

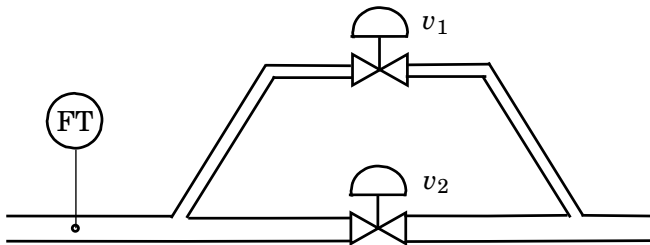
The background features a large, faint watermark of the Lund University seal. The seal is circular and contains a central figure of a lion holding a sword and a book. The text around the seal includes "SIGILLUM UNIVERSITATIS GOTHORVM • CAROLINÆ" at the top, "1666" at the bottom, and "RVMQVIVM" on the left side.

An efficient mid-ranging control strategy based on feed-forward control

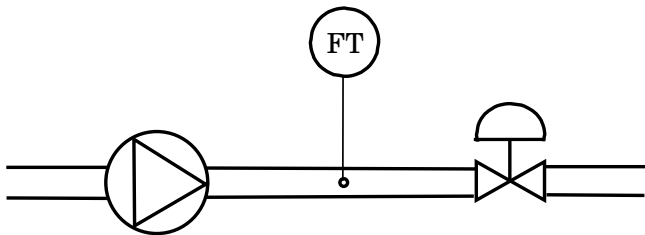
Tore Hägglund

Lunds University

Mid-ranging Application 1



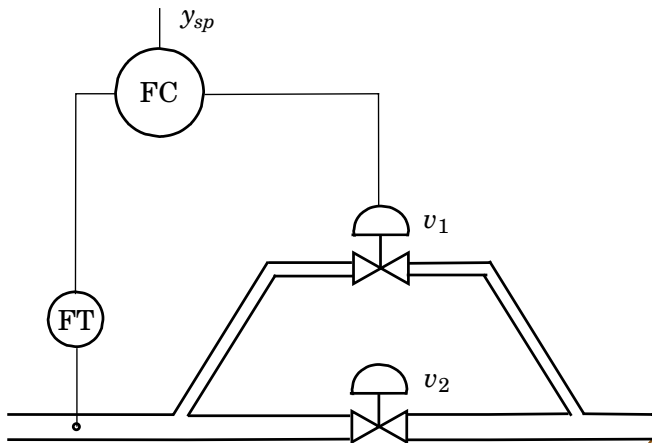
Mid-ranging Application 2



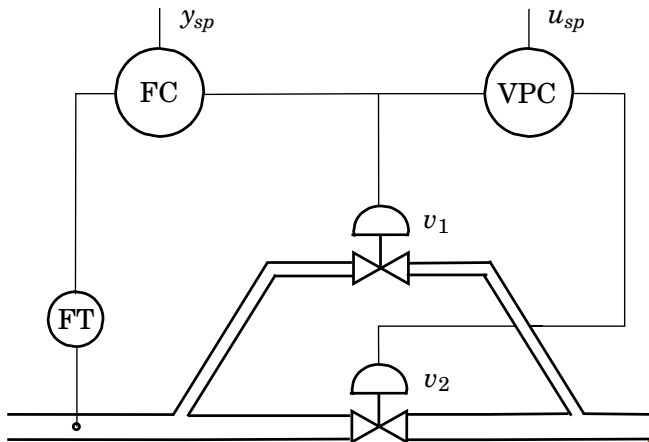
Mid-ranging Application 2



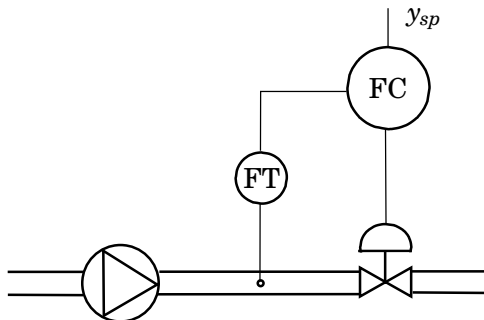
Valve position control (VPC)



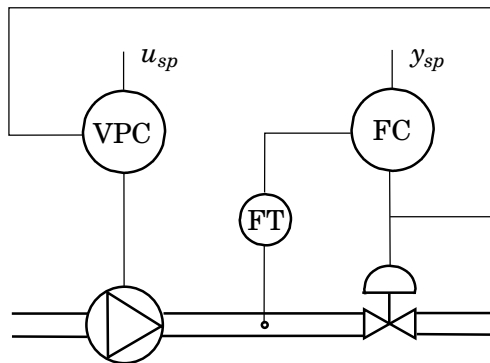
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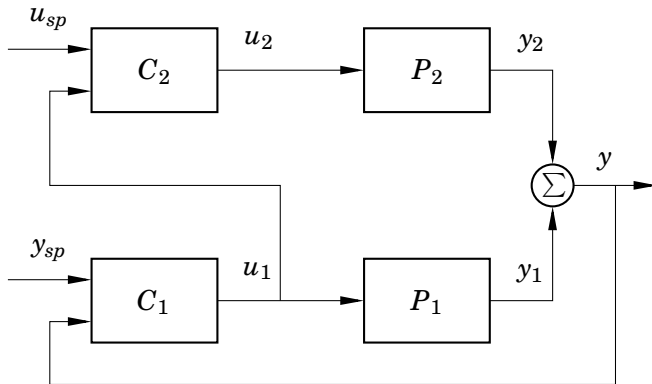
Valve position control (VPC)



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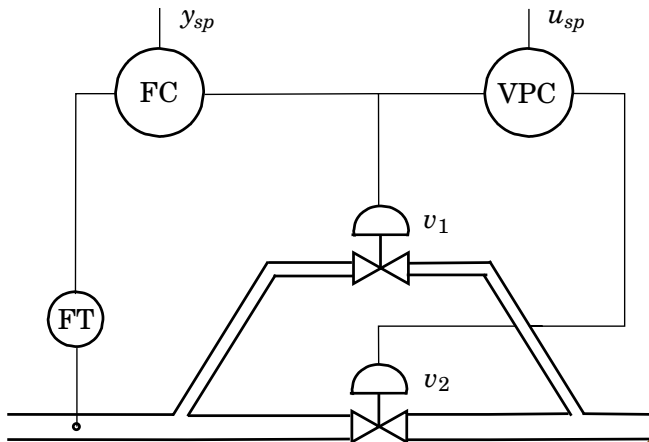


Problems with Valve position control (VPC)

- ▶ Stick-slip motion (Application 1)
- ▶ Sluggish control close to saturations (Application 2)
- ▶ Two controllers, but no redundancy



Valve position control (VPC)



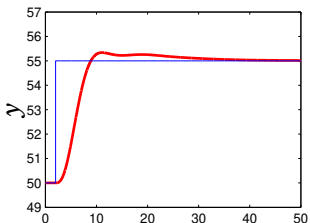
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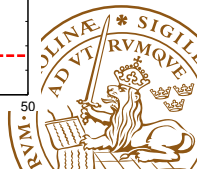
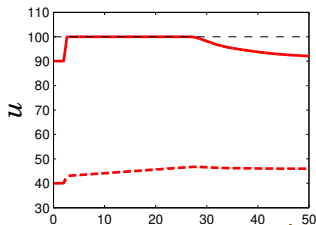
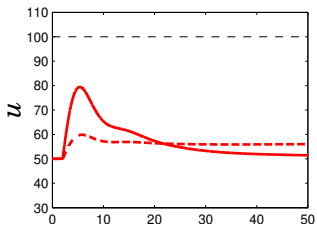
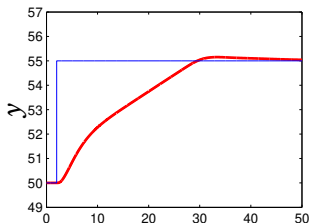


VPC – Application 2

$u_{sp} = 50\%$



$u_{sp} = 90\%$

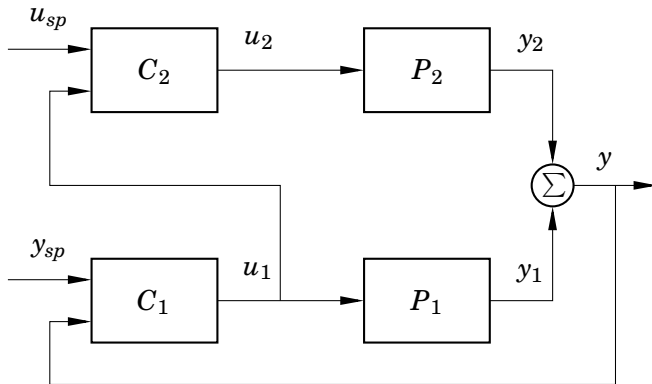


Problems with Valve position control (VPC)

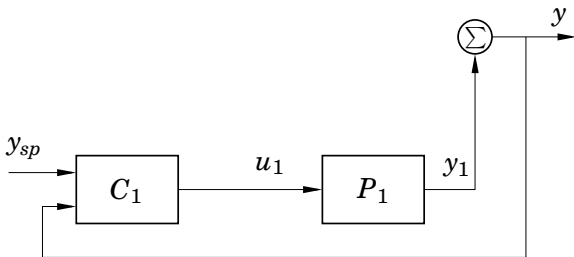
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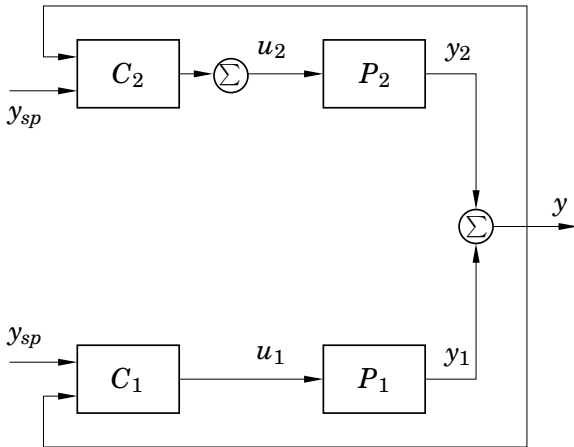
Valve position control (VPC)



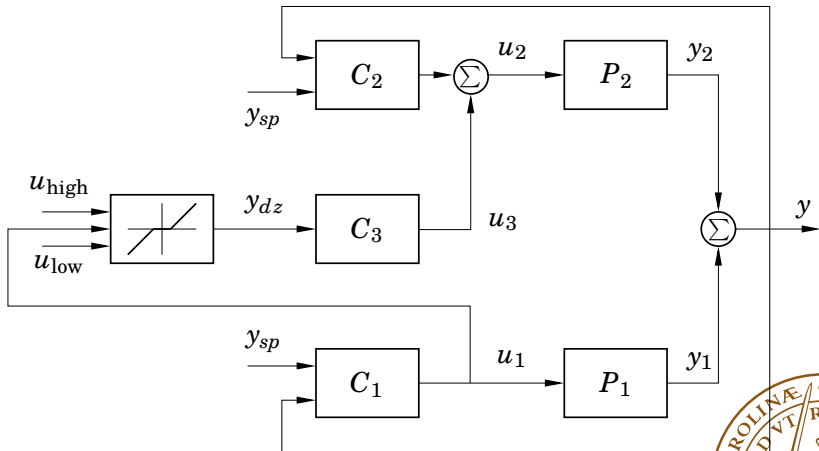
The feedforward midranging approach (FFMRC)



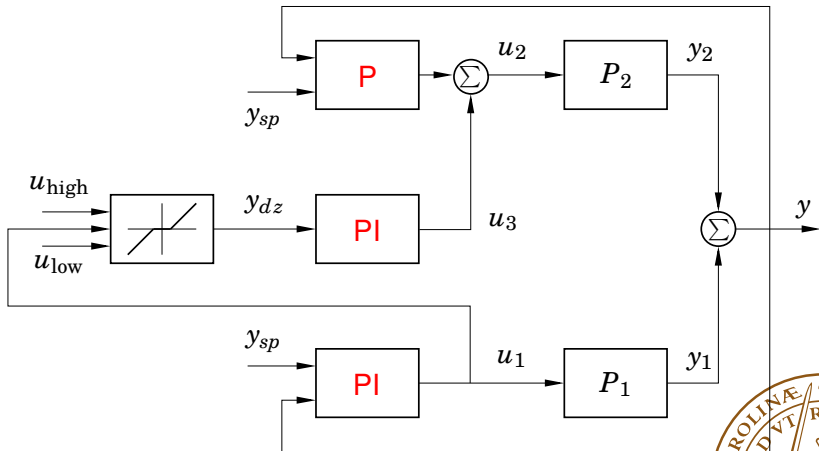
The feedforward midranging approach (FFMRC)



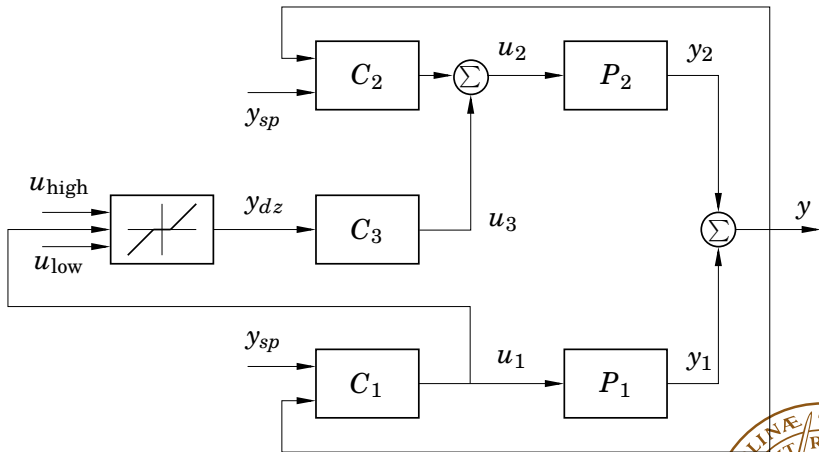
The feedforward midranging approach (FFMRC)



The feedforward midranging approach (FFMRC)



Design of the FFMRC controllers



Design of the FFMRC controllers

$$C_1 = K_1 \left(1 + \frac{1}{sT_{i1}} \right) \quad C_2 = K_2 \quad C_3 = K_3 \left(1 + \frac{1}{sT_{i3}} \right)$$

$$Y = \frac{P_1 C_1 + P_2 C_2 + P_2 C_3 C_1}{1 + P_1 C_1 + P_2 C_2 + P_2 C_3 C_1} Y_{sp} = \frac{L}{1 + L} Y_{sp}$$

Loop transfer function:

$$L = P_1 C_1 + P_2 C_2 + P_2 C_3 C_1$$

Use Loop shaping!



Design of the FFMRC controllers

Goal:

$$L = P_1 C_1 + P_2 C_2 + P_2 C_3 C_1 \approx L_1 = P_1 C_1$$

1. Tune C_1 using some standard tuning procedure.
2. Determine the crossover frequency of L_1 , i.e. frequency ω_1 where $|L_1(i\omega_1)| = 1$.
3. Determine gain K_2 in C_2 so that $|P_2(i\omega_1)C_2(i\omega_1)| \leq \gamma$.
4. Determine integral time T_{i3} in C_3 as N/ω_1 .
5. Determine gain K_3 in C_3 so that $|P_2(i\omega_1)C_3(i\omega_1)C_1(i\omega_1)| \leq \gamma$.

If $\gamma = 0.1$, φ_m is changed less than 10° .



Simplified design of the FFMRC controllers

1. Tune C_1 using some standard tuning procedure.
2. Determine static gain K_{p2} of P_2 .
3. $K_2 = 1/K_{p2}$.
4. $T_{i3} = 5T_{i1}$.
5. $K_3 = K_2/K_1$.



Simulation example

$$P_1 = \frac{0.2}{(1 + 2s)^2} \quad P_2 = \frac{0.8}{(1 + 10s)^2}$$

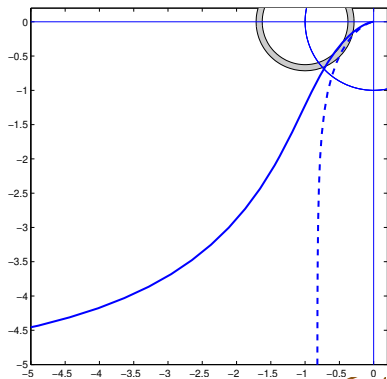
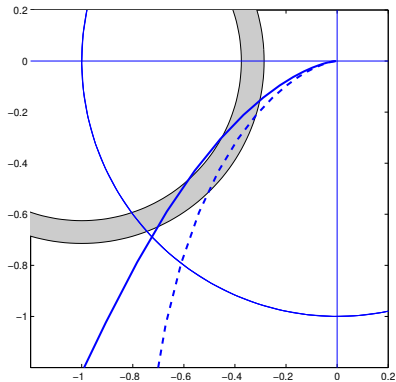
$$K_1 = 8.35 \quad T_{i1} = 2.68 \quad (\text{AMIGO})$$

$$K_2 = 3.2$$

$$K_3 = 0.31 \quad T_{i3} = 10$$

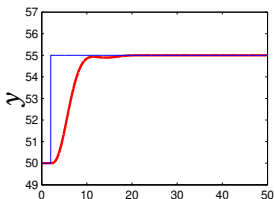


Simulation example

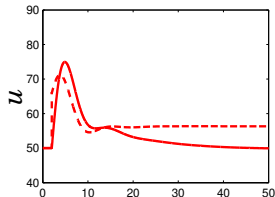
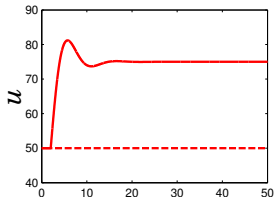
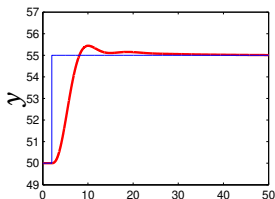


Simulation example

C_2 and C_3 in Man

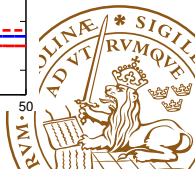
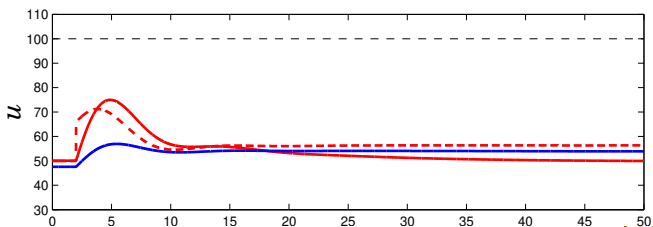
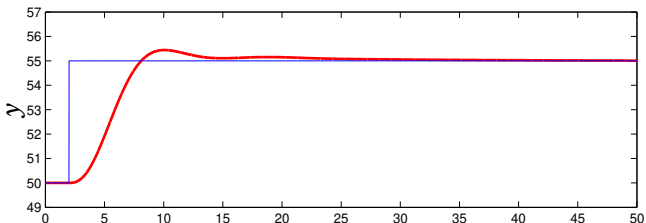


FFMRC



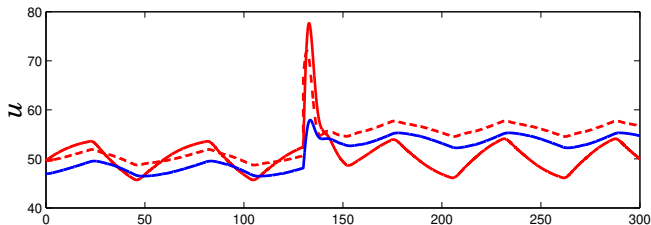
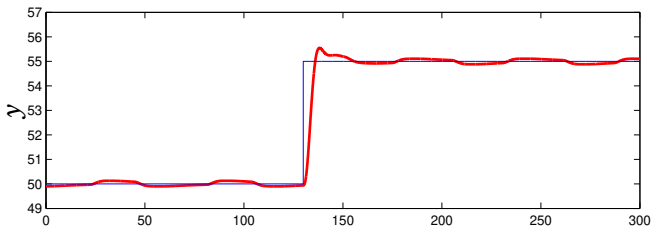
Simulation example

$$u_{\text{low}} = u_{\text{high}} = 50\%$$



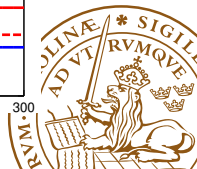
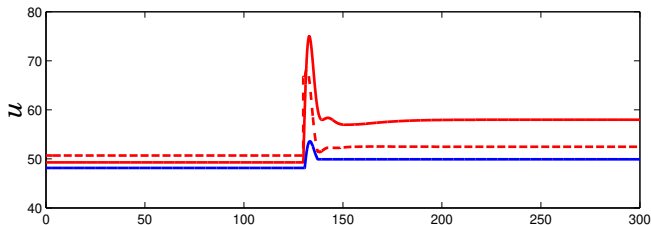
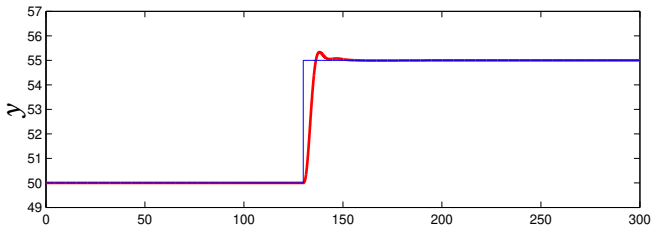
Application 1, Stiction, no deadzone

$$u_{\text{low}} = u_{\text{high}} = 50\%$$



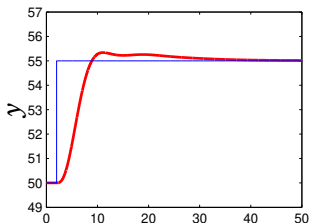
Application 1, Stiction, deadzone

$$u_{\text{low}} = 40\% \quad u_{\text{high}} = 60\%$$

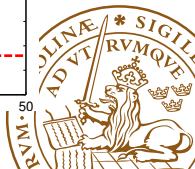
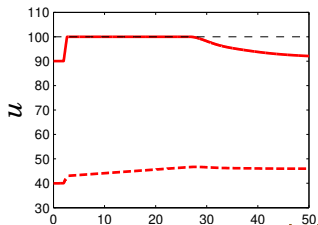
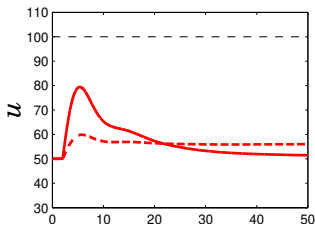
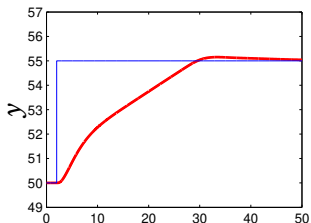


Application 2, VPC

$u_{sp} = 50\%$

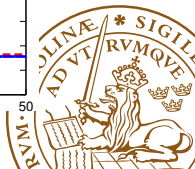
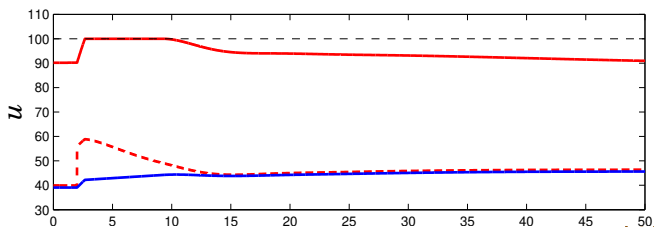
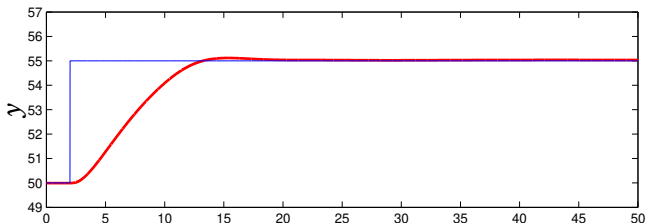


$u_{sp} = 90\%$



Application 2, FFMRC

$$u_{\text{low}} = u_{\text{high}} = 90\%$$



The FFMRC Project

- ▶ Sponsored by Vinnova (PiiA)
- ▶ Collaboration with ABB (Implementation)

