National Exams December 2016

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%)

Find the inverse transform for the following functions:

(10%) a) $Y(s) = \frac{s-3}{s(s^2-6s+18)}$, is the response stable?

(10%) b) $Y(s) = \frac{s-3}{s^2(s^2-6s+18)}$,is the response stable?

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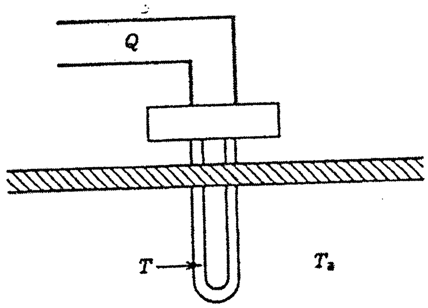
PROBLEM 2 (20%)

The 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 changes 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 should be the sign of the controller to guarantee stability? Justify your answer.

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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

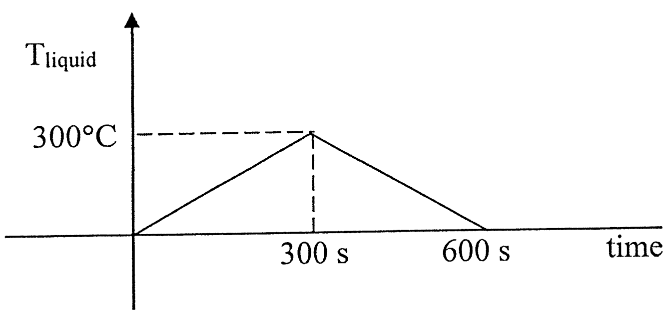
heat capacity = 1 cal/g °C

Heat transfer coefficient between the thermocouple and the liquid = 60 cal/cm^2 h °C

surface area of the thermocouple = 1 cm^2.

(10%) 1. 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%) 2. 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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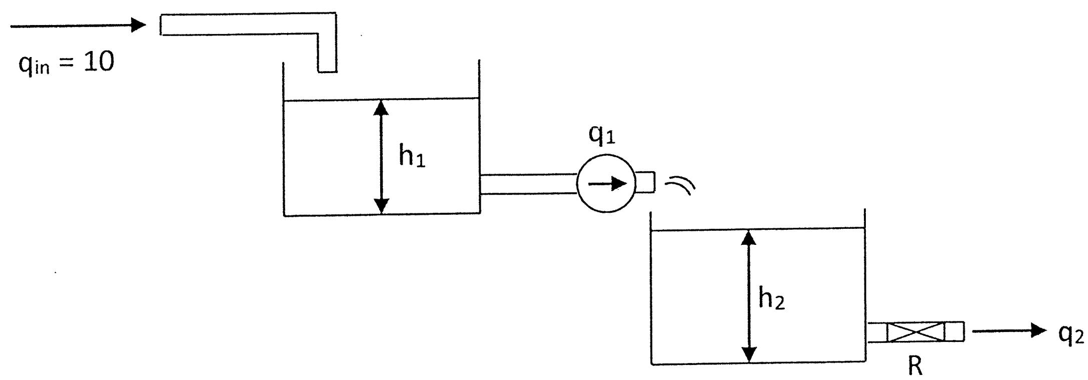
PROBLEM # 4 (20%)



Two tanks are connected in series in a non-interacting fashion as shown in the figure.

Assume: $\rho = 1$ $A = 1$ (A-cross-section of each tank)

$$q_2 = \frac{1}{R}\sqrt{\frac{\Delta P}{\rho g}}$$ and q_1 is determined by a pump.

The initial value of the inlet flowrate is $q_{in} = 10$ and remains constant. The initial level in tank 1 is $h_1(t{=}0) = 10$. q_1 is the manipulated variable. All q's are volumetric flow rates. $R = 2$.

(10%) (a) Show the differential equations that describe the behaviour of $h_1(t)$ and $h_2(t)$.

(10%) (b) Compute transfer functions between δh_1 to δq_{in} and δh_2 to δq_{in}.(δ indicates deviation)

δ

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Problem #5 (20% total)

A process is described by the following transfer function:

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

(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 10.

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PROBLEM 6 (20%)

Consider a closed loop system composed of the following elements: a- proportional controller with gain K_c, b-process with transfer function $G_p = \frac{1}{(s+1)^3}$ and c-sensor with transfer function H.

(5%) a) Find the largest gain K_c for which the closed loop system is stable for the following two cases: i) H=1 and ii) $H = e^{-0.7s}$. Do not use Pade approximation.

(5%) b) Plot the Bode plots (amplitude ratio normalized and phase) for case ii in item 1 above corresponding to the frequency response of the product K_c*G_p*H. Indicate clearly asymptotes, corner frequency, value of slopes of asymptotes and extreme values of the phase angle for very small and very large values of frequencies.

(10%) c) If K_c=1, calculate the gain and phase margins for case i and ii in item a) above.

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PROBLEM 7 (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) where Y and U are transforms of y and u respectively.

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

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Problem #8 (20% total)

A process given by:

$$G_p = \frac{10}{s-5}$$

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

(10%) a) show a qualitative Nyquist 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.