NTNU – Trondheim
Norwegian University of Science and Technology
Department of Chemical Engineering

Digital Exam paper for TKP4140 – Process Control

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Examination date: 18 December 2021
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.**~~
Home exam. Open book

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)

Informasjon om trykking av eksamensoppgave
Originalen er:
1-sidig ☐ 2-sidig ☐
sort/hvit ☐ farger ☐
skal ha flervalgskjema ☐

Checked by:

Date Signature

Problem 1 (25%) – Simple process

Let

$$y_1 = \frac{6}{18s + 1} u$$

$$y_2 = \frac{-3}{2s + 1} u$$

$$y = y_1 + y_2$$

(a) Assume that the system is initially at steady state with $u = y_1 = y_2 = 0$. For a step change in u (u=1 at t=0), compute $y_1(t)$, $y_2(t)$ and y(t) at t=0,1,2,5,10,20,40,100 and plot y_1, y_2 and y as function of time t. (13%)

(b) What do you call the response for y(t)? How can you predict this behavior from the transfer function g(s) from u to y? (You should also find g(s)). (6%)

(c) Suggest PI-settings for this process (with u as the process input and y as the process output). (You may use the half rule + SIMC-settings) (6%)

Problem 2 (35%) – PI control of first-order with delay process

(a) What are the SIMC PI-rules for a first-order plus delay process? (4%)

(b) We have given the following process: g(s) = 6/[(32s+1)(8s+1)]. Suggest PI-tunings for this process based on the SIMC rules. (6%)

(c) Would you recommend using PID control for this process? What would the PID settings be? (6%)

(d) PI-control. Make a block diagram of the control system. Sketch the expected response to a step disturbance at the input, without control and with PI-control (note: by *sketch* is meant that you do not need to do detailed calculations, but you should show the approximate response of the output y as a function of time t). (8%)

(e) PI-control. Draw (sketch) the Bode plot of the loop transfer function L=gc with your PI controller. What is the gain margin, phase margin and allowed time delay to remain stable? (11%)
Comment: If you did not find a PI-controller in (b) then use c=0.02(32s+1)/s

Problem 3 (40%) – Mixing process

Consider the mixing process depicted in Figure 1. Three streams are mixed in a mixer with volume V=100 l with the objective of controlling the total flow (want $q \approx q_s = 1.25$ l/s) and temperature (want $T \approx T_s = 54$C) of the product stream. We can manipulate the flows of the first two streams ($u = [q_1, q_2]^T$) while the third stream is a disturbance. The streams also contain an impurity (as given by the concentrations c_1, c_2 and c_3), but to begin with you can assume that the value of c in the product does not matter.

You can assume that the volume V is constant and that the densities and heat capacities of the three streams are constant and equal.

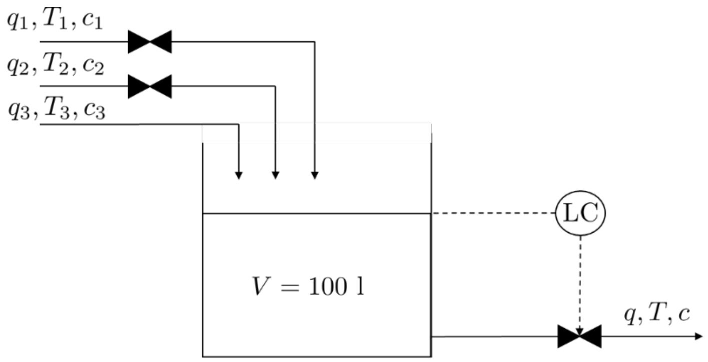

Figure 1. Process flowsheet.

Stream 1: $T_1 = 20$C, $c_1 = 0$ g/l,
Stream 2: $T_2 = 120$C, $c_2 = 0.5$ g/l,
Stream 3: $T_3 = 40$C, $c_3 = 3.8$ g/l, q_3=0.45 l/s

(a) What are the nominal steady-state values for the flows q_1 and q_2 and of the concentration c? (8%).
(b) Formulate a nonlinear dynamic model for predicting the outputs q and T (y's). (8%)
(c) Let $u = [q_1, q_2]^T$ and $y = [q, T]^T$. Linearize the model around the nominal point and determine the transfer matrix G(s) for the process, y = G(s) u. (8%)
(d) What is the RGA-matrix of G? (Comment: it is sufficient to consider s=0 since the RGA-matrix is independent of frequency in this case). (4%).
(e) If you cannot find the RGA, then use:

$$\text{RGA} = \begin{bmatrix} 0.7 & 0.3 \\ 0.3 & 0.7 \end{bmatrix}$$

Suggest a control strategy based on two single loops (you may use the results from the RGA analysis for this, but you may also use common engineering sense). Draw your proposed control system on the flow sheet. (6%)
(f) We want to make sure that the impurity concentration in the product stream always remains below an upper limit ($c < c_{max} = 2$ g/l). Propose a control strategy that will give up controlling the total flow to satisfy this constraint and show it on the flow sheet. (6%)

Bode paper: