[ESS016]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) IN ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER TWO EXAMINATION 2018/19

INSTRUMENTATION AND CONTROL

MODULE NO: EEE5011

Date: Monday 20th May 2019 **Time: 10:00am – 12:30pm**

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.

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

School of Engineering
BEng (Hons) Electrical and Electronic Engineering
Semester Two Examination 2018/19
Instrumentation and Control
Module No. EEE5011

Q1.

(a) A robot control system has the transfer function as:

$$G(s) = \frac{12}{2s+4}$$

And the system is subject to a unit step input

(i) Calculate the time taken for the system to reach 75% of its final position.

[4 marks]

(ii) Calculate the percentage of the system's position after 1.3 seconds, and determine its position value at that time (1.3 seconds).

[6 marks]

(b) Figure Q1 (b) is a block diagram for a servo control system.

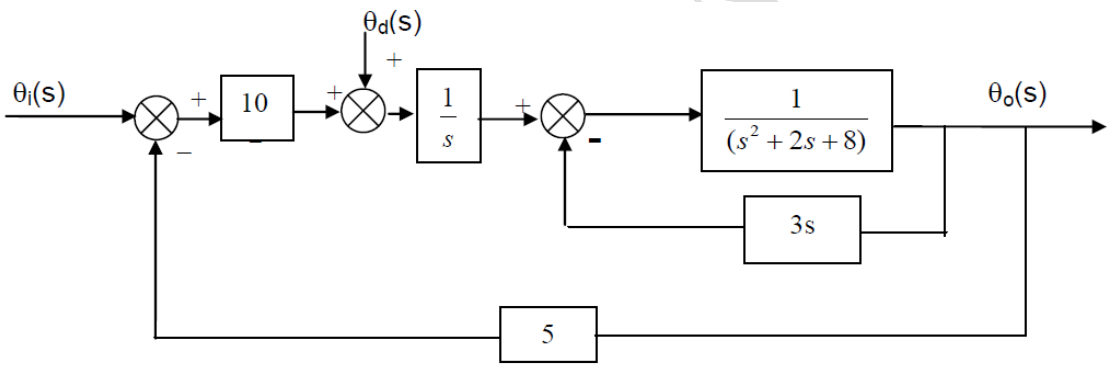

Figure Q1 (b) A Servo Control System.

(i) Determine the output $\theta_o(s)$ of the servo control system.

[9 marks]

(ii) If the system input $\theta_i(s)$ is a unit step input and the disturbance $\theta_d(s)$ is zero, determine the steady-state error.

[6 marks]

Total 25 Marks

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Q2

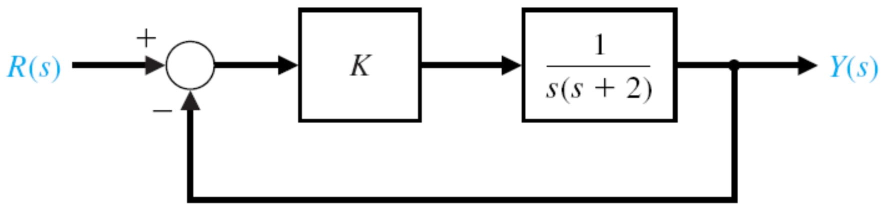

Figure Q2 (a) A car suspension system Control System.

(a) A block diagram of car suspension system is shown as in Figure Q2 (a), where, K=9, Y(s) is the output and R(s) is the input.

(i) Find the differential equation of this system. **[6 marks]**
(ii) Find the damping factor. **[2 marks]**
(iii) Find the damped frequency. **[2 marks]**
(iv) Find the subsidence ratio. **[2 marks]**

(b) Apply Routh-Hurwitz stability criterion to determine the range of values of K for a human-arm control system with the transfer function of T(s) which will result in a stable response.

$$T(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{s+1}{2s^3 + 5s^2 + 8s + K}$$

[7 marks]

(c) If the above system input $\theta_i(s)$ is a unit step and K is 10, determine the steady-state error. **[6 marks]**

Total 25 Marks

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Q3

(a) A RLC circuit is shown in Figure 3(a) below.
where
C is the Capacitance, L is the Inductance,
R is Resistance, i(t) is the current and v(t) is voltage.

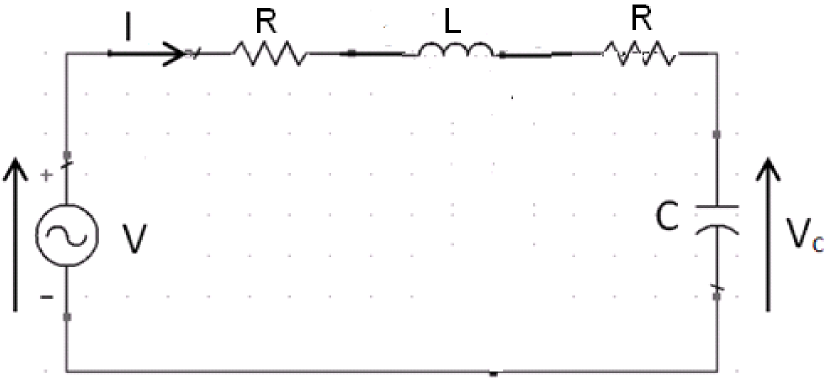

Figure 3(a): RLC electrical circuit

(i) Develop a differential equation for the RLC electrical circuit shown in Figure 3(a) above.

[8 marks]

(ii) Determine the Laplace transforms of the differential equations obtained from (i) above. Assume that the system is subjected to a unit step input ,the initial conditions of the system are zeros (i.e. at time = 0, *x*, *x'*, *x''* are all zeros).

[2 marks]

(iii) Determine the transfer function G(s) = $V_c(s)/V(s)$

[2 marks]

Q3 continues over the page…

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Q3 continued…

(b) A suspension system for a scooter is shown in Figure 3(b) where

f(t) is the input force
y1(t) and y2(t) represents the output displacements.
k1 and k2 are the spring stiffness constants.
c1 and c2 are the viscous damping coefficient.

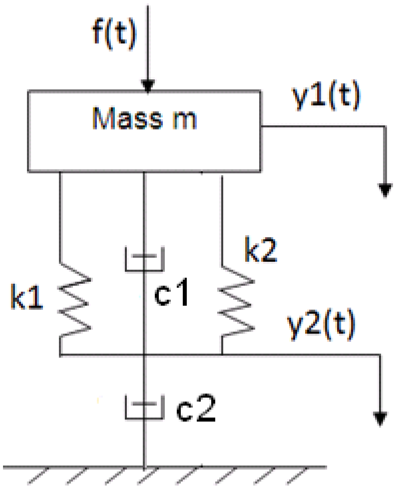

Figure 3(b) A suspension System

(i) Develop the differential equations for the suspension system

[3 marks]

(ii) Determine the Laplace transforms of the differential equations obtained from (i) above. Assume that the system is subjected to a unit step input, y(0) =0 and y'(0)=0.

[6 marks]

(iii) Determine the transfer function G(s)=Y1(s)/F(s)

[4 marks]

Total 25 marks

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Q4

Figure Q4 shows a mechatronic control system, in which the

$$G_P(s) = \frac{2}{10s^2 + 3s}$$

and a controller Gc(s) is applied into the system.

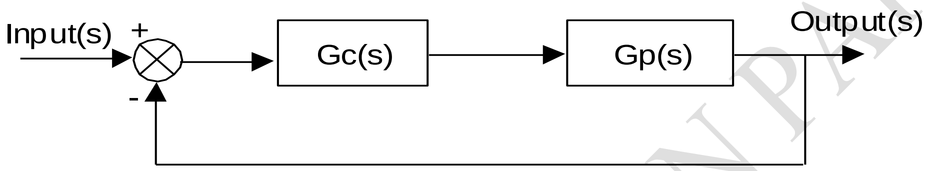

Figure Q4 A Mechatronic Control System

(a) If a PI controller is used (K_d = 0), determine the integral gain K_i causing the system's steady state error to be less than 0.05. The input of the system is a unit parabolic input function ($\theta_i = \frac{1}{s^3}$).

[5 marks]

(b) Use K_i obtained from Question (a) above, design a PID controller that will meet the system design specifications:

Settling time t_s < 5 seconds and
Percentage Overshoot PO < 10%.

Determine K_P and K_d.

[10 marks]

(c) If a velocity feedback is introduced into the system of the Figure Q4 and the Gc is a Proportional controller ($K_i = K_d = 0$):

(i) Draw a block diagram with the velocity feedback and determine the transfer function for the whole system.

[5 marks]

(ii) Determine the velocity gain Kv for the natural angular frequency ω_n is 1.6 rads/s, and the damping ratio ζ' is about 0.8, when the system subjects to a unit step input.

[5 marks]

Total 25 marks

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Q5.

(a) Describe briefly the function of each one of the following in a generalized medical instrumentation system:

(i) Sensor
(ii) Transducer
(iii) Signal conditioning circuit

[6 marks]

(b) What are the four types of biomedical measurands ?

[4 marks]

(c) The DC Wheatstone Bridge is used in medical sensor applications. Describe its operation with the aid of the circuit diagram. Also derive a formula for measured unknown resistance of the bridge.

[15 marks]

Total 25 marks

END OF QUESTIONS

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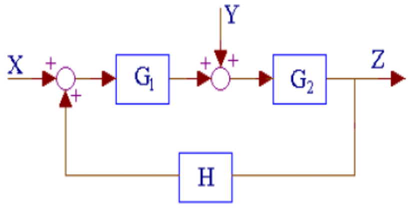
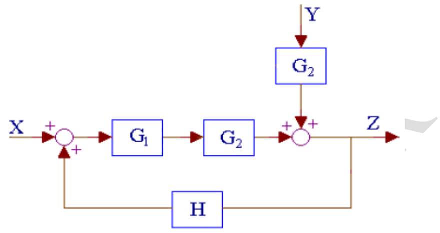
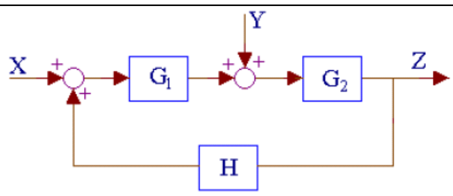
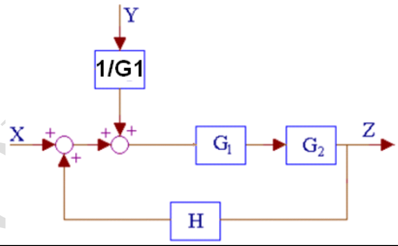
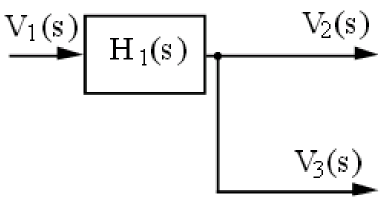
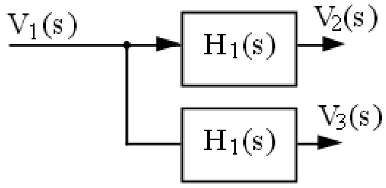
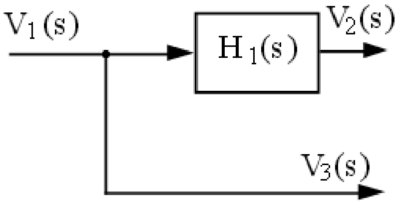
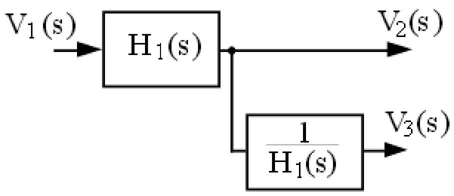
FORMULA SHEET

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)

Steady-State Errors

$e_{ss} = \lim_{s\to 0}[s(1-G_O(s))\theta_i(s)]$ (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)

Laplace Transforms

A unit impulse function	1
A unit step function	$\frac{1}{s}$
A unit ramp function	$\frac{1}{s^2}$

First order Systems

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

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

$\theta_O = G_{ss}(1-e^{-t/\tau})$ (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)

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First order System (non-zero initial condition)

$$\theta_{o(total)}(t) = \theta_{o(final)} + \theta_{o(initial)}(t)$$

Where $\theta_{o(initial)}(t) = \theta_o(0)\left[e^{-(t/\tau)}\right]$

Second order Systems

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

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

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

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

For 2% settling time: $t_s = \frac{4}{\zeta\omega_n}$

For 5% settling time: $t_s = \frac{3}{\zeta\omega_n}$

$\omega_d = \omega_n\sqrt{1-\varsigma^2}$

Subsidence ratio: $= e^{\left(\frac{-2\zeta\pi}{\sqrt{1-\zeta^2}}\right)}$

END OF FORMULA SHEETS

END OF PAPER