National Exams May 2017

04-Bio-A2, Process Dynamics and 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

A heated tank process is described by the following transfer function:

$$G_p = \frac{2.31}{(s+1)(5s+1)}$$

This process is to be controlled by a proportional digital controller with gain k_c.

10% 1- Draw the block diagram for the digital control system. (Indicate clearly all the components, including samplers.)

10% 2- If the sampling period is T = 0.5, compute the range of k_c values to guarantee stability. Use Jury test.

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PROBLEM # 2 (20%)

Consider the following system of equations:

$$\frac{dx_1}{dt} = -2.4048x_1 + 7u$$

$$\frac{dx_2}{dt} = 0.8333x_1 - 2.2381x_2 - 1.117u$$

$$y = x_2$$

10% a-Find the transfer function Y/U

10% b-Solve for y in response to a unit step change in u.

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PROBLEM #3 (20% total)

A process is described by the following transfer function:

$$G_p = \frac{10(0.5-s)e^{-10s}}{100s+1}$$

(10%) (a) Design an IMC (Internal Model Controller) for this process. Show your design with a block diagram.

(10%) (b) Assuming a perfect model of the process, compute the closed loop response for a unit step in set point if the desired closed loop time constant is equal to 5.

PROBLEM # 4 (20% total)

A process given by:

$$G_p = \frac{100}{s-10}$$

is controlled by a proportional controller with gain K_c.

(10%) (a) Using the Nyquist theorem test the closed loop stability for $K_c = 1$ and $K_c = 0.01$.

(10%) (b) Using the Nyquist criterion, compute the limiting value of K_c for which the system is stable.

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Problem #5 (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,

3 - a sensor transfer function H.

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

Find the maximum k_c for the following 2 cases:

(10%) (a) H = 1

(10%) (b) $H = e^{-0.7s}$

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

PROBLEM #6 (20% total)

For the equation

$$\frac{d^2y}{dt^2} + k\frac{dy}{dt} + 10y = 2x$$

(10%) (a) Find the transfer function between the input x to the output y and put it in the standard gain-time constant form.

(5%) (b) Discuss for which values of k is the open loop response for a unit step in x (i) stable, (ii) underdamped, and (iii) overdamped.

(5%) (c) If the response is underdamped, compute expressions as a function of k for the time constant and the damping coefficient according to the standard form definitions.

PROBLEM #7 (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: $r_A = k_1 C_A{}^2$

The mass flowrate is F.

(10%) (a) Derive a mathematical model to describe $C_A(t)$ and compute steady state conditions for concentration.

(10%) (b) Compute a transfer function $\delta C_A / \delta C_{A_0}$ (where δ indicates deviation variables) when the system is operated around the steady state computed in (a).

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Problem #8 (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 the open loop 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.