National Exams May 2018

04-BIO-A2, 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%)

For the system: $G(s) = \frac{10}{s^2+s+9}$

10% 1- Plot the Bode plots (show values at extreme values of frequency i.e. 0 and infinity and show general shape)

10% 2- Determine exactly the phase margin, PM

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PROBLEM 2 (20%)

The transfer function between the flow (manipulated variable) into a tank and the liquid level (controlled variable) $G_p(s) = \frac{1}{s}$. The process is controlled by a proportional controller with gain K. The level is measured by a sensor with transfer function $G_m = \frac{s-1}{s^2+2s+1}$.

10% 1- Draw the block diagram and find the closed loop transfer function.

20% 2- Find the range of values of K for which the closed loop is stable.

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PROBLEM 3 (20%)

A process described by $G(s) = \frac{e^{-0.5s}}{s(s+1)}$ is controlled by a proportional controller with gain K.

10% 1- Find the Phase Margin and Gain Margin for K=1.

10% 2- Find the exact maximum of the controller gain K for stability.

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PROBLEM 4 (20%)

A process is described by the following transfer function $G(s) = \frac{2(1+cs)}{(s+1)(s+2)}$

10% (a) Find the response to a unit step change as a function of c.

10% (b) Find the values of c for which there is an overshoot. Find the magnitude of the overshoot as a function of c.

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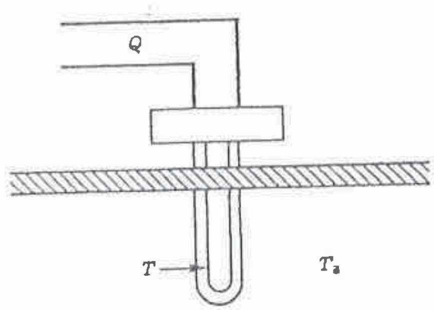
PROBLEM 5 (20%)

The Calrod heating element shown in the drawing transfers heat largely by a radiation mechanism. If the rate of electrical energy input to the heater is Q and the rod temperature and ambient temperatures are, respectively, T and T_a, then an appropriate unsteady-state model for the system is

$$mC\frac{dT}{dt} = Q - k(T^4 - T_a^4)$$

m is the mass of the heater, C is specific heat and k is radiation coefficient.

(15%) a) Linearize and then find the transfer functions relating δT to δQ and δT to δT_a. (Be sure they are both in standard form, i.e. show gain and time constant.)



(5%) b) If you were to design a proportional controller to control T by manipulating Q, what will be the sign of the controller to guarantee stability? Justify your answer.

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PROBLEM #6 (20% total)

A process described by the following transfer function:

$$G(s) = \frac{5e^{-10s}}{10s + 1}$$

Is to be controlled by an IMC (Internal Model Controller) controller. Time is in seconds.

(10%) a) Show the block diagram of the closed loop. Calculate the IMC controller Gc^* and the classical feedback controller equivalent Gc (**without assuming Pade approximation at this point**). Assume that the IMC filter parameter is τ_C=20 sec. Is the resulting Gc of PID form?

(10%) b) Calculate the closed loop response for the controlled variable $\delta C(t)$ for a unit step change in set point for the controller in item a) **where Pade was not assumed and the model is assumed to be perfect.**

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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-derivative (PI) controller given by:

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

(10%) (a) Compute values of k_c that will result in closed loop stability.

(10%) (b) Calculate the closed loop response to a unit step change in set point with k_c=1.

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PROBLEM 8 (20%)

The dynamic response of the reactant concentration in a CSTR reactor, C_A, to a change in inlet Concentration (mol/volume), 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 (mol/time/volume) is: $r_A = kC_A^2$

The volumetric flowrate (volume/time) 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).