UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sc.

D7: Process Dynamics and Control

COURSE CODE	:	**CENG00D7**
DATE	:	**14-MAY-04**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

04-N0009-3-40

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Answer FOUR questions, **TWO** *from Part A and* **TWO** *from Part B.* **Only the first TWO answers from each part will be marked.** *ALL questions carry a total of 25 MARKS each, distributed as shown* [ ]

PART A

1.

i) Why is linearisation often necessary before the dynamics of a process can be investigated using Laplace Transforms? [4]

ii) For a non-linear ordinary differential equation:

$$\frac{dx}{dt} = f(x)$$

the linearised form using Taylor's series expansion is:

$$\frac{dx'}{dt} = \left[\frac{df}{dx}\right]_{x_s} x'$$

where x' is the deviation variable, $x' = x - x_s$ and x_s is the steady-state value of x.

Using the expression derived in (ii), find the transfer function relating the unused reactant concentration at the outlet (C_A) to the inlet concentration, C_{Ai}, for the continuous stirred reactor shown in figure 1, stating your assumptions. The rate of reaction is $r = kC_A^2$. [15]

iii) If the process time constant for the reactor in Figure 1 is 1 minute, what is the change in the outlet concentration after 2 minutes if the inlet concentration suddenly changes from 0.1 to 0.15 units and the static gain is 1? [6]

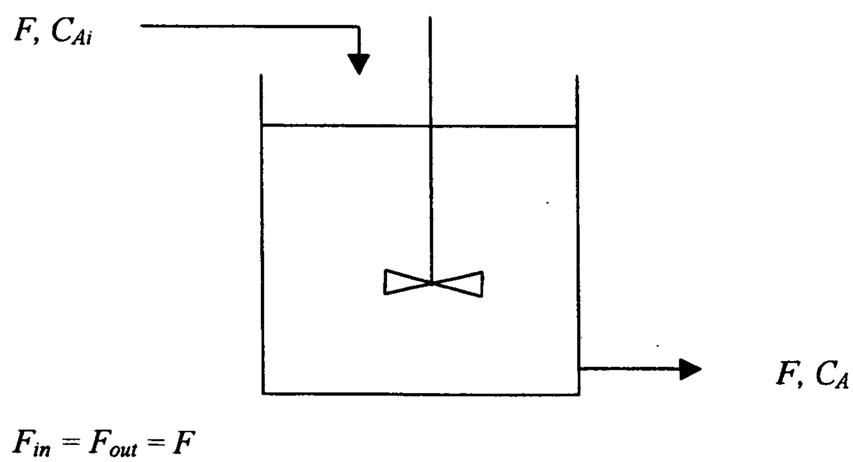

Figure 1

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2.

i) What are the main objectives of a control system in a chemical plant? [3]

ii) A generalised feedback control system is shown in figure 2. Describe, briefly, the difference between an open loop response and a closed loop feedback response. [2]

ii) Define, in terms of stability, what is meant by:

a. A self-regulating open loop response
b. A non self-regulating open loop response [4]

iv) Using the block diagram shown in figure 2 as an aid, derive the overall closed loop feedback response for set-point and load changes, showing all the open loop input/output relationships. [6]

v) Define, briefly, and in physical terms, the servo and regulator control problems. What are the two conditions also known as? [4]

vi) A process has the following open loop response to changes in the manipulated ($m\ (s)$) and input load disturbance ($d\ (s)$) variables:

$$y\ (s) = \frac{3}{s-0.5} m\ (s) + \frac{2}{s-0.5} d\ (s)$$

a. Explain, in terms of the expected form of the response after Laplace inversion, why this process is unstable. [3]

b. Assuming that feedback control is now applied to the process with a proportional controller and that the transfer functions of the measuring device and final control element are both equal to 1, find, from the overall closed loop feedback response, the general condition that must be satisfied to keep the system stable. [3]

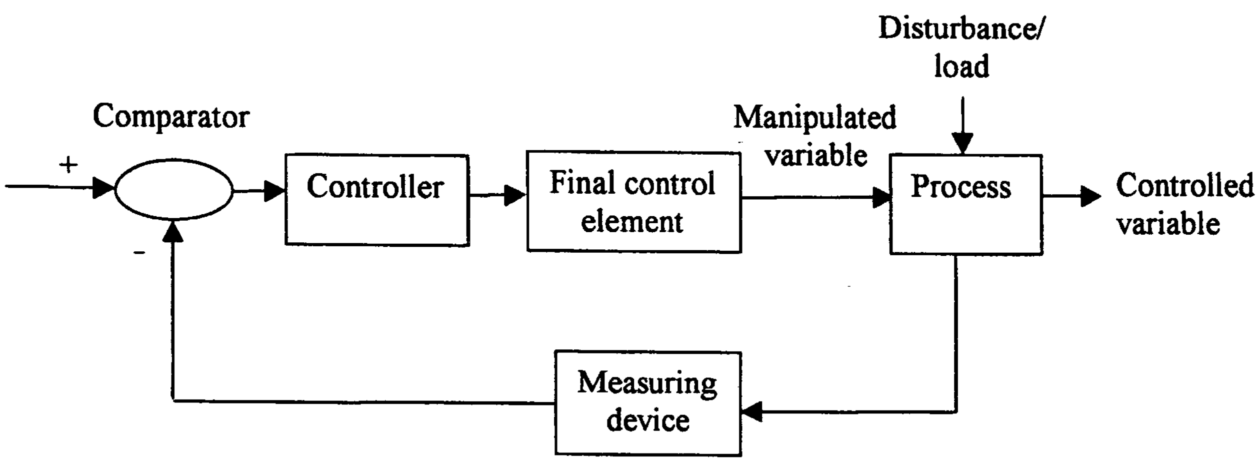

Figure 2

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3.

The general form of a second order transfer function relating the manipulated variable $m(s)$ to the output variable $y(s)$ is:

$$\frac{y(s)}{m(s)} = \frac{1}{\tau^2 s^2 + 2\zeta\tau + 1}$$

i) From which physical situations can second order behaviour arise? [3]

ii) Draw the expected responses to a unit step change in the input to a second order system for different values of the damping factor, ζ. What effect will the time constant τ have on the shape of the response curves? [7]

iii) Show that the closed loop transfer function for disturbance rejection of a first order lag system with proportional-integral control is second order, assuming that the values of the transfer functions $G_d = G_m = G_f = 1$. [10]

iv) A process has been shown to have the following open loop transfer function:

$$G_p = \frac{2}{6s + 1}$$

If the process is then controlled using a PI controller with gain of 1, determine the value of the integral time, τ_I, which will produce a critically damped response to a change in the load. [5]

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PART B

4.

A process is known to exhibit first order dynamics and contains a time delay. The process gain is $K_p = 8$, the time constant is $\tau_p = 5\ s$ and the dead time is $\tau_d = 0.5\ s$.

i) Sketch the open loop response for the process to a unit step in the input. Indicate on your sketch the final value K_p, the time constant τ_p, and the dead time τ_d. [5]

The process is to be controlled in a feedback loop by a P-controller with gain K_c. A disturbance $d(s)$ with transfer function $G_d(s)$ is present. The dynamics for the valve and measurement can be neglected.

ii) Set up the block diagram for the closed loop system. Find the transfer functions relating set point and load changes with the output variable. [4]

iii) Determine expressions for the amplitude ratio and the phase shift for the open loop process. [4]

iv) Assuming no disturbance, determine the proportional *gain* K_c which gives a Gain Margin of 1.7. [5]

v) Identify the transfer function $G_1(s)$ (form and parameters) given in the Bode diagram in Figure 3. [7]

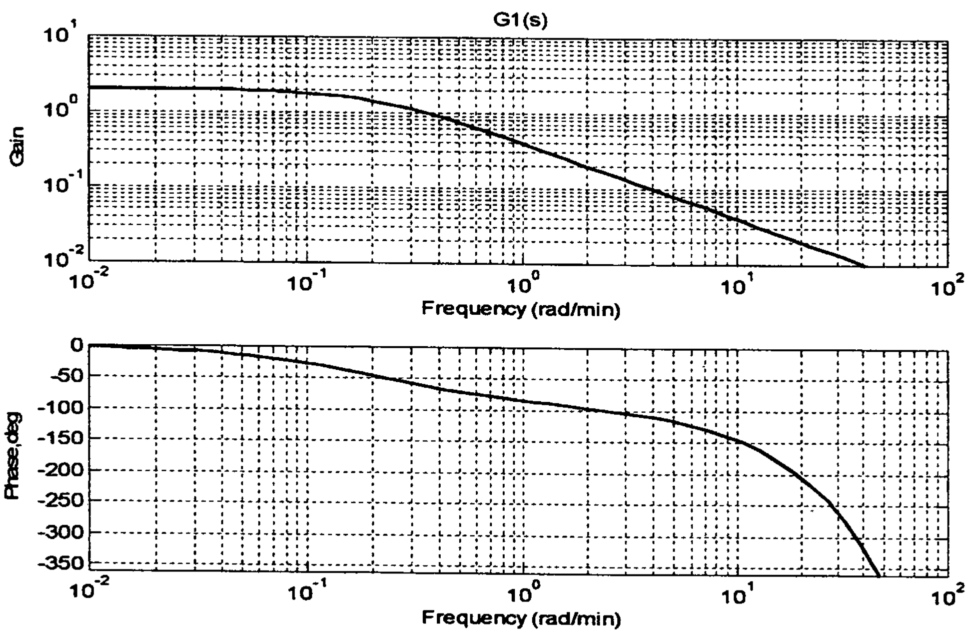

Figure 3. Bode diagram for unknown process.

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5.

i) A general 2 x 2 process can be described by the following steady-state model:

$$y_1 = K_{11}\, m_1 + K_{12}\, m_2$$

$$y_2 = K_{21}\, m_1 + K_{22}\, m_2$$

Show that the relative gain λ_{11} between the controlled variable y_1 and the manipulated variable m_1 is given by :

$$\lambda_{11} = \frac{1}{1 - \dfrac{K_{12}K_{21}}{K_{11}K_{22}}}$$

Find the Relative Gain Array (RGA) for the whole system. [7]

ii) The transfer function matrix for a 2 x 2 process is given by:

$$G_p(s) = \begin{bmatrix} \dfrac{-2e^{-5s}}{10s+1} & \dfrac{1.5e^{-s}}{s+1} \\ \dfrac{1.5e^{-s}}{s+1} & \dfrac{2e^{-5s}}{10s+1} \end{bmatrix}$$

Use the RGA approach to determine the recommended controller pairing based on steady-state considerations. Do dynamic considerations suggest the same pairing and why? [7]

iii) The control loops with the pairing found using the RGA approach are to be implemented using digital control. How often would you sample the two loops? [3]

iv) A process with two controlled outputs and two manipulated inputs can generally be written as:

$$y_1(s) = H_{11}(s)\, m_1(s) + H_{12}(s)\, m_2(s)$$

$$y_2(s) = H_{21}(s)\, m_1(s) + H_{22}(s)\, m_2(s)$$

Assume that m_1 is used to control y_1 but y_2 is left uncontrolled:

$$m_1(s) = G_{c1}(s)\, [\, y_{1,SP}(s) - y_1(s)]$$

Show how a change in the set point $y_{1,SP}(s)$ in the controlled loop may effect the output $y_2(s)$ in the uncontrolled loop.

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5. continued

v) Consider the stirred tank heater given in Figure 4. The effluent flow rate is used to control the liquid level (loop 1) and the steam flow rate to control the tank temperature (loop 2). The input stream is coming from an upstream unit and may vary both in flow rate and temperature. Explain how the two control loops may interact for this system. [8]

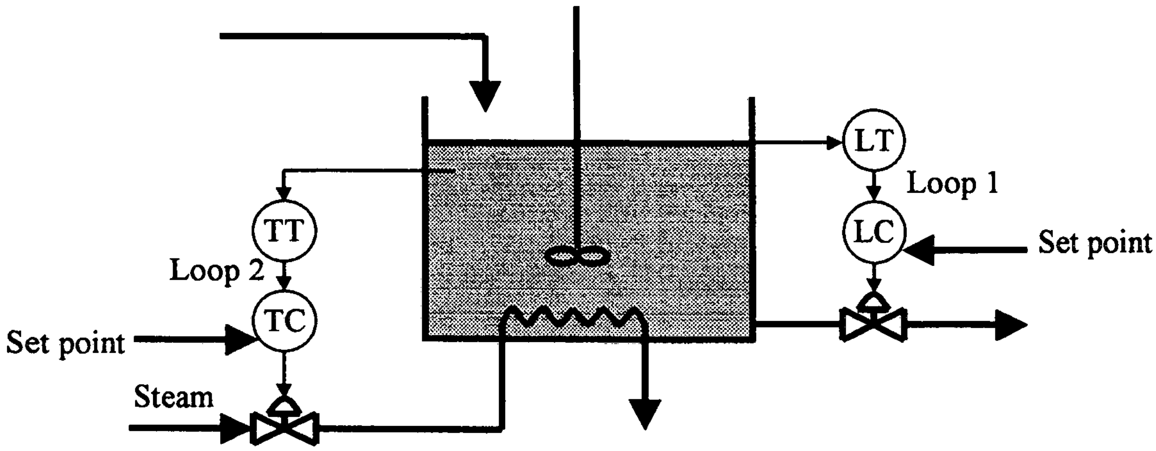

Figure 4. Stirred tank heater with two control loops.

6.

i) Explain briefly in words the main purpose of inferential control and give one chemical engineering example where such a control scheme might be used. [2]

ii) Find the expression for the inferential estimator, *i.e.* the controlled variable $y(s)$ as a function of the manipulated variable $m(s)$ and the secondary measurement $z(s)$. [5]

iii) Set up the block diagram for inferential control of a general process $G_p(s)$ with a controlled but unmeasured variable $y(s)$ and a secondary measured variable $z(s)$, a disturbance $d(s)$ and a feedback controller $G_c(s)$. [3]

iv) Assuming the controlled variable $y(s)$ can be measured intermittently, show a block diagram of how an adaptive mechanism can be used to correct the inferential estimator. [5]

v) What are the potential advantages of feedforward control in comparison to feedback control? Why is feedforward control rarely used on its own in practice? [4]

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6. continued

vi) Show a generalised block diagram of a combined feedforward – feedback controller including transfer functions for valves and measurements and general transfer functions for the controllers. Find the two transfer functions $G_1(s)$ and $G_2(s)$ which describe the overall system:

$$y(s) = G_1(s)\, y_s(s) + G_2(s)\, d(s) \qquad [6]$$

END OF PAPER