Examination paper for TKP 4140 – Process Control

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Examination date: 11 December 2018
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): 5 (including Bode paper which may be handed in)
Problem 1 – Feedforward control (20%)

Feedforward control is frequently used in process control. It may however lead to problems if the model is wrong.

a) Make a block diagram with the feedforward controller \( C_{ff} \) included for the following case:

\[ d \]
\[ \downarrow \]
\[ G_d \]
\[ u \rightarrow G \rightarrow + \rightarrow y \]

b) In which situation is it advisable to use feedforward control? Also consider possible measurement delays associated with \( d \) and \( y \).

c) What is the transfer function for the perfect feedforward controller, \( C_{ff,ideal} \)? Why can you not always realize a perfect feedforward controller?

d) Design a feedforward controller when the process models are \( G = 5 \) and \( G_d = 3/(5s+1) \).

e) Sketch the response in \( y \) to a step in \( d \) (\( d=1 \)) for the following three cases

i. No control (\( u=0 \))
ii. With the feedforward controller from part d and no model error.
iii. With the feedforward controller from part d and the real plant has \( G = 8 \) and \( G_d = 2/(5s+1) \).

Problem 2 . Size of mixing tank for disturbance rejection (15%).

Consider a sinusoidal temperature disturbance in the feed of magnitude \( \pm 5 \) °C and frequency \( \omega = 4 \text{ rad/min} \), \( T_F(t) = 5 \sin(\omega t) \). The feed flow is \( q = 1 \text{ m}^3/\text{min} \). The tank is well mixed and the volume is kept constant (using a level controller which is not shown on the flowsheet). The temperature variations in the outlet flow should be less than \( \pm 1 \) °C.

\[ T_F(t) = 5 \sin(\omega t) \]
\[ q = 1 \text{ m}^3/\text{min} \]
\[ V = ? \]
\[ T(t) = 1 \sin(\omega t) \]
\[ q \]

a) (3%) Find the transfer function from \( T_F \) to \( T \).
b) (2%) What is the period \( P \) [min] of the oscillations?
c) (10%) What should the volume of the tank be to satisfy the desired damping of the temperature disturbance?
Problem 3– SIMC and Disturbance rejection (25%)

a) Consider the closed-loop response to a disturbance $d$. What are the closed-loop transfer functions from $d$ to $y$ and from $d$ to $u$ (using symbols for $g$ and $g_d$)?

b) In the following let:

$$g(s) = \frac{10 \ e^{-0.3s}}{(6s + 1)^2}, \quad g_d(s) = k_d \ g(s)$$

Design a SIMC PI-controller for the process using “tight” tuning.

c) Assume $k_d=1$, that is, $g_d=g$.

i. Plot the magnitude of $g_d$ as a function of frequency (log-log-scale) (you may use the Bode magnitude template).

ii. Make a sketch of the input $u(t)$ to a step disturbance $d$ of magnitude 1 ($|d|=1$). What is the steady-state value of $u$?

d) It is desired that the output change ($y$) should be less than 1 ($|y|<1$), but with the SIMC PI-controller, $y(t)$ goes up to almost 4 before returning back to zero. Is it possible to retune the PI-controller to make $y(t)$ acceptable? What about using PID-control?
Problem 4. Mixing tank with changing control objective (40%)

You are mixing two streams. Stream 1 contains water (W), sugar (S) and some preservative (E). Your task is to mix the feed (stream 1) with pure water (stream 2) to get a product (stream 3) that satisfies:

- Desired sugar content (want to keep product close to this value): $x_{s3} = 0.1$
- Maximum E in product (required at all times): $x_{E3} \leq 0.001$

Both these two mass fractions ($x_{s3}, x_{E3}$) are measured online, and the time delay for both measurements is 8 seconds. You can assume that stream 1 is the DV (disturbance) and stream 2 is the MV. The feed concentration (stream 1) varies, but nominally $x_{s1} = 0.5$ and $x_{E1} = 0.002$. The volumes of the pipes and mixer are small, so dynamics can be neglected (except for the measurement delay of 8 seconds).

(a) (5%) Consider first the nominal case with $x_{s1} = 0.5$ and $x_{E1} = 0.002$. If $F_1 = 1$ kg/s, how large is the value of $F_2$? What are the corresponding concentrations of S and E in the product? (To solve this problem you need to make a steady-state model of the process)

(b) (10%) Linearize the (steady-state) model of the system around the nominal point with $u = F_2$, $d = F_1$, $y_1 = x_{s3}$ and $y_2 = x_{E3}$. What are the steady-state gains from u to $y_1$ and $y_2$?

(c) (5%) Suggest a control structure that handles the nominal case (draw a flow sheet).

(d) (5%) What tunings do you suggest for a pure I-controller ($c_1 = K_i/s$) that uses u to control $y_1$?

(e) (5%) The feed sugar concentrations has quite small variations. However, in the extreme case $x_{E1}$ may get as high as 0.006. Consider the extreme case with $x_{s1} = 0.5$ and $x_{E1} = 0.006$. If $F_1 = 1$ kg/s, how large is the value of $F_2$? What are the corresponding concentrations of S and E in the product?

(f) (10%) Suggest a control structure involving two composition controllers (for $y_1$ and $y_2$) which can handle both the nominal and extreme cases. Do you need to use anti windup?
Bode paper: