Emnemodul: Advanced Process Control

21 Nov. 2023. Time: 1000 – 1300.

Answer as carefully as possible, preferably using the available space. There are in total 5 questions. Answer all questions in English.

No printed or hand-written support material is allowed. A specific basic calculator is allowed.

Problem 1 – General questions (20%)

a) What are the main approaches for decomposing the control system into smaller elements? Make a figure (block diagram) to illustrate the decomposition.

b) What are the main objectives of the supervisory control layer?

c) What are the main objectives of the basic (stabilizing) control layer?

d) Explain the main ideas behind self-optimizing control, RTO and extremum seeking control. How can these three strategies be combined?

e) What is back-off and when is it used? When is it important to minimize back-off?

f) What is a typical cost function in the RTO layer?

g) What is the difference between economic MPC and setpoint-based MPC? What is a typical cost function in the two cases?

h) The "pair-close" rule is the most important rule for choosing pairings for decentralized control. Assume that you have $G(s) = k\, e^{-\theta s}/(\tau s+1)$. What values does this rule that imply that you would you like to have for each of the three parameters k, θ and τ (large, no effect or small)?

i) What is the "input saturation pairing rule"? When should it be used? If it is satisfied, what does it imply in terms of MV-CV switching? Give an example.

Problem 2 – Optimal process operation (20%)

Consider a simple steady-state process (fast dynamics) with one unconstrained degree of freedom and two disturbances. The cost function to be minimized during operation is

$$J = (u-2d_1)^2 + (u-2d_2)^2$$

Nominally we have $d_1=d_2=0$, and the expected magnitudes of the disturbances are $|d_1| \le 1$ and $|d_2| \le 1$. We have available three measurements.

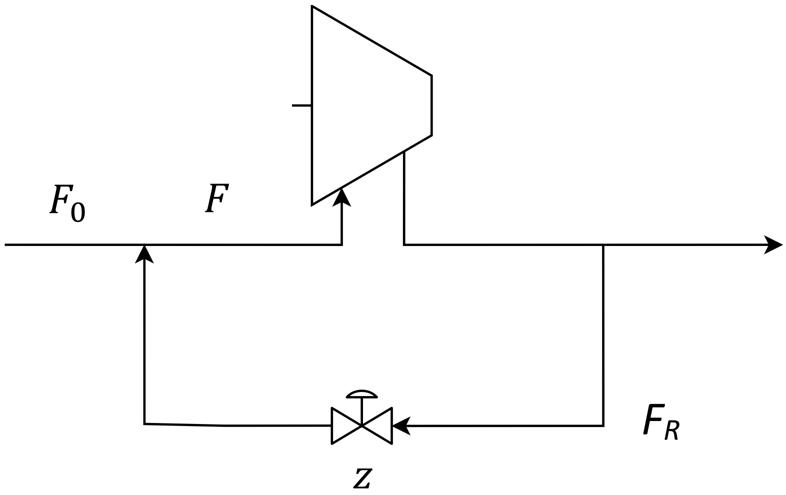
$y_1 = u + 0.1\, d_1$, $y_2 = 0.1u - d_2$, $y_3 = d_1 + d_2$

(a) Use the nullspace method to find the self-optimizing $c=Hy$ which when kept constant gives zero loss for the expected disturbances (at least locally and with perfect measurements). What is the optimal setpoint for c?

(b) Explain how to find the optimal H if we include measurements noise of magnitude $|n_{yi}|\le 0.2$ for each of the three measurements. (Give the formula for H and give the matrices G^y and Y needed to compute H). What is this method called? Finding the final H is maybe a bit too much for hand calculations as it involves a matrix inversion; how large is the matrix to be inverted in this case?

Problem 3 – Compressor with constraints (15%)

Consider a constant-speed compressor (which means that it has no degrees of freedom for control) with an adjustable recycle F_R which should be minimized whenever possible. The following constraints need to be satisfied: $F \geq F_{min}, F_0 \leq F_{0,max}, z \geq 0, z \leq 1$. The first constraint is to avoid compressor surge; the second constraint is because the compressor is feeding a reactor and too high flowrates are bad for the catalyst.

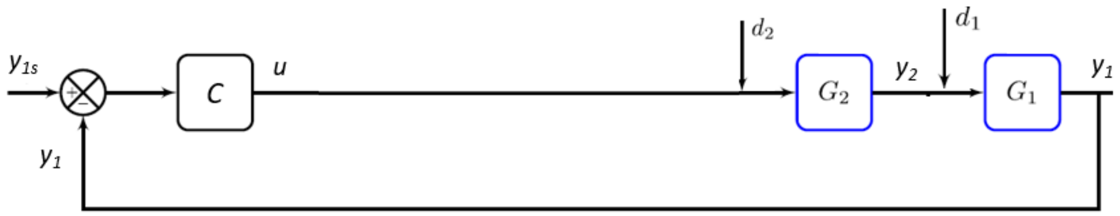


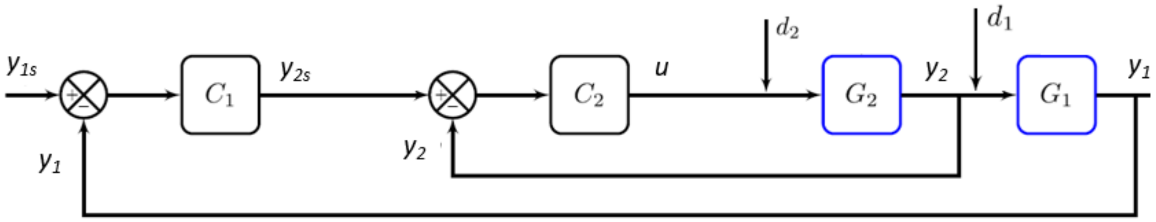
(a) To switch between active constraints we want to use selectors. Give the three selector rules (Rule 1 is about min- or max- selector, Rule 2 is about order of selectors, Rule 3 is about valve constraints).

(b) Use the selector rules to propose a control system. You may add flow sensors as needed.

Problem 4 – Cascade control and tuning (25%)

Below are shown control schemes for the process $G = G_1 G_2$ for the case without and with cascade control.





(a) What motivates the use of cascade control?

(b) Derive the transfer function from d_2 to to y_1 for the two cases.

In the following let: $G_1 = 3/(18s+1)$, $G_2 = e^{-0.4s}/(s+1)$

(c) Do you recommend cascade control in this case?

(d) Suggest "tight" SIMC PI-tunings for C (for the case without cascade).

In the rest consider cascade control.

(e) Suggest "tight" SIMC PI-tunings for the slave controller C_2.

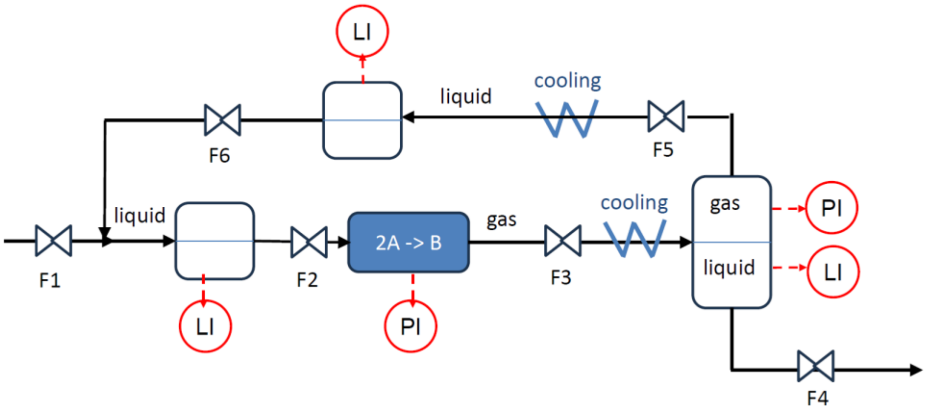
(f) Suggest "tight" SIMC PI-tunings for the master controller C_1.

(g) It is given that the time scale separation between the slave and master loops should be at least 5. What is the motivation for such a requirement? Is this satisfied for your case? If not suggest how to change the PI tunings.

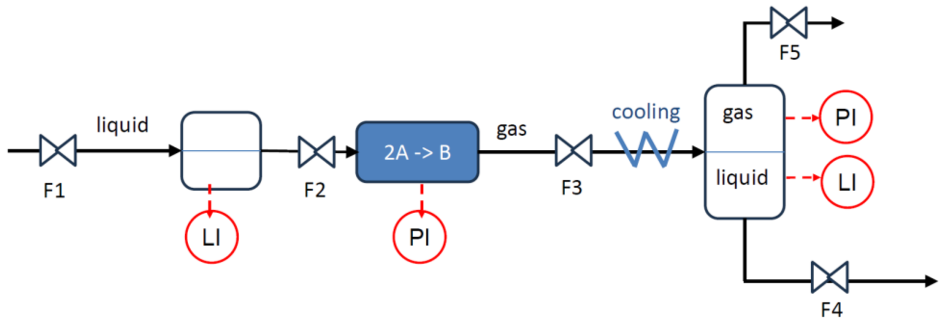
Problem 5 – Inventory control for reactor process (20%)

(a) Consider the flowsheet below. The reactor is exothermic with a liquid feed and gas product. The feed F1 contains mostly component A and the liquid product F4 contains mostly component B. The gas from the separator is recycled. The pressure (PI) and level (LI) sensors should be used for inventory control.

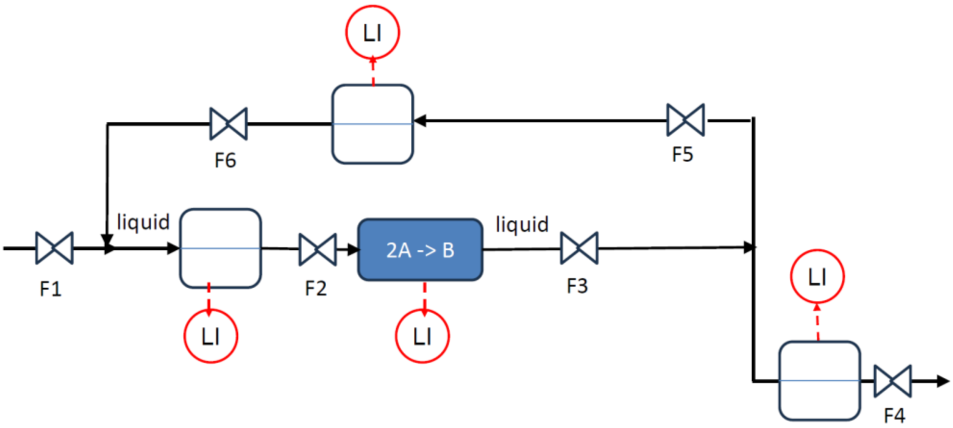
Suggest a control scheme for the case when the feedrate is set (F1 is the TPM).



(b) Consider a similar process without recycle. Suggest a bidirectional inventory control scheme. What advantages does it has compared to a “fixed” control scheme (similar to the one in part a)?



(c) Consider a case where the separator is replaced by a split. All flows are liquid in this case. It is given that we should have a given ratio R=F6/F1. Propose a control scheme for the case where F4 is given (F4 is the TPM). You can add extra flow sensors as needed.



Extra sheet

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