Design and testing of the state controller with the observer
- Conclusions

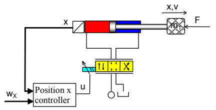
Introduction – Linear Hydraulic Actuator



Mathematical Model of the Valve Controlled Linear Actuator

Motion equation

$$m\ddot{x} + b\dot{x} = S_A p_A - S_B p_B - F - F_T \operatorname{sgn}(\dot{x}) \qquad \alpha = \frac{S_A}{S_B}$$



Differential equations for the pressures in the cylinder chambers

$$\dot{p}_A = \frac{1}{C_A}\left(Q_A - S_A v - Q_{LA} - Q_L\right) \qquad C_A = \frac{V_A + S \cdot x}{K}$$

$$\dot{p}_B = \frac{1}{C_B}\left(S_B v - Q_B - Q_{LB} + Q_L\right) \qquad C_B = \frac{V_B + S \cdot (h - x)}{K}$$

Flow equation

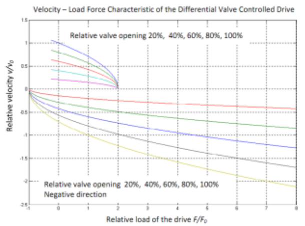
$$Q_i = B \cdot abs\left(x_{sv} \pm x_{sv0}\right) \cdot \sqrt{abs(\Delta p_i)} \cdot \operatorname{sgn}\left(\Delta p_i\right) \qquad \beta = \frac{S_{VA}}{S_{VB}}$$

valves spool flow areas ratio

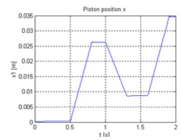
Model of the valve dynamics – 2nd order term T_{sv}, ξ_{sv}

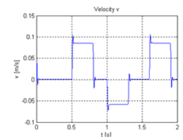
Velocity – Load characteristic of the asymmetric actuator

Velocity gain of the open loop system depends on the direction of the motion – piston velocity



Open loop control of the asymmetric actuator – piston position (left), velocity (right)





Steady state values – valve controlled asymmetric actuator

Steady state values of the system variables of the asymmetric actuator characterized by the ratio α and ratio β, system pressure p_0, specified valve flow Q_{jmen} and pressure p_{jmen}.

	running out of the piston	running in of the piston
velocity v	$v = v_0 x_{sv}\sqrt{1 - \frac{F}{\alpha \cdot F_0}}$	$v = v_0 x_{sv}\sqrt{\frac{1}{\alpha} + \frac{F}{\alpha \cdot F_0}}$
pressure p_A	$p_A = \frac{\beta^2 p_0 + \alpha^2 p_z}{\beta^2 + \alpha^3}$	$p_A = \frac{\alpha^2 p_0 + \alpha^2 p_z}{\beta^2 + \alpha^3}$
pressure p_B	$p_B = \frac{\alpha\beta^2 p_0 - \beta^2 p_z}{\beta^2 + \alpha^3}$	$p_B = \frac{\alpha^3 \cdot p_0 - \beta^2 p_z}{\beta^2 + \alpha^3}$
max. pulling force	$F_{max} = -\frac{\beta^2}{\alpha^2} F_0$	$F_{max} = -F_0$
max. Pushing force	$F_{max} = \alpha \cdot F_0$	$F_{max} = \frac{\alpha^3}{\beta^2} \cdot F_0$
running out velocity without load $v_0 = \frac{Q_{jmen}}{S_B}\beta\sqrt{\frac{\alpha \cdot p_0}{(\beta^2 + \alpha^3)p_{jmen}}}$	force F_0 (used for the normalization) $F_0 = p_0 S_B$	load pressure $p_z = \frac{F}{S_B}$

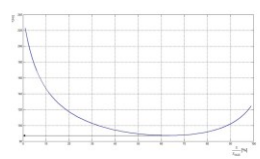
Resonance Frequency of the Hydraulic Cylinder

Hydraulic stiffness of the oil in the chamber A and B

$$K_{HA} = \frac{KS_A^2}{V_A} \qquad K_{HB} = \frac{KS_B^2}{V_B}$$

Stiffness of the piston

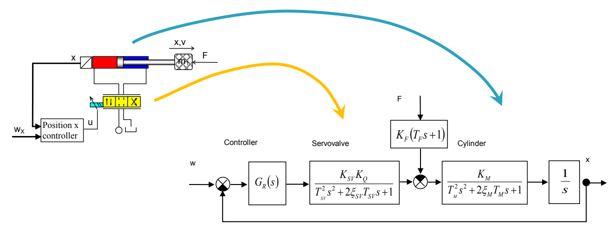
$$K_H = K_{HA} + K_{HB}$$



Resonance frequency of the hydraulic cylinder

$$f_{HM} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{K}{m} \cdot \left(\frac{S_A^2}{S_A \cdot x + V_{A0}} + \frac{S_B^2}{S_B \cdot (x_{MAX} - x) + V_{B0}} \right)}$$

Closed Loop Control of the Asymmetric Hydraulic Cylinder



T_{sv}, ξ_{sv} $T_M\ \xi_M$

$$\kappa = \frac{f_{SV}}{f_M} = \frac{T_M}{T_{SV}}$$

Recommended Controllers for Position Control

Controller	Transfer function	Suitable for ration κ
PDT1 Controller	$G(s)=K_R\frac{T_D s+1}{Ts+1}$	$\kappa=0\div0.5$
P controller	$G(s)=K_R$	$\kappa=0.5\div1$
PT1 controller	$G(s)=K_R\frac{1}{Ts+1}$	$\kappa=1\div3$
State controller	$u=sw-\mathbf{r}^T\mathbf{x}$	$\kappa\geq3$

State Controller

State model of the hydraulic drive

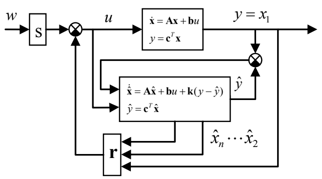
$$\begin{bmatrix}\dot{x}\\ \dot{v}\\ \dot{a}\\ \dot{x}_{sv}\\ \dot{v}_{sv}\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0\\ 0 & -\frac{1}{T_M^2} & -\frac{2\xi_M}{T_M} & \frac{K_M K_Q}{T_M^2} & 0\\ 0 & 0 & 0 & 0 & 1\\ 0 & 0 & 0 & -\frac{1}{T_{sv}^2} & -\frac{2\xi_{sv}}{T_{sv}}\end{bmatrix}\begin{bmatrix}x\\ v\\ a\\ x_{sv}\\ v_{sv}\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 0\\ 0\\ \frac{K_{sv}}{T_{sv}^2}\end{bmatrix}u$$

$$y=\begin{bmatrix}1 & 0 & 0 & 0 & 0\end{bmatrix}\mathbf{x}$$

State observer

$$\dot{\hat{\mathbf{x}}}=\mathbf{A}\hat{\mathbf{x}}+\mathbf{b}u+\mathbf{k}\cdot(y-\hat{y})$$
$$\hat{y}=\mathbf{c}^T\hat{\mathbf{x}}$$

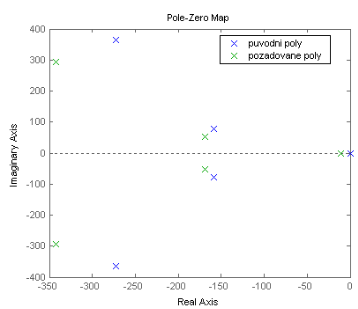
Control system with the state feedback and Luenberger observer



Design of the state feedback

$$u=sw-\mathbf{r}^T\mathbf{x}$$

$$s=\left(\mathbf{c}^T\left(\mathbf{b}\mathbf{r}^T-\mathbf{A}\right)^{-1}\mathbf{b}\right)^{-1}$$



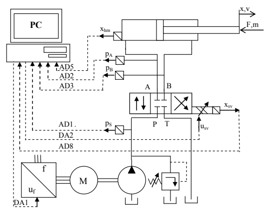
r = [565,74 52,46 –0,0656 14453 92,29]

Design of the Control Algorithm for the Embedded Control System

1. Analysis of the drive – analytical or experimental identification of the components, creation of the mathematical model, natural frequency calculation, modelling;
2. Position controller structure selection and tuning – different controllers are suitable and special rules for setting the controller gain are recommended in dependence on the dynamic properties of the hydraulic cylinder and control valve.
3. Controller implementation – use of the digital control systems and special rules which respect properties of the control of the hydraulic drives must be respected and implemented. The industrial controllers or embedded control systems are recommended. The detailed analysis and description of the control algorithms from the fluid power engineer is recommended.
4. Control system commissioning.

Development and Experimental Verification of the Control System

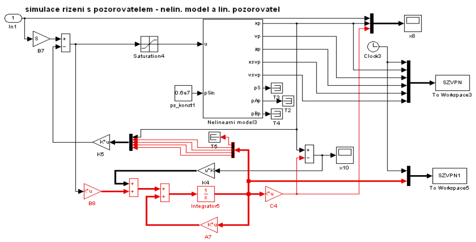
Block diagram of the hydraulic drive installed in the laboratory and connected to the control computer



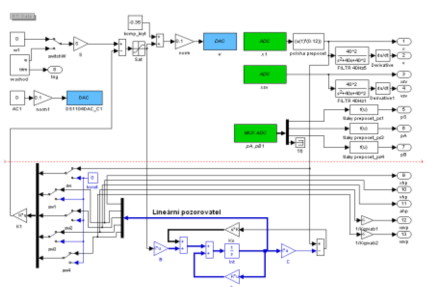
The data acquisition card DS1104 R&D

Simulation using Simulink

Simulation of the state feedback with Luenberger observer



Experimental Realization of the Control with Luenberger observer



Experimental Results – measured and observed variables

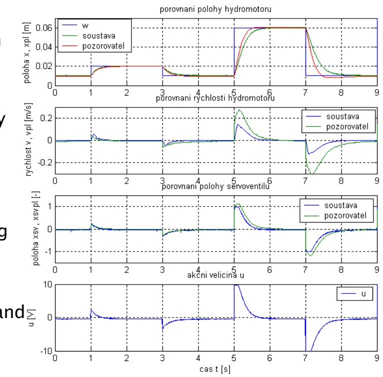
Measured variables and observed using the observer – piston position, velocity, valve opening, input (soustava means system, pozorovatel means observer)

Position

Velocity

Valve opening

Command value



CONCLUSIONS

- The dynamic properties of the asymmetric valve controlled actuator were summarized.
- The controller should respects the velocity depending gain
- The state controller with the Luenberger observer is suitable for the given class of the hydraulic actuators characterized by low damping and low eigen frequency.
- The control algorithm can be implemented into the embedded control system.
- The functionality was confirmed using the simulation and experiments on the test rig.

Thank you for your attention.

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