Examination paper for TKP 4140 – Process Control

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Examination date: 14 December 2013  
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:  4 (including Bode paper which may be handed in)
Problem 1 (25%) – Simple process

Let

\[ y_1 = \frac{5}{20s+1} u \]
\[ y_2 = \frac{-2}{2s+1} u \]
\[ y = y_1 + y_2 \]

(a) For a step change in u (Δu=1), 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? (6%)

(b) We have given the following process: \( g(s) = \frac{6}{(20s+1)(6.5s+1)} \). 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 \( t \)). (6%)

(e) PI-control. Draw 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 \( c=0.025(20s+1)/s \)
Problem 3 (40%) - Mixing process

Three streams are mixed in a mixer with volume $V=100\ l$ such that the total flow is at a given value ($q \approx q_s = 1\ l/s$), given temperature ($T \approx T_s = 50\ C$), and given concentration ($c \approx c_s = 1\ g/l$). The nominal stream data are

Stream 1: $T_1 = 25\ C$, $c_1 = 0.1\ g/l$
Stream 2: $T_2 = 125\ C$, $c_2 = 0\ g/l$
Stream 3: $T_3 = 50\ C$, $c_3 = 4.7\ g/l$

(a) Make a flowsheet of the process. What is the nominal value for the three flows ($q_1$, $q_2$, $q_3$)? (9%)
(b) Formulate a dynamic model (differential equations) for the effect of $q_1$, $q_2$, $q_3$ ($u$'s) on $q$, $T$, $c$ ($y$'s). (9%)
(c) 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 $G$? Compute the RGA-matrix of $G$ (it is sufficient to consider $s=0$ since the RGA-matrix is independent of frequency in this case). (4%). If you cannot find it, then use:

$$
RGA = \begin{bmatrix}
0.6 & 0.2 & 0.2 \\
0.1 & 0.1 & 0.8 \\
0.3 & 0.7 & 0
\end{bmatrix}
$$
(e) Suggest a control strategy based on three 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. (5%)
(f) Use of single loops results in “interaction”. What is interaction? Suggest a control system which reduces the interaction between the loops (again, you may base your arguments on engineering sense). (5%)

Comment. It seems some students had problems understanding the problem.
- It is a continuous process with three feed streams ($q_1$, $q_2$, $q_3$) and one product stream ($q$); so "the total flow" is "the total product flow"
- One may thing of the feed containing two components, water and some "impurity" with concentration $c$, for example, the "impurity" could be sugar.
Bode paper: