[ESS23]

UNIVERSITY OF BOLTON

ENGINEERING, SPORTS AND SCIENCES ACADEMIC GROUP

B.ENG (HONS) BIOMEDICAL ENGINEERING

SEMESTER TWO EXAMINATION 2018/2019

MEDICAL INSTRUMENTATION AND CONTROL

MODULE NO: BME5002

Date: Friday 24th May 2019 **Time: 14:00 – 16:00**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached).**

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Question 1

a) The open-loop transfer function of a system is $G(s) = \frac{K}{s(s+1)(s+5)}$

Determine the value of K which will cause sustained oscillations in the closed loop unity feedback system. You can use Routh-Hurwitz criterion. **[10 marks]**

b) What is the steady-state error of the system whose open-loop transfer function is $G(s) = \frac{K}{s(s+3)(s+8)}$ for a unit step input, and parabolic input?

[15 marks]

Total 25 marks

Question 2

(a) For the system shown in Fig. Q_{2a} below, obtain:

(i) the transfer function $\frac{Y(s)}{F(s)}$ **[9 marks]**

(ii) the damping factor **[3 marks]**

(iii) the undamped natural angular frequency **[3 marks]**

Where M = 12 N, C = 1 Ns/m, K = 5 N/m

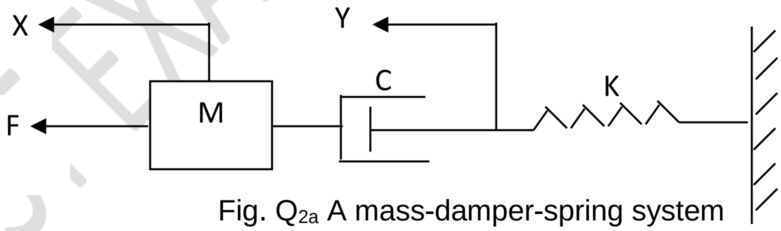

Fig. Q_{2a} A mass-damper-spring system

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Q2 continued….

(b) Derive the transfer function of the system shown in Fig. Q2b **[10 marks]**

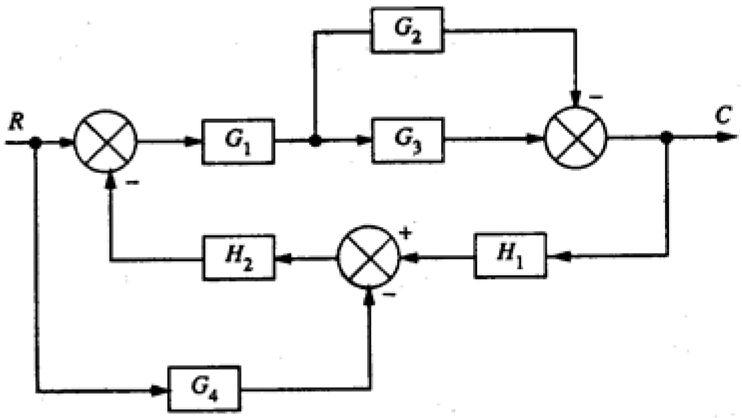

Fig. Q2b

Total 25 marks

Question 3

a) A unity feedback system is characterized by an open-loop transfer function
$G(s) = \frac{K}{s(s+20)}$

(i)Determine the gain K so that the system have a damping ratio of 0.7 **[4 marks]**
(ii) For the value of K obtained in (a) and a unit step input, determine:

1- settling time **[4 marks]**
2- peak overshoot **[4 marks]**
3- time to peak overshoot **[4 marks]**

b) Obtain the y(t) solution of the given Laplace transform making use of the Laplace transform table and the partial fraction method.

$$\frac{(s+3)}{(s+1)(s+6)}$$ **[9 marks]**

Total 25 marks

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Question 4

(a) Enumerate three features that a medical measurement equipment should demonstrate regardless of the nature of data measured **[5 marks]**

(b) Define three of the following static characteristics of a medical instrument**:**

i- Reference value

ii- Resolution

iii- Precision

iv- Accuracy **[6 marks]**

(c) What are the main types of biomedical measurands? **[6 marks]**

(d) Explain the function of an inductive proximity sensor using the parameters of the inductance formula $= \frac{\mu_o \mu_r N^2 A}{l}$. Illustrate your answer with the help of diagrams. **[8 marks]**

Total 25 marks

Question 5

Consider the control system shown in Fig.3 with its closed loop form.

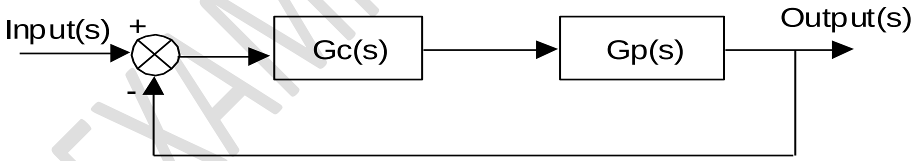

Fig.3

Where Gp(s) = $\frac{1}{s(s^2+7s+12)}$

(a) If Gc(s) is a proportional controller (Ki = Kd = 0), find the range of the gain Kp making the system to be an underdamped system. **[7 Marks]**

Q5 continues over the page….

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Q5 continued….

(b) Find the Ki for a unit parabolic input ($\frac{1}{s^3}$) if Gc(s) is a PI controller and the steady state error is less than 0.01. **[9 marks]**

(c) The designer needs to achieve less than 20% overshoot and t_s less than 5 seconds. Design a PID controller by determining Kp and Kd (using the Ki obtained from (b) above) to satisfy these requirements. **[9 marks]**

END OF QUESTIONS

Formula sheets over the page….

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Formula sheet

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.

The Laplace Transform

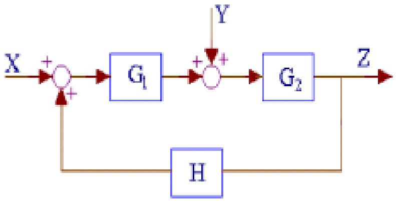
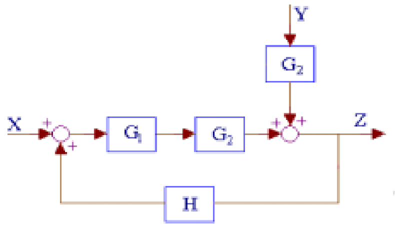
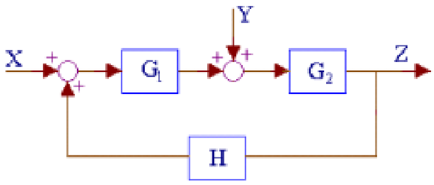
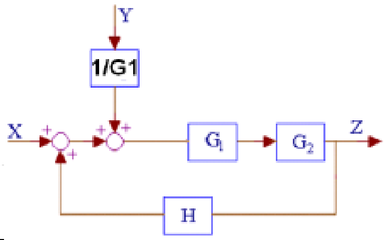
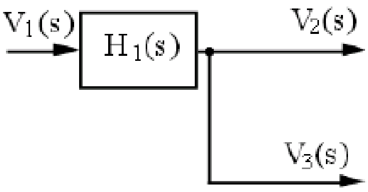
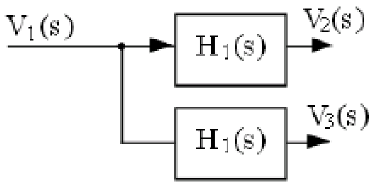
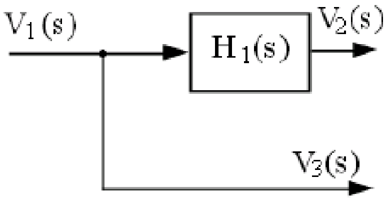
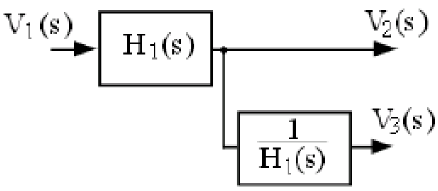
Transform table:

	f(t)	*F(s)*	
1.	$\delta(t)$	1	Impulse function
2.	$u(t)$	$\frac{1}{s}$	Step function
3.	$t\,u(t)$	$\frac{1}{s^2}$	Ramp function
4.	$t^n\,u(t)$	$\frac{n!}{s^{n+1}}$	
5.	$e^{-at}\,u(t)$	$\frac{1}{s+a}$	
6.	$\sin \omega t\,u(t)$	$\frac{\omega}{s^2+\omega^2}$	
7.	$\cos \omega t\,u(t)$	$\frac{s}{s^2+\omega^2}$	

	f(t)	*F(s)*
	df(t)/dt	sF(s)-f(0)
	$df^2(t)/dt^2$	$s^2F(s)$-sf(0)-f'(0)

$$M_p = e^{\frac{-\xi\pi}{\sqrt{1-\xi^2}}} \quad , \quad t_p = \frac{\pi}{\omega_n\sqrt{1-\xi^2}} \quad , \quad t_s = \frac{4}{\xi\omega_n}$$

Block Diagram Algebra

Rule	Original Diagram	Equivalent Diagram
1. Moving a summing point beyond a block		
2. Moving a summing point in front a block		
3. Moving a takeoff point to front of a block		
4. Moving a takeoff point to beyond a block		

Blocks with Feedback Loop

G(s) = $\dfrac{Go(s)}{1+Go(s)H(s)}$ (for a negative feedback)

G(s) = $\dfrac{Go(s)}{1-Go(s)H(s)}$ (for a positive feedback)

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Steady State Error

$$e_{ss} = \lim_{s\to 0}[s(1-G_O(s))\theta_i(s)]$$ (for an open-loop system)

$$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+G_o(s)}\theta_i(s)]$$ (for the closed-loop system with a unity feedback)

$$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+\frac{G_1(s)}{1+G_1(s)[H(s)-1]}}\theta_i(s)]$$ (if the feedback H(s) ≠ 1)

$$e_{ss} = \lim_{s\to 0}[-s\cdot\frac{G_2(s)}{1+G_2(G_1(s)+1)}\cdot\theta_d]$$ (if the system subjects to a disturbance input)

First Order System

$$G(s) = \frac{\theta_o}{\theta_i} = \frac{G_{ss}(s)}{\tau s+1}$$

$$\tau\left(\frac{d\theta_o}{dt}\right) + \theta_o = G_{ss}\theta_i$$

$$\theta_O = G_{ss}(1-e^{-t/\tau})$$ (for a unit step input)

$$\theta_o(t) = G_{ss}[t-\tau(1-e^{-(t/\tau)})]$$ (for a unit ramp input)

$$\theta_o(t) = G_{ss}(\frac{1}{\tau})e^{-(t/\tau)}$$ (for an impulse input)

Second order system

$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\omega_d t_r = 1/2\pi \qquad \omega_d t_p = \pi$

$$\text{P.O.} = \exp\left(\frac{-\zeta\pi}{\sqrt{(1-\zeta^2)}}\right)\times 100\%$$

$t_s = \dfrac{4}{\zeta\omega_n} \qquad \omega_d = \omega_n\sqrt{(1-\zeta^2)}$

Standard PID controllers

- *Proportional only:* $G_P(s) = K_P$
- *Proportional plus Integral*:
  $G_{PI}(s) = K_p + K_i/s = K_P(1+1/\tau_i s)$

  Where $\tau_i = K_P/K_i$
- *Proportional plus derivative*:
  $G_{PD}(s) = K_p + K_D s = K_P(1+\tau_d s)$

  Where $\tau_d = K_d/K_P$
- *Proportional, integral and derivative*:
  $G_{PID}(s) = K_p + K_i/s + K_d s = K_P(1+1/\tau_i s + \tau_d s)$

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