National Exams May 2018

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.

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PROBLEM 1 (20%)

Consider a water storage tank with inlet and outlet flowrates that can be adjusted independently from each other. The tank has crossectional area 100 ft^2. The flowrates in (q_{in}) and out (q_{out}) are 5 ft^3/min. The initial height is 4 ft and the height of the tank is 10 ft. At 1 PM the inlet flow is increased to 6 ft^3/min while the outlet flow is maintained unchanged at 5 ft^3/min.

10% 1-Find the transfer function of H(s)/Qin(s) where H and Qin are the Laplace transforms of the height h and the inlet flow q_{in} respectively.

10% 2-Find at what time the tank overflows.

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PROBLEM 2 (20%)

A process with transfer function $G_1(s)$ is controlled with a proportional controller with gain Kc=1 and the controlled variable is measured by a sensor with transfer function $G_2(s)$ and the measured variable is then compared to the set-point.

5% 1- Find the closed loop transfer function C(s)/R(s) where C(s) and R(s) are the Laplace transforms of the controlled and set-point variables respectively.

15% 2-Find the range of values of the sensor gain k_2 for which the closed loop system is stable for the following transfer functions:

$$G_1(s) = \frac{2}{(5s+1)(3s+1)}$$

$$G_2(s) = \frac{-k_2}{10s+1}$$

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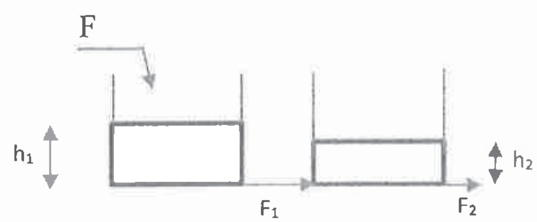
PROBLEM 3 (20%)

Two interacting tanks are shown in the figure:



The levels of liquid in the tanks are h_1 and h_2 respectively. The inlet flow to the first tank is F. The crossectional areas of the tanks are A_1 and A_2 respectively. The volumetric flowrates are given as a function of the levels as follows:

$$F_1 = \beta_1\sqrt{h_1 - h_2} \qquad F_2 = \beta_2\sqrt{h_2}$$

10% 1- Write a set of differential equations that describe the changes of the levels as a function of time.

10% 2- Write a linear state space model that approximates the set of original nonlinear equations about a steady state corresponding to an input flowrate F=Fs.

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PROBLEM 4 (20%)

A thermometer with a time constant of 0.2 min is immersed in a temperature bath and after the thermometer comes to equilibrium with the bath, the bath temperature is increased linearly with time at the rate of 1 ^{0}C / min.

10% (a) what is the difference between the indicated temperature and bath temperature (i) 0.1 min (ii) 1 min after the change in temperature is applied?

5% (b) What is the maximum deviation between the indicated temperature and bath temperature and when does it occurs?

5% (c) Plot the forcing function and the response on the same graph. After a sufficiently long time by how many minutes the response will lag after the input?

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PROBLEM 5 (20%)

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 (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 5.

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PROBLEM #6 (20% total)

For the equation

$$\frac{d^2y}{dt^2} + k\frac{dy}{dt} + 2y = x$$

(10%) (a) Find the transfer function and put it in the standard gain time constant form.

(10%) (b) Discuss the response for values of $-20 < k < 20$.

Specify for which values the response converges and where it will not. Write the form of the response without evaluating any coefficients.

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PROBLEM #7 (20% total)

A process given by:

$$G_p = \frac{1}{s^2 - s - 2}$$

is controlled by a proportional controller with gain k_c.

(10%) (a) Show a qualitative Nyquist plot (show only 2-3 key points and the general shape of the plot for this problem) for $k_c = 1$. Assess the closed loop stability based on the Nyquist criterion.

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

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PROBLEM 8 (20%)

For the transfer function: $G(s) = \frac{1}{s(s+2)^2}$

10% 1-Plot the Nyquist diagram qualitatively indicating main points, intersection with axis of plot and asymptotic values (at frequency=0 and frequency tends to infinity)

10% 2-Find analytically the Gain Margin (GM).