

# Exam paper for TKP4140 – Process Control

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Examination date: 11 December 2023 Examination time (from-to): 09:00 – 13:00 Permitted examination support material: One (1) A4 double-sided piece of paper with your handwritten notes. Standard calculator.

Other information: State clearly all assumptions you make. You may answer in Norwegian or English

Language: English Number of pages (front page excluded): 4 (including Bode paper which may be handed in)

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#### Problem 1 (35%). Controller tuning



- (a) (5%) What is the disturbance transfer function G<sub>d</sub> from d<sub>2</sub> to y? Sketch y(t) for a unit step change d<sub>2</sub>(t)=1 for the case with no control (c=0). Assume that we want |y(t)| ≤ 1: Do we need control?
- (b) (10%) Design a PI-controller for c using the SIMC-rule with "tight" tunings.
- (c) (7%) Design a PID-controller for c using the SIMC-rule with "tight" tunings.
- (d) (3%) Will PI- or PID-control give acceptable disturbance rejection for disturbance d<sub>2</sub>? (assuming that |d<sub>2</sub>| ≤ 1 and that you want to keep |y-y<sub>s</sub>|≤ 1)
- (e) (5%) Consider adding feedforward control. Show  $c_{\rm ff}$  on the block diagram. Propose a constant gain feedforward controller,  $c_{\rm ff} = k_{\rm ff}$ . Do you recommend using feedforward control in this case?
- (f) (5%) Consider using cascade control. Show the slave controller  $c_2$  on the block diagram. Design  $c_2$  using the SIMC rule with  $\tau_c = 0.6$  (when is this value reasonable?). Do you recommend using cascade control in this case? Why would you need to change the design of c if you add a slave controller  $c_2$ ?
- (g) Extra credit (3%): Propose new PI-tunings for c for the case with cascade control.

## Problem 2 (35%). Closed-loop stability

Consider control of the process

$$G(s) = \frac{4(-2s+1)}{(20s+1)(6s+1)}.$$

It is proposed to use a PI-controller with integral time  $\tau_I$ =20 and gain K<sub>c</sub>=1. We want to find out if the closed-loop system stable and how far it is from instability.

- (a) (8%) All closed-loop transfer functions can be written on the form n(s)/d(s) where d(s) is always the same. Find the expression for d(s). The closed-loop system will be unstable if some of the coefficients in d(s) are negative (or more precisely if they have different signs). Is the closed-loop system stable? Is this condition necessary and sufficient?
- (b) (5%) What is the gain margin? You can find it by computing for which value of K<sub>c</sub> one of coefficients in d(s) becomes zero. Alternatively, you can use the Bode stability condition.
- (c) (10%) Sketch the Bode plot and indicate the gain and phase margins.
- (d) (5%) What is the time delay margin (that is, how much time delay can be added before get closed-loop instability)?

Now consider other controllers for G(s).

- (e) (7%) Assume that we use pure P-control. At what value K<sub>u</sub> does the system become unstable and what is the corresponding period of oscillations P<sub>u</sub>? Use this to find the Ziegler-Nichols PI-tunings for the process G (K<sub>c</sub> = 0.45 K<sub>u</sub> and  $\tau_1$  = P<sub>u</sub>/1.2).
- (f) (3%) Extra credit: What are the SIMC PI-settings for the process G?

### Problem 3 (30%). Modelling and control of mixing process



The flowsheet shows a process for producing a product  $F_2$  with concentration  $c_2$  by mixing water  $F_1$  with a solid  $F_d$  (which is pure A, for example, A=sugar). The main control objective is to keep the composition  $c_2$  constant, but there is some delay in the measurement of  $c_2$ . The main disturbances are related to  $F_d$  and the other water consumers (which may result in varying pressure  $p_1$ ). It is desirable to keep the pressures  $p_1$  and  $p_2$  constant. There are three available manipulated inputs, namely the valve positions  $z_1$  and  $z_2$  and the speed  $\omega$  of the pump (VSD=variable speed drive).

- (a) (5%) Formulate a static model (valve equation) for F<sub>1</sub> and find the gain k from z<sub>1</sub> to F<sub>1</sub> (analytical expression only; show how it depends on pressure). You can assume a linear valve characteristic.
- (b) (10%) (i) Formulate a dynamic model for the mixer involving the total and component mass balances. (ii) What is the steady-state value of F<sub>d</sub> at the nominal point? (iii) Derive the transfer function (with numbers) from F<sub>1</sub> to y=c<sub>2</sub> assuming that V and p<sub>2</sub> are constant. *Data*: F<sub>1</sub> is pure water and the concentration of F<sub>d</sub> is c<sub>d</sub> [kg/m3], *Nominal steady-state data*: c<sub>2</sub>=20 kg A/m<sup>3</sup>, c<sub>d</sub>=700 kgA/m<sup>3</sup>, F<sub>2</sub>=2 m<sup>3</sup>/min, V=0.36 m<sup>3</sup>.
- (c) (15%) Propose a control system which also includes ratio and cascade control. Explain your thinking and comment on in which order the control elements should be added and tuned. You may add flow, pressure and concentrations measurements as needed. Note that F<sub>d</sub> sets the production rate for the process (so it's the TPM).

## Bode paper:

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