NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Chemical Engineering

Exam paper for TKP4140 – Process Control

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Academic contact present at the exam location: Yes (10:45)

Examination date: 14 August 2025

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): 3 (including Bode paper which may be handed in)

Informasjon om trykking av eksamensoppgave
Originalen er:
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Date Signature

Problem 1 (60%) – Mixed process control questions

1) (5%) Given an unknown process, suggest a test you can perform to check if it is linear.

2) (5%) PID controller. What is the effect on performance (faster/slower) and robustness (more/less) of:
   (i) decrease in controller gain
   (ii) increase in integral time
   (iii) decrease in derivative time.

3) (10%) Show a block diagram for feedforward control for a measured input disturbance d, that is, y = g(s)(u+d). What feedforward controller would you suggest for the process $g(s)=3\,e^{-2s}$. Plot the expected response to a disturbance in d.

4) (5%) Consider a system with loop transfer function L(s) = 0.4/s. Sketch the Bode plot.
   (i) What is the gain and phase at low frequency (as $\omega \to 0$) ?
   (ii) What is the gain and phase margin?
   (iii) What is the closed-loop time constant of the system?

5) (5%) Why is in not recommended to pair on negative steady-state RGA elements?

6) (5%) Consider a system described by the differential equation dx/dt=Ax+Bu, and static equation y =Cx+Du. Is the system linear? What is the steady-state gain from u to y?

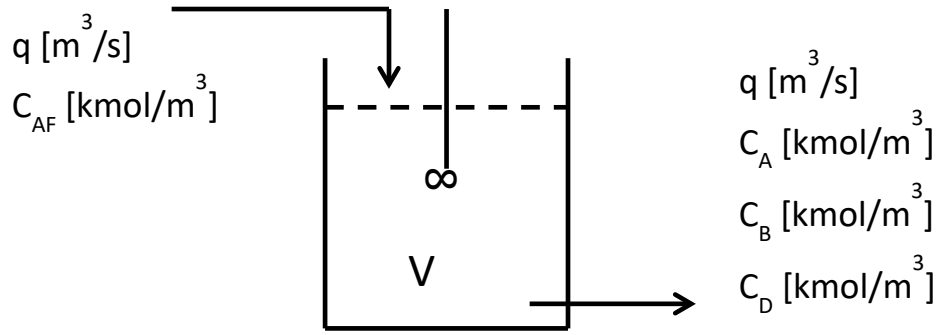
7) (10%) Consider the process $g(s)=3\,e^{-2s,}$ with y = g(s) (u+d). Plot the output y(t) in response to a unit step change in u (without control). Suggest PI controller tunings for this process. Plot the expected response y(t) to a unit input disturbance d (with control).

8) (5%) What is anti-windup?

9) (5%) Model predictive controllers (MPC) are widely studied but less used in practice that was expected when they came into use about 40 years ago. What do you think is the reason?

10) (5%) When do we use split range control? Give an example.

Problem 2 (40%) - Reactor dynamics



The following reactions take place in an isothermal mixing tank reactor (CSTR).

$A \rightarrow B$; $r_1 = k_1 C_A$

$B \rightarrow D$; $r_2 = k_2 C_B$

where r_j [kmol /m^3,s] is the rate of reaction j. The feed only contains component A. The reactor volume V [m3] is assumed constant (Temperature and level controllers needed to keep temperature and volume constant are not shown on the figure).

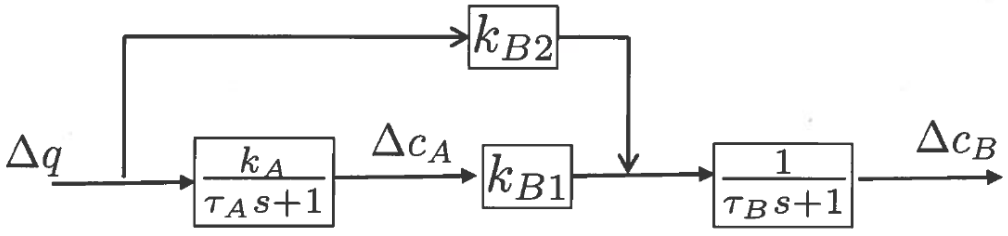
We are considering using the feedrate (q) to control the concentration of B, so we want to derive a dynamic model for the effect of q on C_B.

(a) (12%) Derive a dynamic model for the system using balances for components A and B (Note that you need not use the energy balance because the temperature is assumed constant, and you need not use the total balance because the volume is assumed constant).

(b) (8%) At steady state we have :
V=8m^3, q=0.4 m^3/s, C_{AF} = 7 kmol/m^3, C_A=1 kmol/m^3, C_B=5.5 kmol/m^3, C_D=0.5 kmol/m^3. What are the values of k_1 [s^{-1}] and k_2 [s^{-1}]?

(c) (10%) Linearize the model. Show that the model can be written as shown in the figure below. Determine the constants k_A, k_{B1}, k_{B2}, τ_A,τ_B. (Note that the sign of k_{B2} is negative whereas the others are positive).

(d) (10%) Determine the transfer function G(s) from u=Δq to y= ΔC_B. What are the poles and zeros (you can do this just based on the block diagram below). When you put in numbers, G(s) should have one RHP-zero (please check this if you did part c). Would you recommend using u=Δq to control y= ΔC_B?



Bode paper: