National Exams December 2013

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.

Note: 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.

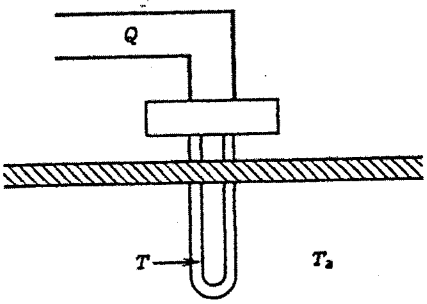
PROBLEM 1 (20%)

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.

Note: 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

PROBLEM 2 (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.

Note: 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

PROBLEM 3 (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.

Note: 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

PROBLEM 4 (20%)

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

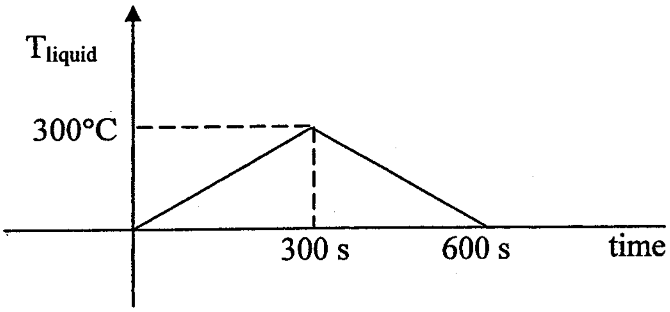
mass = 0.25 g

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.



Note: 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

PROBLEM 5 (20%)

A process described by the following transfer function:

$$G(s) = \frac{5e^{-2s}}{10s + 1}$$

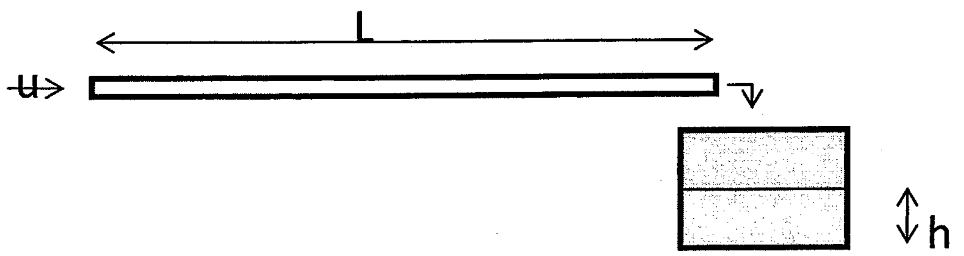
Is to be controlled by an IMC (Internal Model Controller) controller. Time is in seconds.

(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.**

Note: 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

PROBLEM 6 (20%)



A pipe of length L=10 m is feeding liquid into a tank. The speed of the liquid in the pipe is u=1 m/s. The level of liquid in the tank is h. The cross section area of the tank is $A=1\ m^2$.

(5%) a) Calculate the time delay in the pipe between inlet to outlet for the given velocity. Assume that this delay remains constant for the rest of this problem despite changes in flowrate.

(5%) b) Model the system, i.e. formulate differential equations to calculate h(t) with respect to inlet velocity u and find the open loop transfer function between h to u.

(10%) c) If the height h is controlled by manipulating the velocity u with a proportional controller with gain Kc, find the closed loop transfer function between the set point changes in h to changes in h.

Note: 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

PROBLEM 7 (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.

Note: 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

PROBLEM 8 (20%)

A first order process is given by

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

This process is controlled by a PI controller given by:

$$Gp = K_c(1 + \frac{1}{s})$$

(10%) a) Compute ranges of K_c values for which the closed loop is stable.

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