NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Chemical Engineering

Examination paper for TKP 4140 – Process Control

Academic contact during examination: Cristina Zotica
Phone: 92290702

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)

Informasjon om trykking av eksamensoppgave
Originalen er:

1-sidig ☐ **2-sidig** ☐

sort/hvit ☐ **farger** ☐

skal ha flervalgskjema ☐

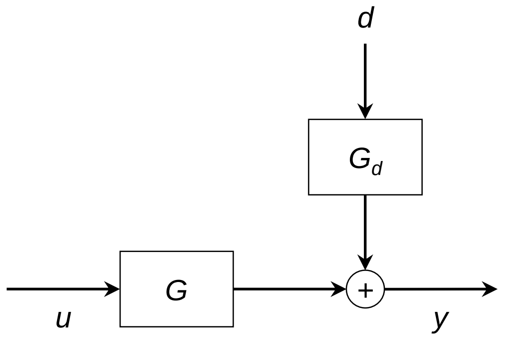
Checked by:

Date Signature

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:



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

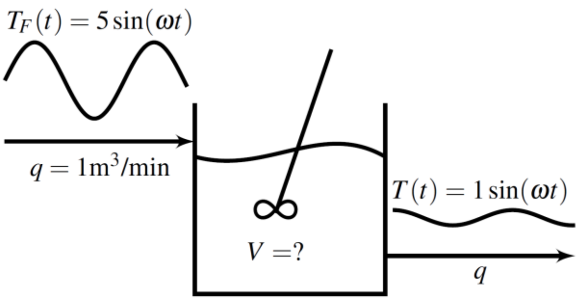
   i. No control (u=0)

   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 ± 5 °C and frequency $\omega = 4\, rad/min$, $T_F(t) = 5\ \sin(\omega t)$. The feed flow is $q = 1\, m^3/min$. 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 ± 1°C.

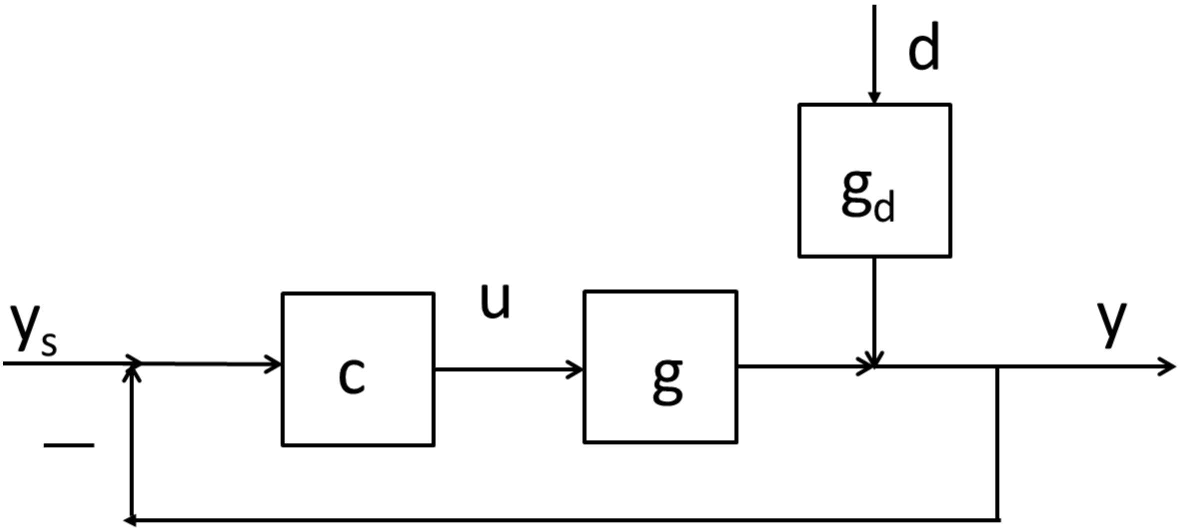


a) (3%) Find the transfer function from T_F to T.

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:

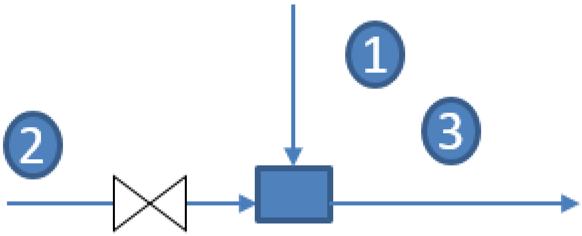
$$g(s) = \frac{10\, e^{-0.3s}}{(6s+1)^2}, \quad g_{d(s)} = k_d\, g(s)$$

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:

$$\text{Desired sugar content (want to keep product close to this value): } x_{S3} = 0.1$$
$$\text{Maximum E in product (required at all times): } x_{E3} \leq 0.001$$

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: