Examination paper for TKP 4140 – Process Control

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Examination date: 09 December 2016
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: 5 (including Bode paper which may be handed in)

Checked by:

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Date                      Signature
**Problem 1 (25%) – SIMC tuning**

Consider the process

\[ G(s) = \exp(-2s)/(9s+1) \]

(a) Design a SIMC PI-controller for the following two cases

(i) \( \tau_c = 0 \)

(ii) \( \tau_c = 50 \)

(b) For each of the two cases, sketch the setpoint response.

(c) For each of the two cases, compute the gain margin, phase margin and delay margin.

**Problem 2 (10%) – Feedforward control**

Consider the linear process \( y = Gu + G_d d \) (in deviation variables).

(a) Make a block diagram which shows the use of feedforward control.

(b) Let \( G(s) = \exp(-2s)/(9s+1) \) and suggest a feedforward controller for each of the following three disturbances:

(i) Disturbance at the input (\( d_1 \)), \( G_d = G \)

(ii) Disturbance at the output (\( d_2 \)), \( G_d = 1 \)

(iii) Disturbance (\( d_3 \)) with \( G_d = \exp(-4s)/(4s+1) \)

**Problem 3 (25%) – Control strategies**

The objective is to control the outlet temperature, \( y = T_2 \) [K] using the heat input \( u = Q_1 \) [MW]. Disturbances are \( d_1 = T_0 \) [K] and \( d_2 = Q_2 \) [MW]. The linear process model in deviation variables is
\[ T_1 = G_1(s) Q_1 + G_{d1}(s) T_0 \]
\[ T_2 = G_2(s) T_1 + G_{d2}(s) Q_2 \]
\[ G_1 = 15 \exp(-50s)/(20s+1) \]
\[ G_{d1} = \exp(-50s)/(20s+1) \]
\[ G_2 = 1/(5s+1) \]
\[ G_{d2} = 15/(5s+1) \]

Measurements: \( T_1, T_2, T_0, Q_2 \)

Manipulated variable: \( Q_1 \)

Consider the following control strategy cases:

(a) Simple feedback (based on only measuring \( y=T_2 \))
(b) Cascade control
(c) Feedforward control
(d) Input resetting (also known as valve position control or midranging control): In this case you must assume that also \( Q_2 \) is a manipulated variable, but its range is small (\( Q_1 \) is about 2.5 MW whereas \( Q_2 \) is only about 0.2 MW).

For each of the control strategies

(i) Show the control structure on the flow sheet and/or in the block diagram,
(ii) Suggest tunings for the controllers in cases (a) and (c),
(iii) State whether you would recommend the control structure (taking into account that you don’t want to make the control unnecessarily complicated).

Problem 4 (15%) – Level control

(a) Derive a dynamic model for the level \( (y=h [m]) \) in a tank with one inflow \( (u=q_1 [m^3/s]) \) and one outflow \( (d=q_2 [m^3/s]) \). The volume of the tank is \( V=Ah \) and you can assume constant density of the liquid.

(b) Linearize the model, introduce deviation variables and find a model of the form \( y = G_u + G_d d \). Find the transfer functions \( G(s) \) and \( G_d(s) \). What is this kind of process called?

(c) What is meant by averaging level control?
Problem 5 (10%) – Block diagram

Consider a closed-loop system described by the following equations:

\[
\frac{dx_1}{dt} = -0.1 x_1(t) + 3 u(t) \\
30 \frac{dx_2}{dt} + x_2(t) = x_1(t) \\
y(t) = x_2(t-0.5) \\
u = K_c e(t) + K_I e(t) \\
\frac{de}{dt} = e(t) \\
e(t) = y_s(t) - y(t)
\]

Make a block diagram for the system and fill in the correct transfer function (find $C(s)$ and $G(s)$).

Problem 6 (15%) – Simple process

Let $y = g(s) u$ and consider the process $g(s) = \frac{-0.25 s+1}{10s-1}$.

(a) What is the open-loop response $y(t)$ to a unit step change in $u$ (give a formula for $y(t)$ involving an exponential term)? Sketch the response $y(t)$ for $t$ from 0 to 10.

(b) Consider proportional control with gain $K_c$. For what values of $K_c$ is the closed-loop system stable (for example, you may consider the closed-loop poles)?

(c) Consider P-control with $K_c=10$. Sketch the closed-loop response to a step change in the setpoint.

Note: The parts of this problem can be done independently.
Bode paper: