16-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%)

Given: $$Y(s) = \frac{(s-3)}{s(s^2-6s+18)}$$

(10%) a-Find the inverse $y(t)$.

(10%) b-Is the response stable? 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

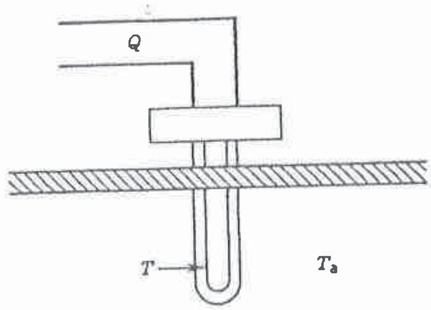
PROBLEM 2 (20%)

The heating element shown in the drawing below 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 this model 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 should 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 3 (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. (note: all other transfer functions in the loop are equal to 1).

(10%) 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.

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

16-Chem-A6, Process Dynamics and Control

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:

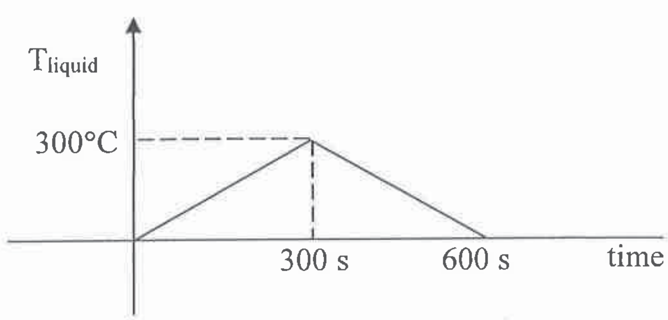
mass = 0.25 g

heat capacity = 1 cal/g °C

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



<u>Note</u>: 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) **do not use Pade approximations and assume a perfect model.**

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% total)

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.

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% 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.

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 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.