National Exams December 2019

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%)

A transfer function is given as:

$$G(s) = \frac{K(\tau_a s + 1)}{(\tau_1 + 1)(\tau_2 + 1)}$$

If $\tau_1 > \tau_2$, for a step input show:

10% 1- overshoot occurs only for $\frac{\tau_a}{\tau_1} > 1$

10% 2-Inverse response occurs only for $\tau_a < 0$

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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(s)/U(s)

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

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PROBLEM 3 (20%)

A thermocouple is immersed in a well stirred bath of liquid. The geometry and properties of the thermocouple's material are as follows:

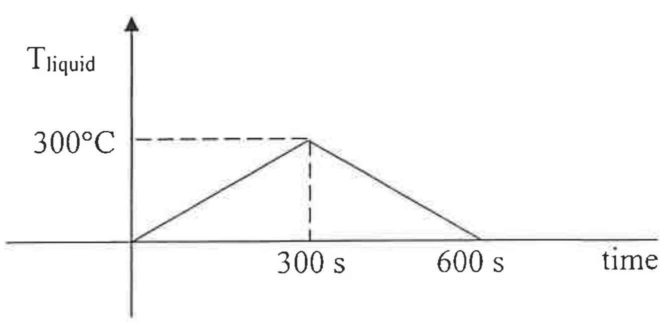
mass = 0.25 g

heat capacity = 1 cal/g °C

Heat transfer coefficient between the thermocouple and the liquid = 60 cal/cm^2 h °C surface area of the thermocouple = 1 cm^2.

(10%) a) Find the transfer function that relates the temperature of the thermocouple to the temperature in the liquid. Assume that there are no gradients in the thermocouple bead, no conduction through the thermocouple wires and the conversion from Millivolt to degrees occurs by a very fast reading device.

(10%) b) If the temperature in the liquid changes according to the following diagram, calculate the temperature registered by the thermocouple as a function of time.



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PROBLEM 4 (20%)

A process described by the following transfer function:

$$G(s) = \frac{5e^{-10s}}{20s + 1}$$

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 (**do not use approximations of the delay**).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) **do not use approximations of the delay and assumed the model to be perfect.**

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PROBLEM 5 (20%)

A process given by:

$$G_p = \frac{20}{s-3}$$

Is to be controlled by a proportional controller with gain K_c.

(10%) a) show a qualitative Nyguist plot (show only 2-3 key points along the plot and the general shape of the plot and the general shape of the plot for this problem) $K_c = 1$. Is the system stable for this gain?

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

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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.

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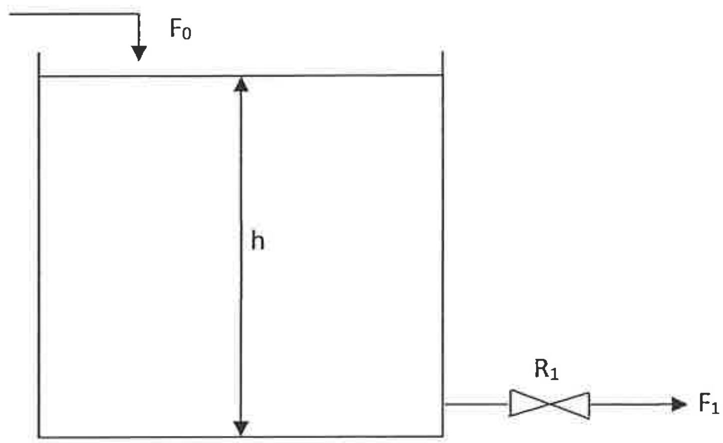
PROBLEM #7 (20% total)

For the draining tank shown in the figure



Compute the change in level $\delta h(t)$ with respect to an initial steady state for the following two cases:

(10%) (a) a unit step in inlet flow F_0

(10%) (b) a unit impulse in inlet flow F_0

The cross section area is $1 m^2$. The initial level is 7m.

The flow out is given by $F_1 = R_1 \bullet h$, where the coefficient $R_1 = 4\frac{m^2}{min}$.

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PROBLEM 8 (20%)

A first order process is given by:

$$G_p(s) = \frac{1}{s+2}$$

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. Use the Routh Test.

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