NTNU – Trondheim
Norwegian University of
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Department of Chemical Engineering

Examination paper for TKP 4140 – Process Control

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Examination date: 06 December 2017
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): 4 (including Bode paper which may be handed in)

Informasjon om trykking av eksamensoppgave
Originalen er:

1-sidig ☐ **2-sidig** ☐

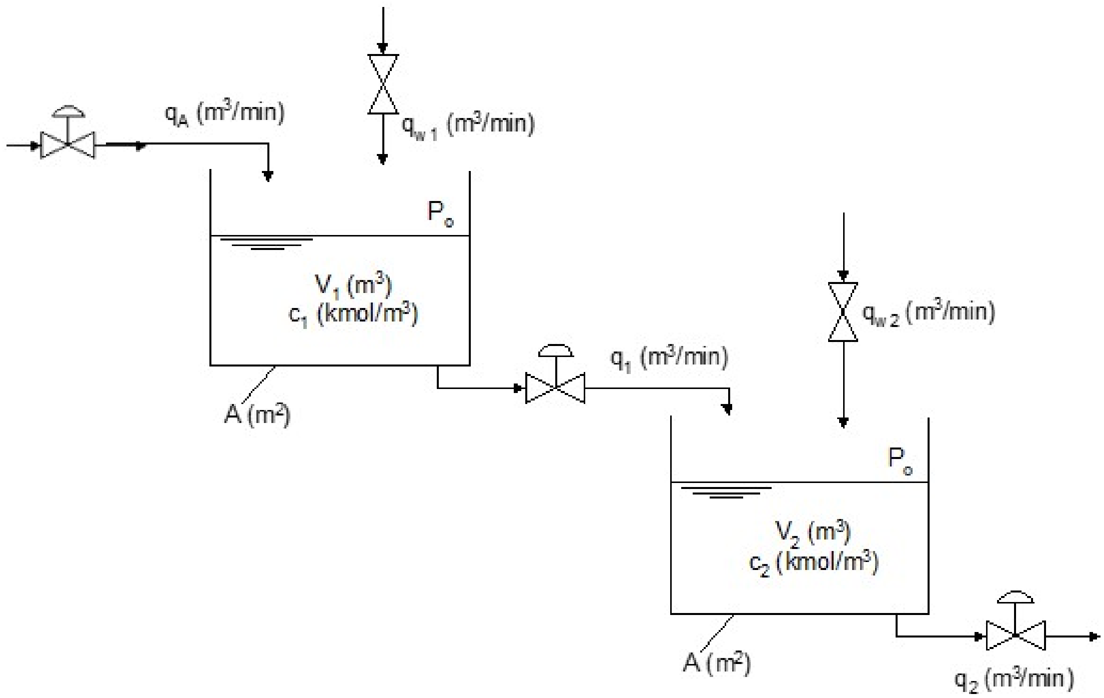
sort/hvit ☐ **farger** ☐

skal ha flervalgskjema ☐

Checked by:

Date Signature

Problem 1 - Mixing process (30%)



Note that the three parts of this problem can be done independently.

Two mixing tanks are used to produce a diluted acid (q_2) from concentrated acid (q_A) and water (q_{w1} and q_{w2}), (see figure). The main part of the dilution is done in tank 1, while tank 2 is used to fine tune the dilution to obtain the desired concentration (q_{w1} is about 10x q_{w2}).

(a) Write a dynamic model for the process (two balances for each tank). You may need to introduce symbols (variables) in addition to the ones given on the figure. No linearization or Laplace is required.

(b) Formulate the 2x3 transfer matrix G_1 for the first tank with q_A, q_{w1} and q_1 as independent variables (inputs or disturbances) and V_1 and c_1 as dependent variables (outputs). No numbers are required, just the form (first-order, integrating, etc.) and sign of the gain.

(c) Now we consider control. The flow of dilute acid is set by the downstream process, so q_2 is a disturbance. Suggest a control structure on the flowsheet for each of the following two cases:

1) Measurements are c_1, c_2 and the two levels. Suggest a control structure with four feedback loops.

2) Measurements are c_2 and the two levels. Suggest a control structure that makes q_{w2} return to its desired value at steady state.

Problem 2 – PID controller tuning (15%)

Consider a process given by the following process model

$$G_1(s) = \frac{3}{(100s+1)(10s+1)} e^{-2s}$$

In addition, the measurement has a time delay θ_m given by $G_m(s) = e^{-\theta_m s}$.

Design a PI- or PID-controller (say which one you suggest) using the SIMC rules with $\tau_c = \theta$ (effective delay) for the following two cases:

a) $\theta_m = 1$.
b) $\theta_m = 20$.

Problem 3 – Closed-loop transfer functions and tuning (10%)

Consider a process G(s) with no measurement dynamics.

(a) We use a standard feedback controller, u = C(s) (y_s-y). Draw the block diagram. Derive the closed-loop transfer function T_1 from the setpoint y_s to the output (measurement) y, and the closed-loop transfer function T_2 from the setpoint y_s to the input u.

(b) Let $G(s) = \frac{k}{\tau_1 s + 1}$ and design a PI controller tuned with the SIMC rules and $\tau_c = \tau_1$ (this choice for τ_c is the basis for the so-called λ-tuning). Derive T_1 and T_2 for this case (make the result as simple as possible).

Problem 4 – Pairing and decoupling (15%)

The relative gain array (RGA) is a tool one can use to analyze interactions and decide on controller pairings in multivariable systems. Consider the following process and steady-state RGA:

$$G(s) = \begin{bmatrix} 10e^{-5s} & -3 & 6 \\ 3 & 1.5 & -0.5 \\ 5 & 2 & -1.5 \end{bmatrix}, RGA(0) = \begin{bmatrix} 0.45 & 0.22 & 0.33 \\ -0.82 & 2.45 & -0.64 \\ 1.36 & -1.67 & 1.31 \end{bmatrix}$$

Note that input 1 corresponds to the first column in G, output 1 to the first row in G, etc.

a) How would you pair the inputs with the outputs (controlled variables)?
b) What are the implications if you pair on the following RGA values $\lambda_{i,j}$?

1. $\lambda_{i,j} < 0$
2. $0 < \lambda_{i,j} < 1$

3. $1 < \lambda_{i,j}$

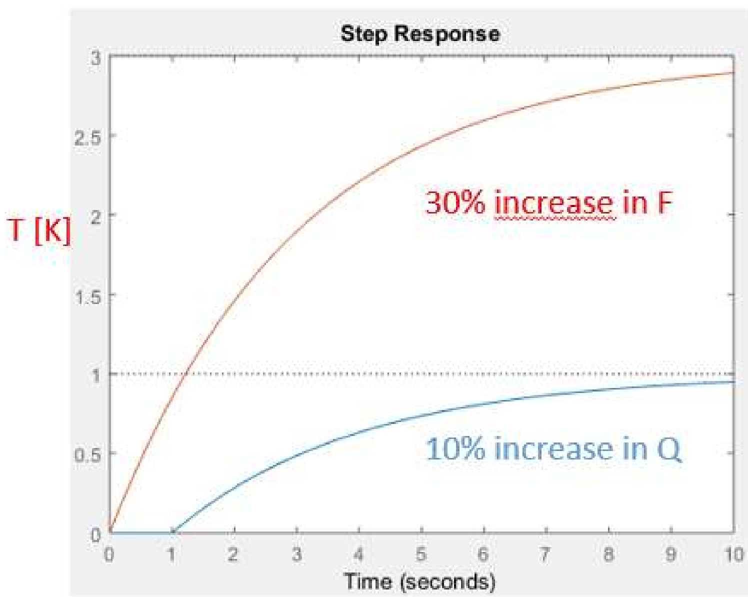
c) Explain what decoupling is and how it can be used to reduce the effect of interactions. Design a one-way decoupler for a 2x2 process G which may improve the control of y_1. Can the one-way decoupler always be realized?

Problem 5 – Closed-loop stability of inverse-response process (15%)

(a) Consider PI-control of the process G(s) = (1-5s)/(8s+1) with integral time τ_I = 8. For what controller gain K_c is the closed-loop system stable?

(b) Design a SIMC PI-controller for this process with $\tau_c = \theta$ (effective delay). What is the gain margin? What is the time delay margin?

Problem 6 – Controllability (15%)



We want to control the temperature (y=T) in a reactor. The MV is the cooling rate (u=Q) and the disturbance is the feed rate (d=F).

In the figure is shown the response in temperature to a large step disturbance (F + 30%) and to a change in the input (Q + 10%). Note that the largest possible input change is Q +50%.

We would like the temperature deviations to stay within +- 1K.

(a) Suggest transfer functions for G(s) and G_d(s). For the scaling, let u=1 correspond to Q=50%, let d=1 correspond to F=30% and let y= 1 correspond to a temperature change of 1K.

(b) Is the process controllable? Sketch the expected closed-loop response in temperature to a 30% increase in F.

Bode paper: