National Exams December 2012

04-Chem-A6, Process Dynamics & Control

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM. Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. Most questions require an answer in essay format. Clarity and organization of the answer are important.

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Problem #1 (20% total)

Consider a closed loop system composed of the following elements:

1 - a proportional controller with gain k_c,

2 - a process transfer function G_p,

$$G_p = \frac{1}{(s+1)^3}$$

3 - a sensor transfer function H.

Find the maximum k_c for the following 2 cases:

(10%) (a) $H = 1$

(10%) (b) $H = e^{-0.7s}$ (DO NOT USE PADE APPROXIMATION)

If iterations are required to solve an equation, show only the first 3 iterations (steps).

Problem #2 (20% total)

Two stirred tank reactors are separated by a plug-flow dead time of D seconds as shown in the figure.

Assume constant holdups V_1 and V_2, constant mass flow F, constant density, isothermal operation at temperatures T_1 and T_2 and first order kinetics with simultaneous reactions

$$A \xrightarrow{k_1} C \quad \text{and} \quad A \xrightarrow{k_2} C.$$

No reaction occurs in the plug flow section.

(20%) Develop the modelling equations describing the system.

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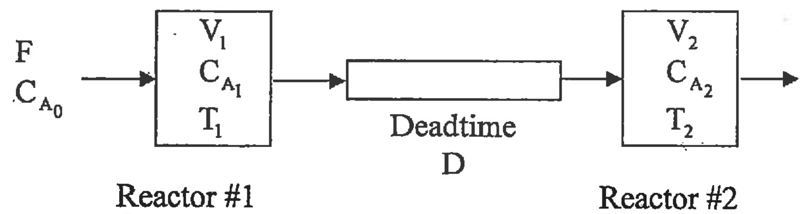
Find the transfer function:

$$\frac{C_{A_2}(s)}{C_{A_0}(s)}$$



Problem #3 (20% total)

A process given by:

$$G_p = \frac{10}{s-1}$$

is controlled by a proportional controller with gain k_c.

(10%) (a) Show a qualitative Nyquist plot (show only 2-3 key points and the general shape of the plot for this problem) for $k_c = 1$. Assess the closed loop stability based on the Nyquist criterion.

(10%) (b) Based on the Nyquist criterion, compute a range of k_c values to obtain closed loop stability.

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Problem #4 (20% total)

A process is described by the following transfer function

$$G_p = \frac{10e^{-5s}}{100s+1}$$

(5%) (a) Design an IMC (Internal Model Controller) for this process. Show your design with a block diagram. DO NOT USE PADE APPROXIMATION.

(10%) (b) Compute and plot the closed loop response to a unit step change in the set point using the controller computed in (a). Select the time constant for the IMC filter to be $\tau_c = 10$. Assume perfect model (no model error).

(5%) (c) If the time delay is approximated by using a 1-1 Pade approximation calculate the PID tuning parameters of the feedback controller equivalent to the IMC design.

Problem # 5 (20%)

The dynamic behaviour of the levels in each leg of an industrial manometers is given by the following differential equation:

$$\frac{d^2 h'}{dt^2} + \frac{6\mu}{R^2 \rho}\frac{dh'}{dt} + \frac{3}{2}\frac{g}{L}h' = \frac{3}{4\,\rho\,L}p'$$

where h' and p' are the level and the measured pressure in deviation variables with respect to an initial steady state.

(10%) 1. Find the transfer function between the level to the measured pressure. Show a condition for the physical constants for which the response in level will be oscillatory.

(10%) 2. Does an increase in density help to reduce oscillations?
Does an increase in viscosity help to reduce oscillations?
Justify your answers by using the condition developed in the previous item.

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Problem #6 (20% total)

A process given by:

$$G_p = \frac{e^{-0.1s}}{0.5s+1}$$

is controlled by a proportional controller with gain k_c.

(10%) (a) Plot qualitatively the Bode Plot for this system (show slope values, corner frequencies and extreme amplitude and phase values).

(10%) (b) Compute the gain k_c to obtain a gain margin of 1.7.

Problem #7 (20% total)

A first order process is given by:

$$G_p(s) = \frac{1}{s+5}$$

This process is controlled by a Proportional Integral (PI) controller given by:

$$G_c(s) = k_c\left(1+\frac{1}{s}\right)$$

(10%) (a) Compute ranges of k_c values for which the closed loop is stable using the Routh test.

(10%) (b) For a controller with gain $k_c = 1$, compute the closed loop time response for a unit step in set point.

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Problem #8 (20% total)

The dynamic response of the reactant concentration in a CSTR reactor, C_A, to a change in inlet concentration, C_{A_0}, has to be evaluated.

The reactor is operated with constant volume V and isothermal conditions.
The density ρ is constant.

The reaction rate is:

$$r_A = \frac{k_1 C_A}{1 + k_2 C_A}$$

The mass flow is F.

(5%) (a) Derive a mathematical model to describe $C_A(t)$.

(5%) (b) Compute steady state conditions for concentration.

(10%) (c) Compute a transfer function $\delta C_A / \delta C_{A_0}$ (where δ indicates deviation variables), i.e. changes in exit concentration to inlet concentration, when the system is operated close to the steady state found in (b).