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-03**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

03-N0015-3-30

TURN OVER

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.

Consider the tank shown in figure 1, where the outlet stream flows through a partially opened restriction:

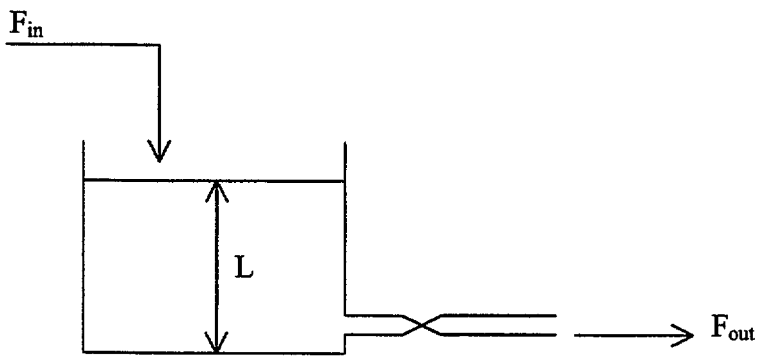

Fig. 1

The initial steady-state conditions are $F_{in} = F_{out} = 100$ m^3/hr and liquid level L= 7.0m. The cross-sectional area of the tank, A = 7.0 m^2. In addition we know that:

$$F_{out} = kL^{0.5}$$

where k is a proportionality constant.

a) Derive, stating clearly your assumptions, the dynamic material balance of the system. [3]

b) Using the expression derived in a), derive the overall linearised material balance of the system, in terms of deviation variables. [5]

c) Find the transfer function relating the liquid level in the tank, L, to a change in the inlet flowrate, F_{in}. [4]

d) Sketch the responses of the level in the tank L to a small step change (10 m^3/hr) and a large step change (60 m^3/hr) in the inlet flowrate, F_{in}, over a period of 0 – 5 hours. [10]

e) Comment on the accuracy of the approximate linearised model. When is it deemed suitable to use such a model? [3]

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2.

a) What is offset and why is there always offset associated with proportional-only control? [5]

b) Show, graphically, the difference between the offset in set-point tracking and disturbance rejection when proportional-only control is used. [2]

c) A first order (lag) process is controlled by a proportional feedback controller. The transfer functions for the measuring sensor, final control element and the disturbance are all equal to unity. From the expression for the overall closed loop response, derive the expression for the offset of the ultimate value of the response to the new desired set point when there is a unit step change in the set point. [8]

d) A stirred tank reactor with the transfer function:

$$\frac{1}{\tau s + 1}$$

is to be controlled with a proportional plus integral controller. All other transfer functions in the feedback loop are unity.

Using the feedback control loop shown in figure 2 and the expression for the overall control loop response, show that the transfer function relating the response to changes in the load is:

$$\frac{\bar{y}(s)}{\bar{d}(s)} = \frac{\left(\frac{\tau_I}{K_c}\right)s}{\frac{\tau\tau_I}{K_c}s^2 + \tau_I\left[1 + \frac{1}{K_c}\right]s + 1}$$

Hence, using the final value theorem, show that the offset is zero when a unit step change occurs in the load. [10]

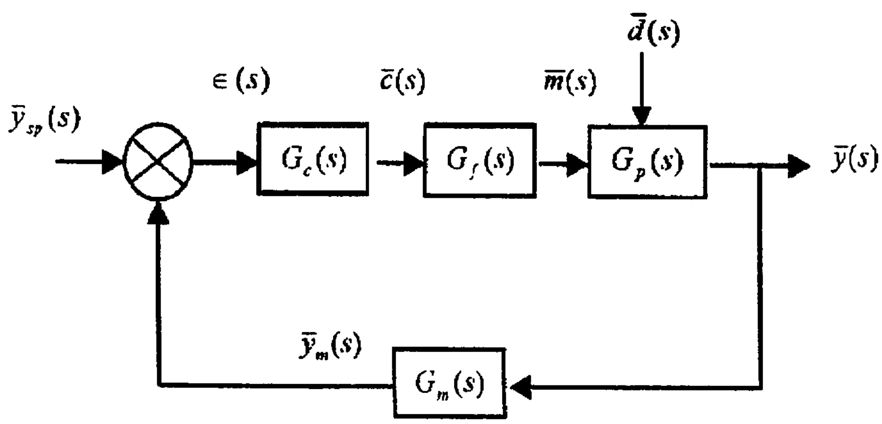

Figure 2

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3.

a) Define what is meant by the stability of a system. [2]

b) What are poles in relation to process control and how can they assist in the qualitative analysis of the stability of system responses? [3]

c) Discuss, briefly, the common type of responses that can arise from the following types of poles, indicating the range of values that poles must possess for a process to be stable:

i) Real, distinct
ii) Real, multiple
iii) Complex conjugates [10]

d) Two reactors in series have an overall process transfer function as follows:

$$G_p(s) = \frac{0.10}{(0.5s+1)^2}$$

The outlet concentration from the second reactor is controlled using a PI feedback controller. The sensor and final control element are assumed to be fast.

If the integral time, τ_I, is set at 0.2 min, find, using the Routh-Hurwitz criterion, the limits to the value of the controller gain, K_c, which will ensure that the system has a stable response. [10]

General formula for the Routh array:

Row	1	a_o	a_2	a_4	a_6
	2	a_1	a_3	a_5	a_7
	3	A_1	A_2	A_3	...
	4	B_1	B_2	B_3	...

where:

$$A_1 = \frac{a_1 a_2 - a_0 a_3}{a_1}, A_2 = \frac{a_1 a_4 - a_0 a_5}{a_1}, A_3 = \frac{a_1 a_6 - a_0 a_7}{a_1}$$

$$B_1 = \frac{A_1 a_3 - a_1 A_2}{A_1}, B_2 = \frac{A_1 a_5 - a_1 A_3}{A_1}$$

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PART B

4.

A process controlled by a feedback control loop is known to exhibit first order dynamics and contains a time delay. The process gain is K_p, the time constant is τ_p and the dead time τ_d. The dynamics for the valve and measurement can be neglected and it is assumed that there are no disturbances. The controller is a PI controller with a gain K_c and integral time τ_I.

a) Set up the block diagram for the closed loop system consisting of the process with transfer function G_p and the controller with transfer function G_c. Find the transfer function relating set point changes with the output variable. [3]

b) Find the open loop transfer function for the system consisting of the process and the controller. Find expressions for the amplitude ratio and the phase shift for this open loop system. [7]

c) Find the crossover frequency of the open-loop system for the following parameters: the process gain K_p is 2, the time constant τ_p is 5, the time delay τ_d is 0.1 and the controller gain K_c is 10 and the integral time τ_I is 0.1. (Use $\varpi = 5$ rad/min as your starting point.) Find the system gain margin. Is the system closed loop stable? [8]

d) Ziegler-Nichols (ZN) method is to be used to find more appropriate control parameters. Find the ultimate gain Ku and the ultimate period Pu for the open-loop system with the same process parameters as in c) but with the integral action turned off. Find the new controller parameters based on the ZN-table below. [7]

	K_c	τ_I	τ_D
P	Ku/2	-	-
PI	Ku/2.2	Pu/1.2	-
PID	Ku/1.7	Pu/2	Pu/8

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5. a) Consider the cascade block diagram illustrated in Figure 3.

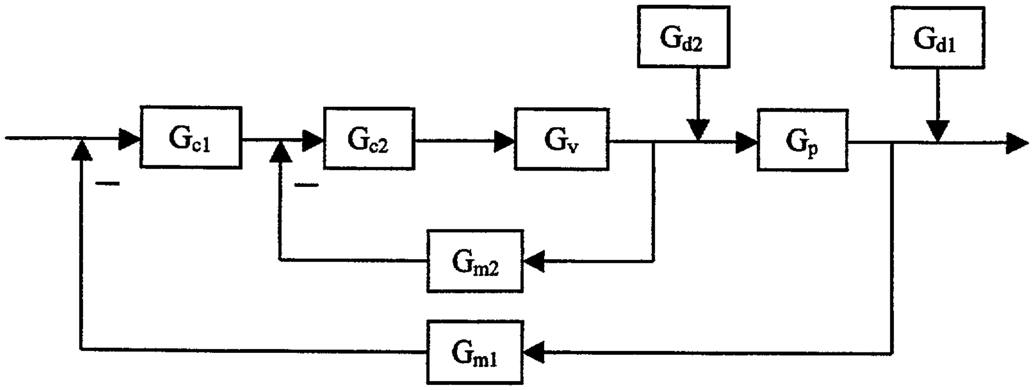

Figure 3. Cascade block diagram

The transfer functions are given by:

$$G_p = \frac{4}{(2s+1)(4s+1)}, \qquad G_v = \frac{5}{s+1}$$

$$G_{d1} = \frac{1}{3s+1}, \qquad G_{d2} = 1, \qquad G_{m1} = 0.05, \qquad G_{m2} = 0.2$$

Find the transfer function for the inner, or secondary, loop of the cascade system.

What is the main purpose of the secondary loop?
Find the characteristic equation for the whole cascade system.

What is the typical controller tuning procedure for a cascade control system?

Set up the open loop transfer functions for the secondary, or inner, and the primary, or outer, loops. [9]

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b) The stirred tank heater shown in Figure 4 is to be controlled using a feedforward-feedback control system. The control objective is to maintain a constant temperature T in the exit stream. The input stream is coming from an upstream unit and might vary in temperature T_i. The steam input Q_s can be manipulated.

Propose and illustrate a control strategy based on feedforward-feedback control for this system.

Draw the corresponding block diagram. [8]

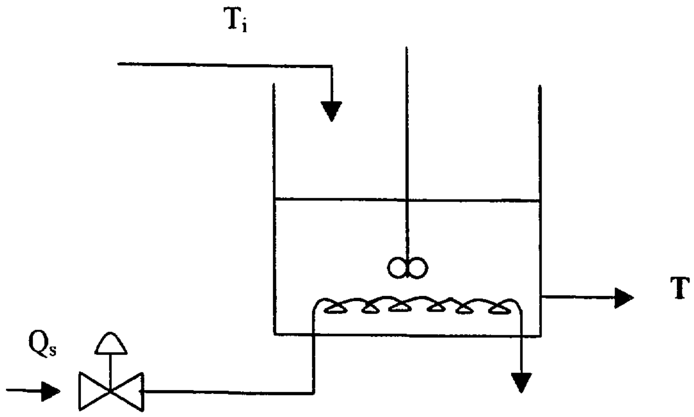

Figure 4. Stirred tank heater.

c) Give examples of where time delays may occur in chemical processes and explain why time delays can cause unsatisfactory closed loop response for conventional feedback controllers.

What are the benefits of a deadtime compensator?

What are the potential problems with using deadtime compensators? [8]

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6.

a) Considered the Continuous Stirred Tank Reactor (CSTR) given in Figure 5. The inlet flow rate F_i is used to control the product concentration C_A (loop 1) and the coolant flow rate F_{CW} to control the tank temperature T (loop 2). The input stream is coming from an upstream unit and might vary both in concentration C_{Ai} and temperature T_i.

Explain how the two control loops may interact for this system.

Explain why interactions in multivariable processes are undesirable from a control point of view. [6]

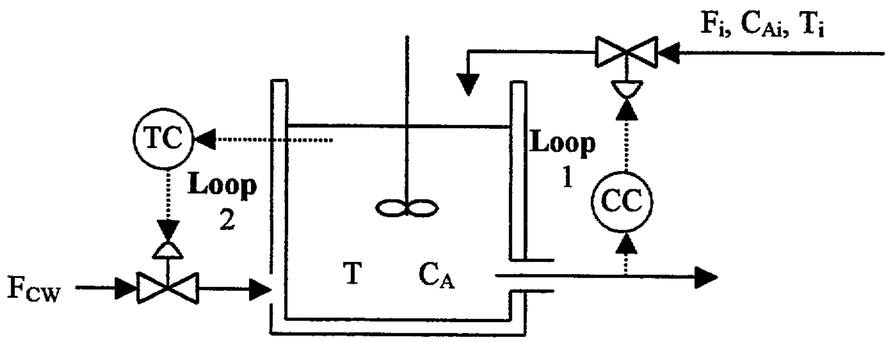

Figure 5. Control loops for CSTR

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b) It is proposed to implement heat integration on the exothemic reactor process given in Figure 6. Propose a heat integration scheme for this process.

What is the main potential benefit from the heat integration scheme?

What are the potential control problems associated with the heat integration scheme? [5]

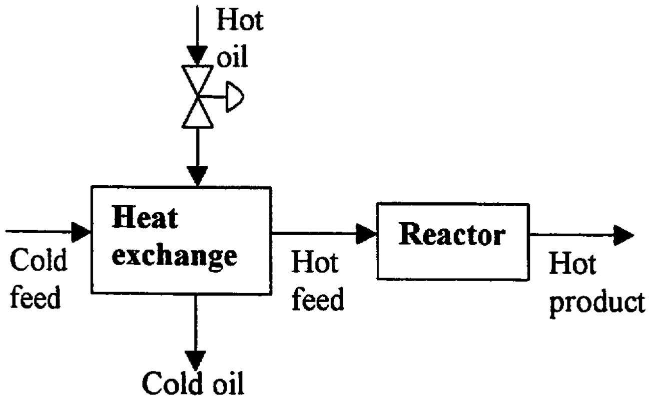

Figure 6. Exothermic reactor with feed pre-heater.

c) A general 2x2 process can be expressed 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:

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

The transfer function matrix for a 2x2 process is given by

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

Use the RGA approach to determine the recommended controller pairing based on steady state considerations.

Do dynamic considerations suggest the same pairing? [14]

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