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 : **22-MAY-06**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

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* [ ]

Laplace Transform tables supplied.

PART A

1

i) Briefly describe the role of process control in the sustainable operation of a chemical plant in relation to economics, environment and society. [5]

ii) A water treatment process monitors the level of contamination of the E. Coli bacteria in a surge tank before discharge into a local river. An alarm sounds if the measured value exceeds the environmental limit of 7 ppm. The dynamic behaviour of the sensor can be described by the following first order transfer function:

$$\frac{C'_m(s)}{C'(s)} = \frac{1}{10s+1}$$

where $C'(s)$ is the deviation of the actual contaminant concentration from the steady-state value and $C'_m(s)$ is the response of the measured value to this change. C_m has an initial value of 5 ppm.

If the contaminant concentration C gradually increases according to the expression $C(t) = 5 + 0.2t$, where t is the time in seconds:

a) Find the steady-state value of the actual contaminant concentration. [1]

b) Derive the expressions showing how the actual contaminant concentration and the measured value, in deviation form, change with time, i.e. $C'(t)$ and $C'_m(t)$. [5]

c) Using a graphical method, find the time interval between when the actual contaminant concentration first exceeds the environmental limit and the alarm sounds. [7]

iii) Why does the surge tank require control? [2]

iv) A purge stream is now added to the surge tank, complete with a control valve connected to a proportional controller that acts on the change in the contaminant concentration (measured by the sensor) to keep the concentration at a desired level. Show, using the Routh-Hurwitz criteria, that the system is now stable. [5]

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The Routh-Hurwitz 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	....
5	C_1	C_2	C_3	....
....				
$n+1$	W_1	W_2	W_3	....

where:

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

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

$$C_1 = \frac{B_1 A_2 - A_1 B_2}{B_1}, \quad C_2 = \frac{B_1 A_3 - A_1 B_3}{B_1} \ldots\ldots\ldots\ldots\ldots$$

etc....

PLEASE TURN OVER

2

The dynamic behaviour of the liquid level in each leg of a manometer tube, responding to a change in pressure, is given by:

$$\frac{d^2h'}{dt^2} + A\frac{dh'}{dt} + Bh' = CP'(t)$$

where $A = \dfrac{6\mu}{R^2\rho}$, $B = \dfrac{3g}{2L}$, $C = \dfrac{3}{4L\rho}$, $h'(t)$ is the level of fluid measured with respect to the initial steady-state value, $P'(t)$ is the pressure change and R, L, g, ρ and μ are constants.

i) Rearrange this equation into the standard gain-time constant form for a second-order process and find the expressions for K_p (static gain), τ (time constant) and ζ (damping factor) in terms of the physical constants. [7]

ii) For what values of the physical constants will the manometer response oscillate? What is this type of response called? [3]

iii) Would changing the manometer fluid so that ρ (the density) is larger make its response more or less oscillatory? Repeat the analysis for an increase in μ (the viscosity). [3]

iv) Show that adding a PI controller to a first-order process of transfer function:

$$G_p = \frac{K_p}{\tau_p s + 1}$$

gives a second-order response and that the offset is eliminated for a unit step change in the load variable. Assume that the transfer functions for the final control element and the sensor are both equal to 1 and that the load transfer function is: [12]

$$G_d = \frac{1}{\tau_p s + 1}$$

PLEASE TURN OVER

3

A tank, shown in figure 1, is designed with a slotted weir so that the outflow rate, F_o, is proportional to the liquid level in the main tank to the power 0.5, i.e:

$$F_o = Lh^{0.5}$$

where L is a proportionality constant. The initial steady-state conditions are $F_{in} = F_o = 100\ m^3/hr$ and $h = 7.0m$. The cross-sectional area of the tank, $A = 7.0\ m^2$.

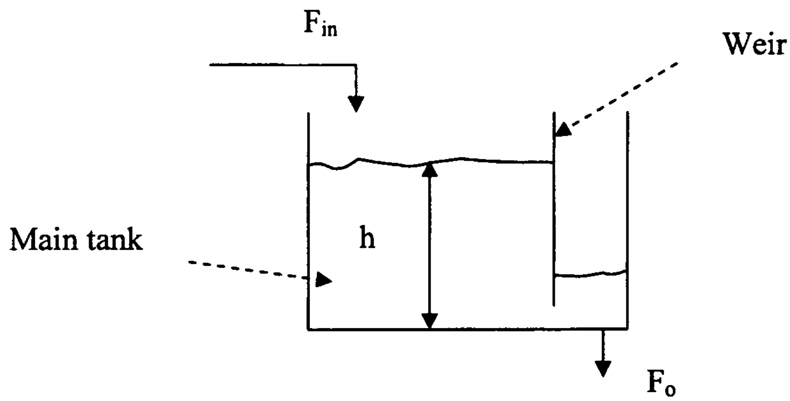

Figure 1: Tank with slotted weir

i) Derive, stating your assumptions, the overall linearised material balance of the system, in terms of deviation variables. [6]

ii) Find the transfer function relating the liquid level in the main tank, h, to a change in the inlet flowrate, F_{in}, and the values for the static gain, K_p, and the time constant, τ_p. [6]

iii) Derive the expression for the response of the tank to a step change of any size in the inlet flowrate. [4]

iv) Sketch the response of the level of liquid in the main tank to a step *decrease* in the inlet flowrate of 60 m^3/hr, from t = 0 to t = 5 hr. Comment on the accuracy of the approximate linearised model. When is it deemed suitable to use such a model? [9]

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PART B

4

A process controlled by a feedback loop is known to exhibit first order dynamics and to contain a time delay. The process gain is 2 and the time constant is 5 minutes. The dead time is assumed to be 0.5 minutes. The dynamics for the valve and measurement can be neglected.

(i) Set up the block diagram for the closed loop system including a P-controller with gain $K_c=1$. [2]

(ii) Obtain the transfer function relating set point and load changes with the output variable y(s). [4]

(iii) Show that the crossover frequency for the system described above is 3.264 rad/s. [6]

(iv) The process is to be controlled using a P-controller. Find the proportional gain for this controller which gives a Gain Margin of 1.7. [6]

(v) Identify the transfer function $G_1(s)$ (form and parameters) given in Figure 2. [7]

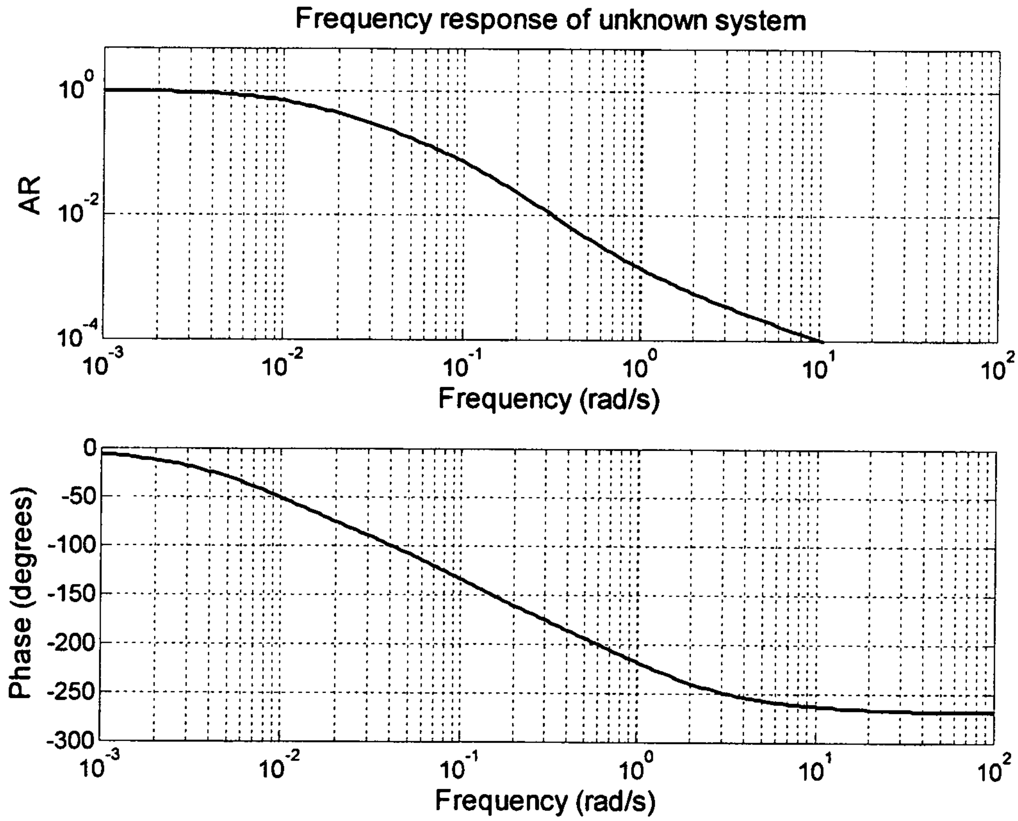

Figure 2. Bode diagram for transfer function $G_1(s)$.

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5

i) What is an adaptive controller? What is the main objective of an adaptive controller? Under which process conditions might it be appropriate to use an adaptive controller to control a dynamic process? [4]

ii) Show a block diagram of a self-tuning regulator. Discuss the main attributes of a self-tuning regulator. [5]

iii) Consider the cascade system illustrated in Figure 3. 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?

Assume a P-controller is used in the inner loop, *i.e.* $G_{c2} = K_{c2}$. Find the characteristic equation for the whole cascade system.

What is the typical controller tuning procedure for a cascade control system? [10]

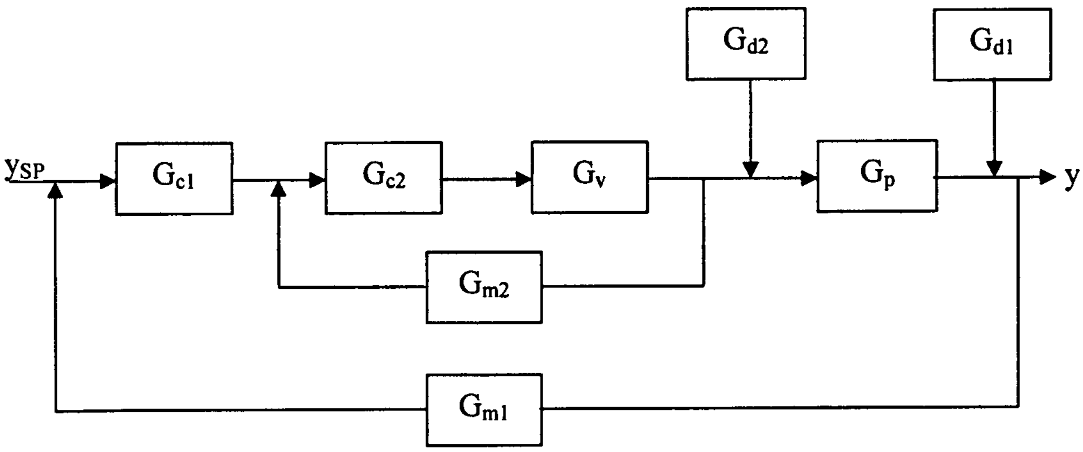

Figure 3. Cascade block diagram.

iv) The heated tank shown in Figure 4 is known to be subject to disturbances in the feed temperature. What would be the appropriate measured and manipulated variables that would be chosen for:

a) A Feed-back controller?

b) A Feed-forward controller?

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What are the main advantages and disadvantages of feed-forward controllers?
[6]

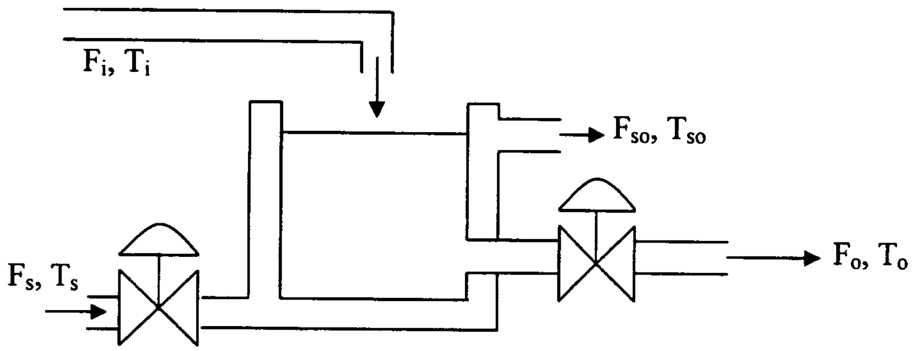

Figure 4. Heated tank.

6

A 2 x 2 process is to be controlled using two feedback control loops. The transfer functions for the process are given by:

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = H(s)m(s) = \begin{bmatrix} H_{11}(s) & H_{12}(s) \\ H_{21}(s) & H_{22}(s) \end{bmatrix} \cdot \begin{bmatrix} m_1(s) \\ m_2(s) \end{bmatrix} = \begin{bmatrix} \dfrac{1e^{-0.1s}}{10s+1} & \dfrac{3e^{-7s}}{75s+1} \\ \dfrac{4e^{-5s}}{100s+1} & \dfrac{-4e^{-0.15s}}{3s+1} \end{bmatrix} \cdot \begin{bmatrix} m_1(s) \\ m_2(s) \end{bmatrix}$$

i) Explain briefly, in words, what interaction in a multivariable process means and why interactions may cause problems for the control of the process. [4]

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

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \cdot \begin{bmatrix} m_1(s) \\ m_2(s) \end{bmatrix}$$

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

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

Calculate the Relative Gain Array for the process given by the transfer function *H(s)* shown above. [6]

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iii) In order to confirm the controller pairing of the 2x2 process experimentally, two experiments are performed:

a) With both loops open, m_2 is kept constant and a unit step in m_1 is introduced and the response in y_1 is recorded.

b) With y_2 assumed perfectly controlled using m_2, a unit step in m_1 is introduced and the response in y_1 is recorded.

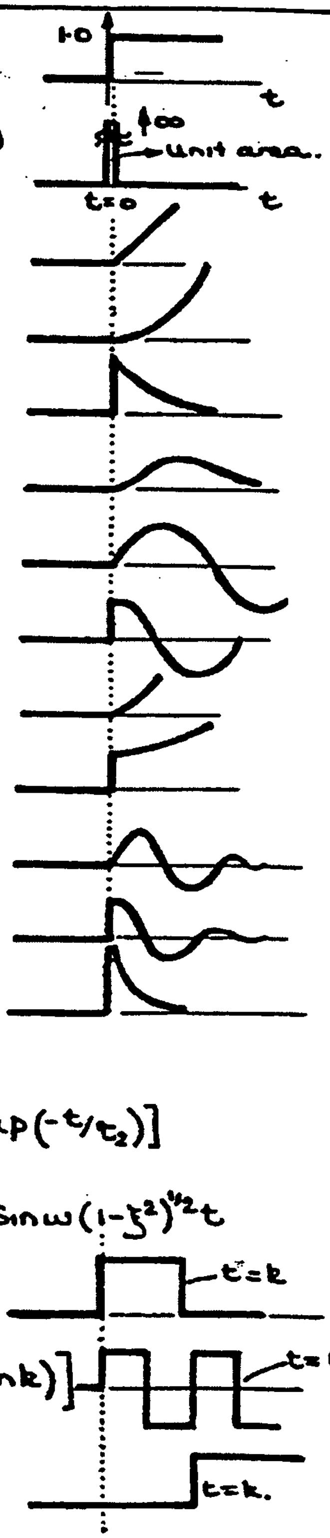
Sketch the two responses in y_1 as a function of time that would be obtained from experiments 1 and 2, given the transfer function *H(s)* shown above. [4]

iv) Suggest a controller pairing for the process and explain your choice. Comment on the dynamics of the proposed controller pairing. [5]

v) What is the purpose of a decoupler? Find the transfer functions for two dynamic decouplers which may be introduced into the control system to eliminate the interactions in the process given by H(s) shown above. [6]

TURN OVER

FUNCTION AND REPRESENTATION.	LAPLACE TRANSFORM
Unit step function $u(t)$	$1/s$
Unit impulse function $\delta(t)$ (dirac δ function)	1
$t \times u(t)$	$1/s^2$
$t^n \times u(t)$	$n!/s^{n+1}$
$e^{-at} \times u(t)$	$\frac{1}{s+a}$
$t^n e^{-at} \times u(t)$	$\frac{n!}{(s+a)^{n+1}}$
$\sin kt \times u(t)$	$\frac{k}{s^2+k^2}$
$\cos kt \times u(t)$	$\frac{s}{s^2+k^2}$
$\sinh kt \times u(t)$	$\frac{k}{s^2-k^2}$
$\cosh kt \times u(t)$	$\frac{s}{s^2-k^2}$
$e^{-at} \sin kt \times u(t)$	$\frac{k}{(s+a)^2+k^2}$
$e^{-at} \cos kt \times u(t)$	$\frac{s+a}{(s+a)^2+k^2}$
$\frac{1}{\sqrt{\pi t}} \times u(t)$	$1/\sqrt{s}$
$\frac{1}{\tau^n (n-1)!} t^{n-1} \exp[-t/\tau]$	$\frac{1}{(\tau s+1)^n}$
$\frac{1}{[\tau_1 - \tau_2]} [\exp(-t/\tau_1) - \exp(-t/\tau_2)]$	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
$\left(\frac{\omega}{1-\xi^2}\right)^{1/2} \exp[-\xi\omega t] \sin\omega(1-\xi^2)^{1/2} t$	$\frac{1}{\left[1 + \frac{2\xi s}{\omega} + \frac{s^2}{\omega^2}\right]}$
$[u(t) - u(t-k)]$	$1/s\,[1-e^{-ks}]$
$\left[u(t) + 2\sum_{n=1}^{\infty}(-1)^n u(t-2nk)\right]$	$1/s \tanh ks$
$u(t-k)$	$1/s\; e^{-ks}$



$\frac{d^n f(t)}{dt^n}$	$s^n f(s) - s^{n-1} f(0) - s^{n-2} f^1(0) \cdots\cdots - s f^{n-2}(0) - f^{n-1}(0)$ where $f^i(0) \equiv \left.\frac{d^i f(t)}{dt^i}\right\|_{t=0}$

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<u>THEOREMS</u>

1.	$a\,f(t)$		$a\,F(s)$
2.	$f_1(t) \pm f_2(t)$		$F_1(s) \pm F_2(s)$
3.	$f(t/a)$		$a\,F(a\,s)$
4.	$e^{-at}\,f(t)$		$F(s+a)$
5. Initial Value	$\lim_{t \to 0} f(t)$	=	$\lim_{s \to \infty} sF(s)$
6. Final Value	$\lim_{t \to \infty} f(t)$	=	$\lim_{s \to 0} sF(s)$

END OF PAPER