Position Control of Hydraulic Servo Axis in Fluid Mechatronics Lab

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Seminar given at

AUB

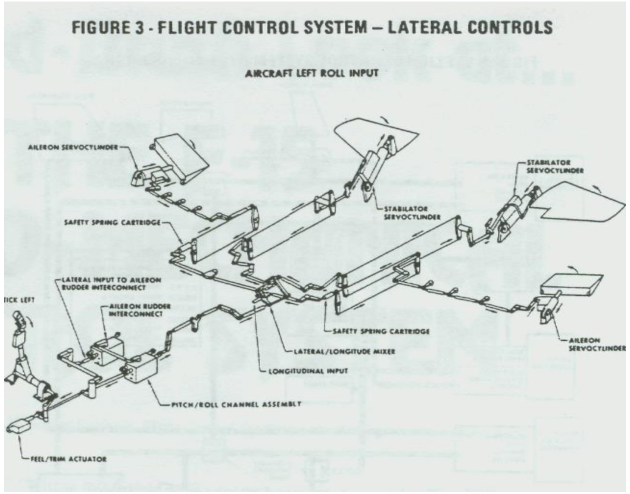
as part of MECH 647 graduate course on Hydraulic Servo Systems

Content

- Introduction, servo hydraulic systems
- Test bench description
- Control problem
- Physical modeling
- Control technics

Hydraulic Servo Systems

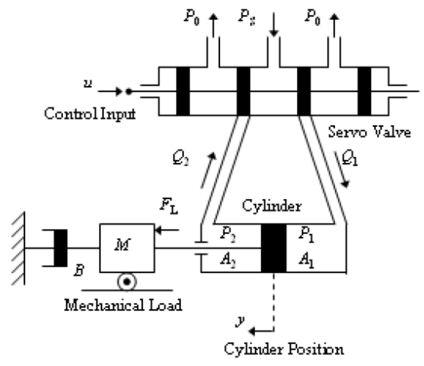
- **Description**: control system that converts a low power motion into much greater power motion.
- *Applications in industry aerospace*

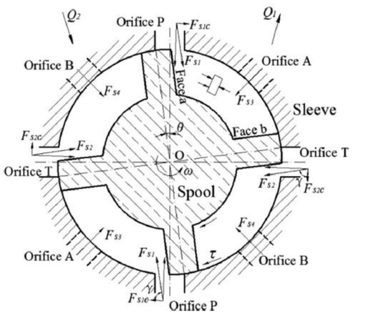


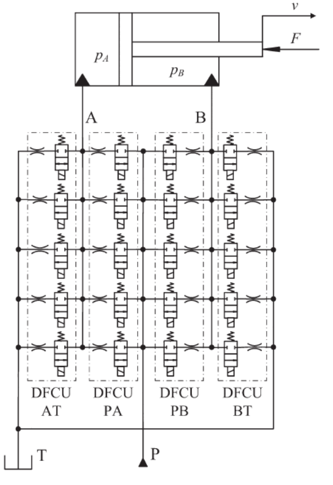
- **Advantages**:
  - High power density
  - Accurate
  - high cut-off frequency
  - Sensitive application
- **Disadvantages**:
  - High cost
  - vulnerable

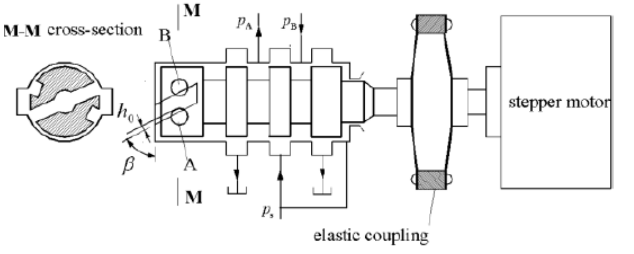
HSS Components

- Pump
- Pipelines
- fluid
- Control valves:
  - sliding spool
  - rotary spool
  - sliding + rotary
  - digital
- Actuators:
  - Linear
  - Rotary

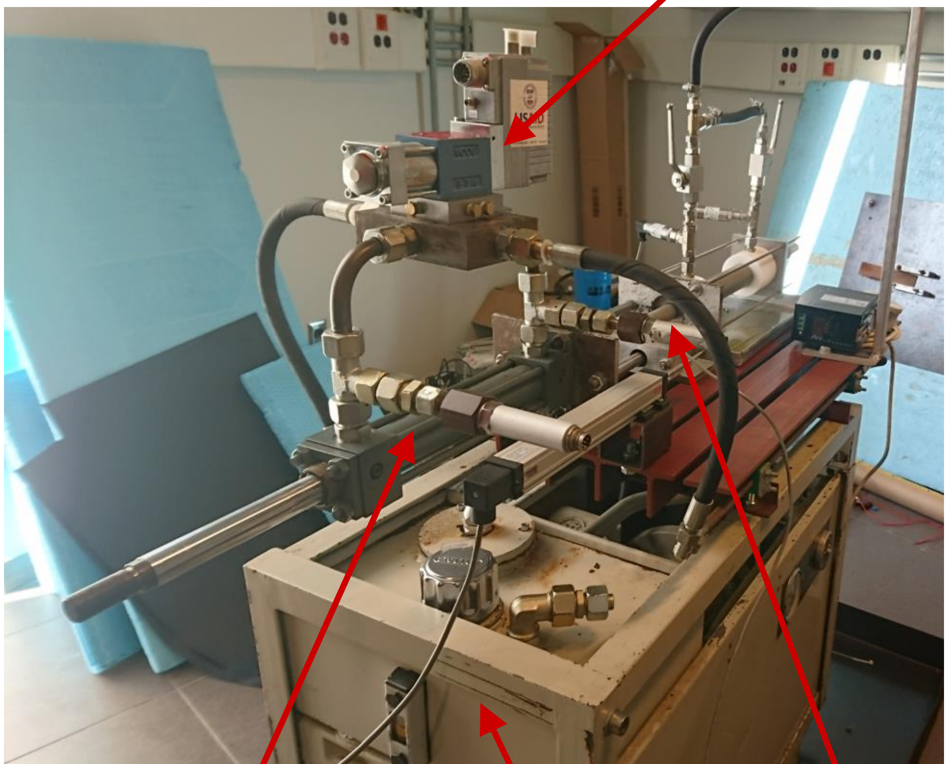


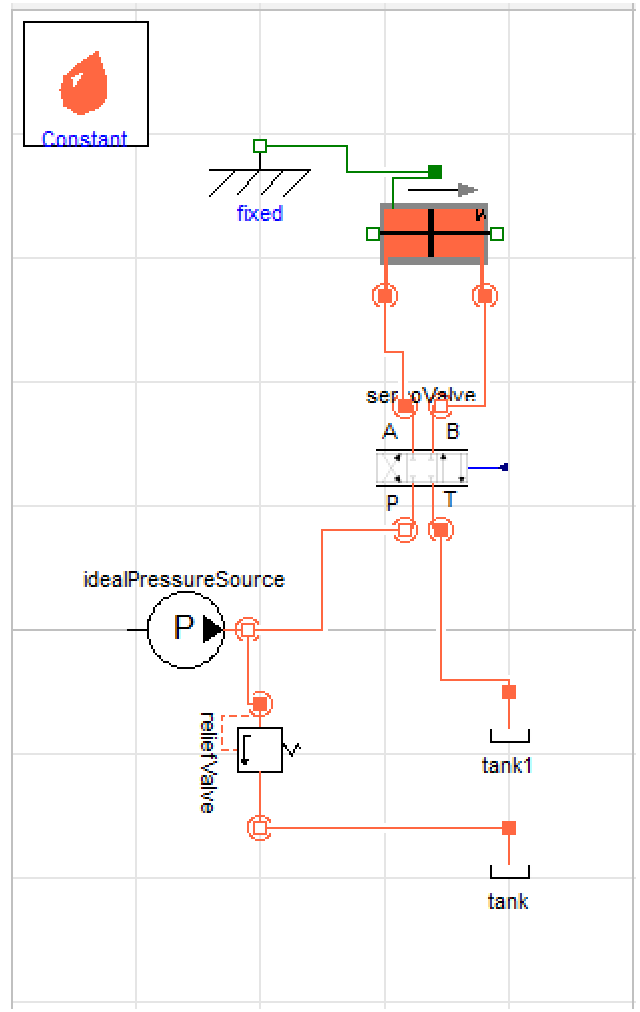




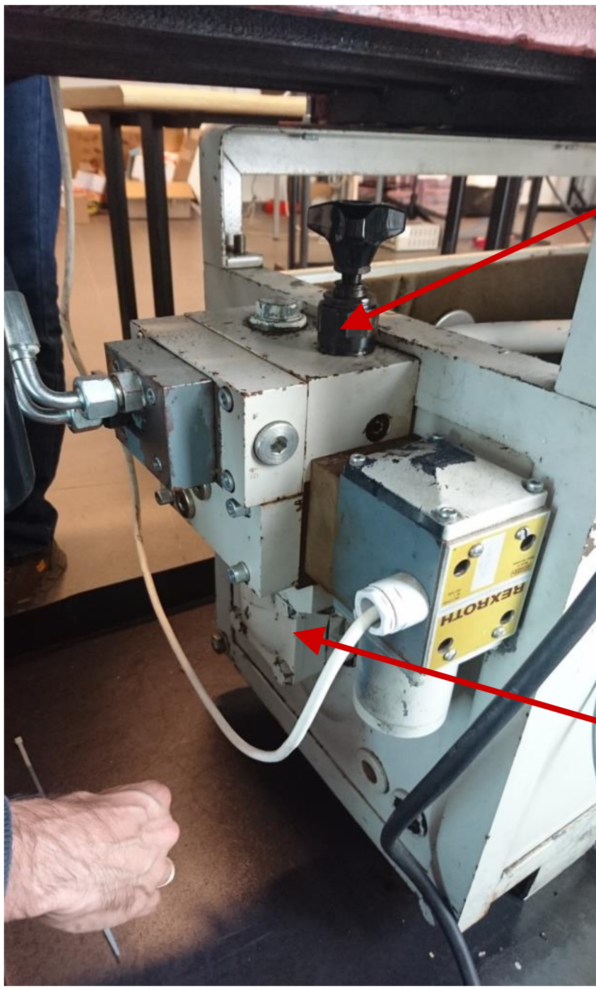


Basic Test Bench Elements



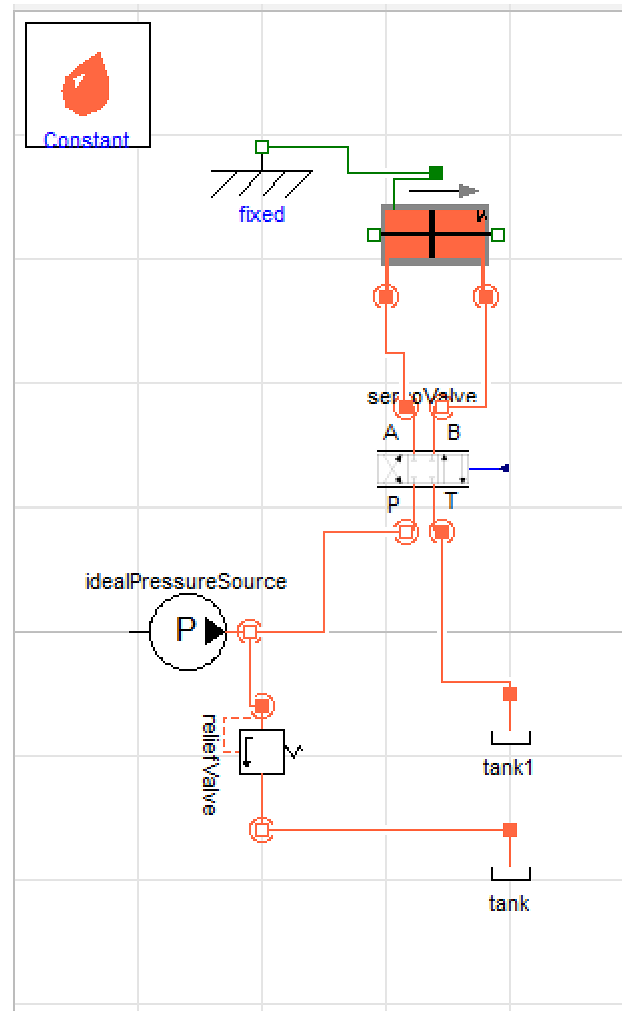


Basic Test Bench Elements



pressure relief valve

Pump
5 kW,
110 bar



Control Problem

Position control of hydraulic Servo axis using MOOG servo-valve, without applicable load

Desired performance:

- Response time
- accuracy

Modeling challenges

- Multidisciplinary knowledge required for complete modeling

- Nonlinearities:
  - fluid compressibility
  - flow properties of the servo-valve
  - friction in the hydraulic actuators
- Uncertainties:
  - operating conditions: valve, oil and load parameters (temperature dependent…)
  - disturbances

Physical Modeling

The hydraulic-servo system is divided into the following subsystems:

- Power supply
- Pipelines between power supply and servo valve
- Servo-valve
- Pipelines between the servo valve and the actuator
- Actuator

Physical Modeling

In the literature, researchers have formulated mathematical models for all the subsystems mentioned by using the basic formulas:

$$\sum Forces = m\ddot{x}$$

&

$$\dot{p} = \frac{E}{V}(\sum Q - \dot{\mathrm{V}})$$

Non-linear Model

Non linear state-space equations for the valve and actuator are:

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \frac{1}{m_t(x_1)}[(x_3 - \alpha x_4)A_p - \mathrm{F}_f(x_2) - \mathrm{u}_2]$$

$$\dot{x}_3 = \frac{\dot{E}_A(x_3)}{V_A(x_1)}[\mathrm{Q}_A(x_3, x_5) - A_p x_2 + \mathrm{Q}_{Li}(x_3, x_4)]$$

$$\dot{x}_4 = \frac{\dot{E}_B(x_4)}{V_B(x_1)}[\mathrm{Q}_B(x_4, x_5) + \alpha A_p x_2 - \mathrm{Q}_{Li}(x_3, x_4)]$$

$$\dot{x}_5 = x_6$$

$$\dot{x}_6 = \omega^2{}_v[\mathrm{u}_1 - \frac{2D_v}{\omega_v} x_6 - x_5 - \mathrm{f}_{hs}\mathrm{sign}(x_5)]$$

where

$$x_1 = x_p$$

$$x_2 = \dot{x}_p$$

$$x_3 = p_A$$

$$x_4 = p_B$$

$$x_5 = x^*{}_v = \frac{x_v}{x_{v,\max}}$$

$$x_6 = \dot{x}^*{}_v = \frac{\dot{x}_v}{x_{v,\max}}$$

$$u_1 = u^*{}_v = \frac{u_v}{u_{v,\max}}$$

$$u_2 = F_{external}$$

Assumptions

Nonlinear model assumptions:

- Neglecting pipeline dynamics (short pipe lengths)
- Constant supply pressure
- Rigidly fixed cylinder
- Turbulent valve flow

Simplified Linear Model

To build a simple or reduced "linear" model that accounts for the dominant servo system characteristics:

1. Load pressure was introduced
2. Valve dynamics were neglected
3. Linearizing

$$p_L = p_A - p_B$$

Simplified Linear Model

The new linear and reduced state space model becomes:

zero in our case

$$
\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\dfrac{\sigma}{m_p} & \dfrac{A_p}{m_p} \\ 0 & -2\dfrac{A_p}{C_h} & -\dfrac{1}{T_h} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ K_Q \end{bmatrix} u_1 + \cancel{\begin{bmatrix} 0 \\ -\dfrac{1}{m_p} \\ 0 \end{bmatrix}} u_2
$$

where

$x_1 \equiv \Delta x_p$ $\quad x_2 \equiv \Delta \dot{x}_p$ $\quad x_3 \equiv \Delta p_L$

$u_1 \equiv \Delta u_v^*$ $\quad u_2 \equiv \Delta F_{ext}$

$$T_m = \frac{m_p}{\sigma}, \qquad K_d = \frac{A_p}{C_h},$$

$$C_h = \left(\frac{E_A'}{V_A} + \alpha^2 \frac{E_B'}{V_B} \right)$$

$$K_Q = \frac{E_A'}{V_A} K_{Qx,A} - \alpha \frac{E_B'}{V_B} K_{Qx,B}$$

$$T_h = \frac{1}{\alpha \dfrac{E_B'}{V_B} \left[\dfrac{-K_{Qp,B}\alpha^2 + C_{Li}(1+\alpha^2)}{1+\alpha^3} \right] - \dfrac{E_A'}{V_A} \left[\dfrac{K_{Qp,A} - C_{Li}(1+\alpha^2)}{1+\alpha^3} \right]}$$

Piston Response

- In frequency domain, piston's position can be described as:

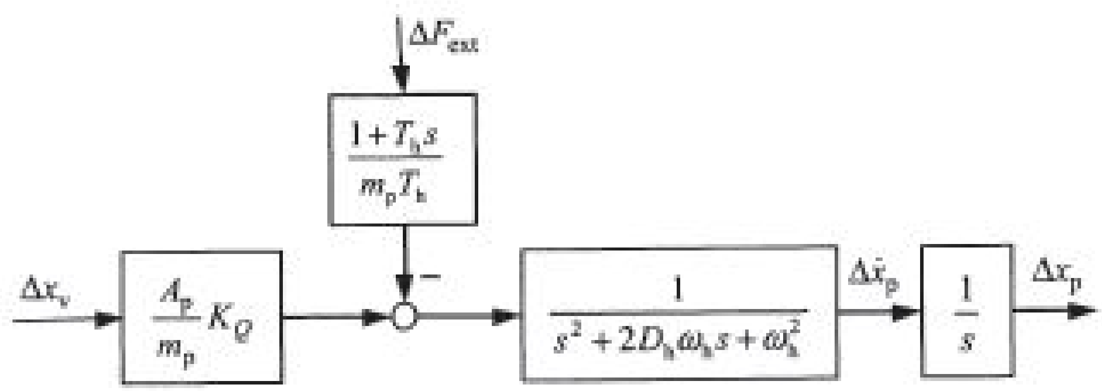
$$\Delta x_p(s) = \frac{\frac{A_p}{m_p} K_Q \Delta x_v(s) - \frac{1+T_h s}{m_p T_h}\Delta F_{ext}(s)}{s\left[s^2 + (\frac{1}{T_m}+\frac{1}{T_h})s + \frac{1}{T_m}(\frac{1}{T_h}+K_m K_d)\right]} = \frac{\frac{A_p}{m_p} K_Q \Delta x_v(s) - \frac{1+T_h s}{m_p T_h}\Delta F_{ext}(s)}{s(s^2+2D_h\omega_h s+\omega_h{}^2)}$$

- By identification we get:

$$\omega_h = \sqrt{\frac{1}{T_m T_h} + K_m K_d}$$

&

$$D_h = \frac{1}{2\omega_h}(\frac{1}{T_m}+\frac{1}{T_h})$$

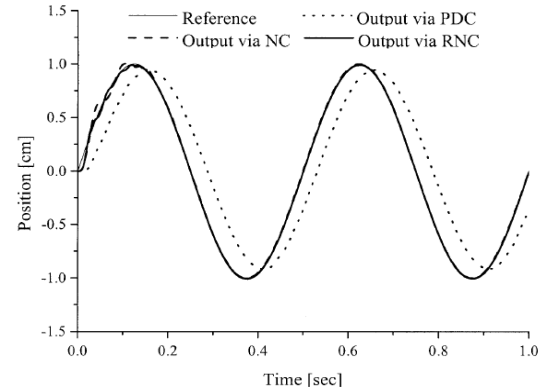


Control Techniques

- Classical feedback control
- State feedback control
- Extensions to feedback control
- Adaptive control
- Variable structure control
- Fuzzy control
- Neuro-control

Which one to chose?

➢ (Application, accuracy, effort, cost, feasibility)



Robust two-stage non-linear control

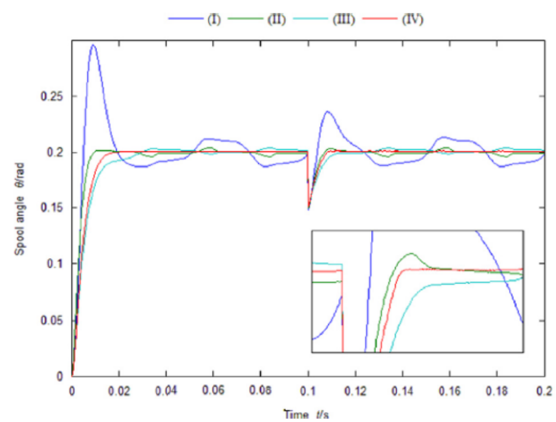


Fig. 13. Step response under an output fluctuation using (I) PID control, (II) state feedback control, (III) state feedback integral control, and (IV) the proposed controller.

State feedback integral control using a Lyapunov function

System Control

- position control methods are based on “classical feedback control” to control the position of the piston in the cylinder.

Table 6.2. Overview of linear controls performance on a scale from – – (worst) to + + (best)

	Linear controller						
	P	I	PI	PD	PID	PT_1	PPT_1
Transfer function	K_p	$\frac{1}{T_I s}$	$K_p\left(1+\frac{1}{T_I s}\right)$	$K_p(1+T_D s)$	$K_p\left(1+\frac{1}{T_I s}+T_D s\right)$	$\frac{K_{p1}}{1+sT_p}$	$K_{p1}+\frac{K_{p2}}{1+sT_p}$
Position control	+	– –	– / 0	–	0 / –	+ +	+ +
Velocity control	–	+	+ +	– –	++	+ / 0	
Force control	–	+	+ +	– –	+ +		

Control Design Steps

1) Modelling → equations
2) Input-Output Controllability Analysis → expected behavior
3) Control Structure Selection → links between measured variables
4) Controller Design → equations
5) Control System Analysis → assessment against performance specs
6) Controller Implementation → simulations using software
7) Commissioning and Tuning → tuning and optimization

Implementation and Testing

The actual results are to be validated against simulation results

Thank you for your attention