National Exams May 2012

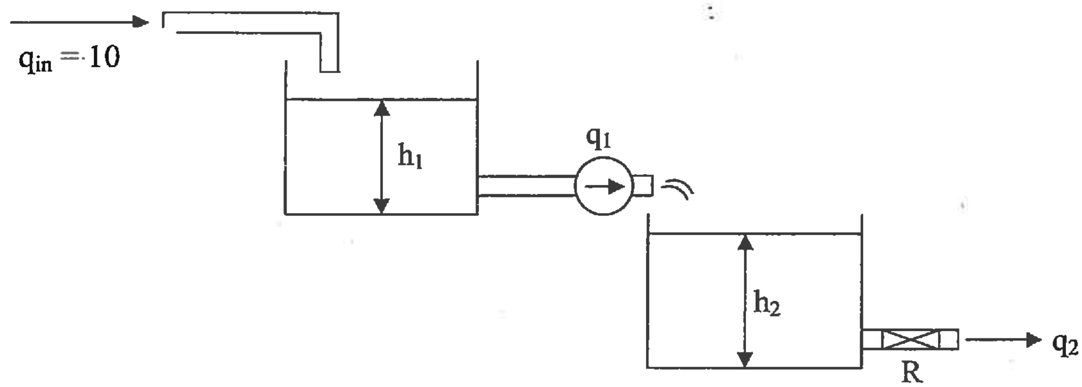
04-Chem-A6, Process Dynamics and Control

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.

Problem #1 (20% total)



Two tanks are connected in series in a noninteracting 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.

$q_{in} = 10$ 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 h_1 to q_{in} and h_2 to q_{in}.

Problem #2 (20% total)

A process is described by the following transfer function:

$$G_p = \frac{10(0.5 - s)e^{-10s}}{100s + 1}$$

(10%) (a) Design an IMC controller for this process. Show your design using a block diagram. Select the IMC filter to be of 1st order with a time constant $\tau = 5$.

(10%) (b) Compute and plot qualitatively the closed loop response of the system to a unit step in set point. Assume a perfect model (i.e. no model error).

Problem #3: (20% total)

A second order process is given by

$$G_p(s) = \frac{1}{s^2 + 3s + 2}$$

This process is controlled by a proportional-derivative (PD) controller given by:

$$G_c(s) = k_c(1 + s)$$

(10%) (a) Compute values of the k_c that will result in closed loop stability. Use Routh-test.

(10%) (b) If instead of a PD, a proportional only controller $G_c(s) = 0.1$ is used, compute the closed loop response as a function of time for a unit step change in set point.

Problem 4 (20% of total)

For a second order process:

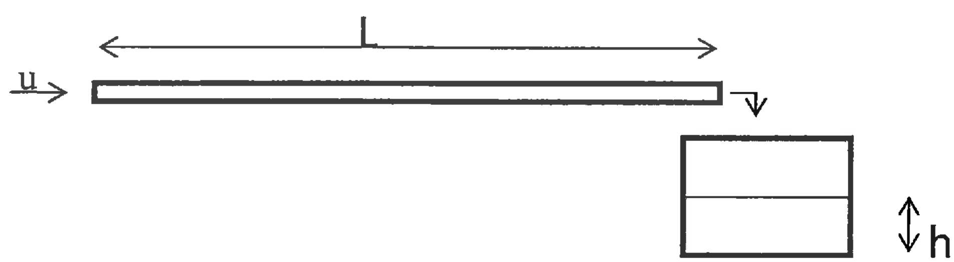
$$G(s) = \frac{1}{\tau^2 s^2 + 2\tau\xi s + 1} \qquad \textit{asume } \xi \textit{ and } \tau \textit{ are both positive}$$

(5%) (a)- Find the frequency response B(ω) and Φ(ω) for an input A*sin(ωt) for $\xi<1$.

(5%) (b)-Plot qualitatively the Bode plots for the amplitude ratio and the phase angle for $\xi<1$. Show asymptotes for very small and very large values of ωτ, show value of slope of the asymptote in logarithmic scale, show "corner" frequency.

(10%) (c)-If a proportional controller with gain Kc is used to control this process, what is the Largest Kc that can be used for stabiltity? (use a stability test of your choice)

Problem 5 (20% of total)



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

(5%) (a)- Model the system, i.e. formulate differential equations to calculate h(t) with respect to inlet volumetric flowrate to the pipe q and find the open loop transfer function between h to q.

(5%) (b)- If the height h is controlled by manipulating the flowrate q with a proportional controller with gain Kc, find the closed loop transfer function between the set point changes in h to changes in h.

(10%) (c)-What is the largest gain Kc for stability. Do not use Pade approximation. Then, calculate the gain margin for Kc=0.1.

Problem #6 (20% total)

The dynamic response of the reactant concentration C_A in a CSTR reactor, to a change in inlet concentration C_{A_i}, has to be evaluated. The reactor is operated with constant volume V and at isothermal conditions. The density of the liquid inside the reactor ρ is constant.

The reaction rate is:

$$r_A = k_1 C_A^2$$

The mass flow rate is F.

(10%) (a) Derive a mathematical model for C_A as a function of time.

(10%) (b) Compute an approximate transfer function $\delta C_A / \delta C_{A_i}$, where δ indicates deviation variables, i.e. changes in exit concentration to inlet concentration, when the system is operated close to a steady state corresponding to an inlet concentration of C_{Ai}^0. Express the transfer function as a function of ρ, V, C_{Ai}^0, F and k_1.

PROBLEM # 7 (20% of total)

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.

Problem #8 (20% total)

For the process modelled by:

$$\frac{dy_1}{dt} = -y_1 + y_2 + x_1$$
$$\frac{dy_2}{dt} = y_1 - 2y_2 + x_1 + x_2$$

(10%) (a) Find the two transfer functions relating the inputs x_1 and x_2 to the output y_2. The x's and y's are deviation variables.

(10%) (b) Compute y_2 as a function of time for $x_1 = 0$ and a unit step in x_2.