[ENG 04]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) IN ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER 2 EXAMINATION 2021/22

INSTRUMENTATION AND CONTROL

MODULE NO: EEE5011

Date: Monday 16th May 2022 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

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

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Question 1

(a) What are the main types of biomedical measurands? **[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) Enumerate three features that a medical measurement equipment should demonstrate regardless of the nature of data measured **[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

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Question 2

(a) For the system shown in Figure Q2a below, obtain:

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

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

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

Assuming that M=5 kg, C=5 Ns/m, K=1 N/m

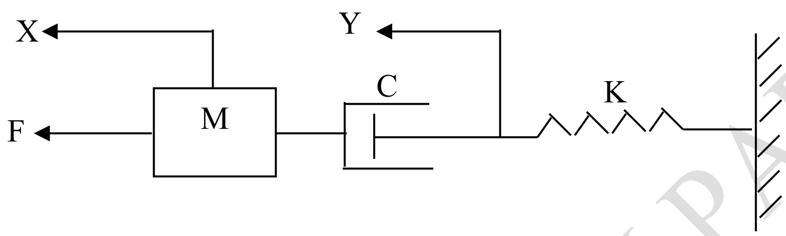

Fig.Q2a Spring-Mass-Damper system

(b) A series RLC circuit is connected to a voltage source with voltage V_{in}.

(i) Develop the differential equations for the relationship between the input voltage V_{in} and the capacitor voltage V_C as an output. **[4 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, $V_C(0)=0$ and $V_C'(0)=0$. **[2 marks]**

(iii) Find the coefficients of the A, B, C, and D matrices of the state-space model.

[4 marks]

Total 25 marks

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Question 3

(a) A robot control system has the transfer function as: $G(s) = \frac{100}{2s+5}$
And the system is subject to a unit step input.

(i) Calculate the time taken for the system to reach 50% of its final position.

[4 marks]

(ii) Calculate the percentage of the system's position after 1.5 seconds, and determine its position value at that time (1.5 seconds).

[6 marks]

(b) Figure Q3b is a block diagram for a servo control system.

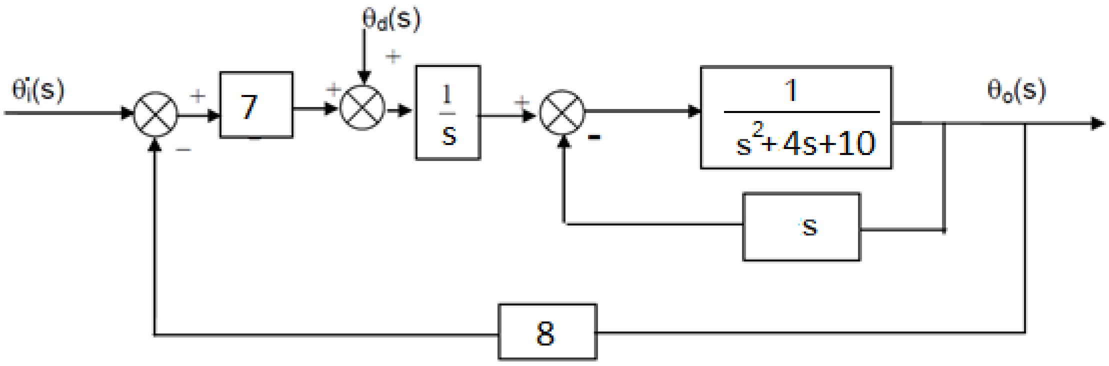

Figure Q3b A Servo Control System.

(i) Using Figure Q3b, determine the output $\theta_o(s)$ of the servo control system.

[9 marks]

(ii) If the system input $\theta_i(s)$ in Fig Q3b is a unit step input and the disturbance $\theta_d(s)$ is zero, determine the steady-state error.

[6 marks]

Total 25 Marks

Please turn the page

Question 4

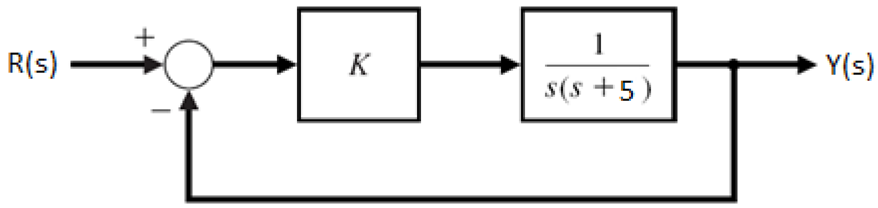

Figure Q4a A car suspension system Control System.

(a) A block diagram of car suspension system is shown as in Figure Q4a, 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.

$$T(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{1}{s^3+3s^2+6s+K}$$

[8 marks]

(c) If the above system input $\theta_i(s)$ is a step of size 10 and K is 16, determine the steady-state error.

[5 marks]

[Total 25 Marks]

Please turn the page

Question 5

Figure Q5a shows a mechatronic control system, in which the $G_P = \frac{4}{3s^2+5s}$ and a controller Gc(s) is applied into the system.

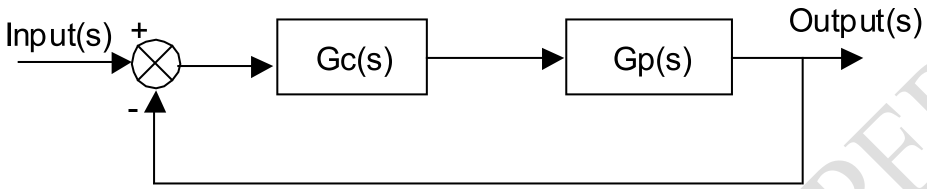

Figure Q5a A Mechatronic Control System

(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 0.04. The input of the system is a unit parabolic input function ($\theta_i(s) = \frac{1}{s^3}$). **[5 marks]**

(b) Use K_i obtained from Q5(a) above, design a PID controller that will meet the system design specifications: Settling time $t_s < 5$ seconds and percentage Overshoot PO < 15%. Determine K_P and K_d. **[10 marks]**

(c) If velocity feedback is introduced into the system of the Figure Q5a 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 1.5 rad/s, and the damping ratio ζ is 0.7, when the system subjects to a unit step input. **[5 marks]**

Total 25 marks

Question 6

The relationship between the input signal to a radio telescope dish and the direction in which it points is a second-order system. Figure Q6 shows the output of the system which subjects to a unit step input.

Determine:

(i) the system's natural angular frequency (the undamped angular frequency) ω_n, **[3 marks]**

(ii) the damped angular frequency ω_d, **[4 marks]**

(iii) damping factor ζ, **[5 marks]**

(iv) the 100% rise time t_r, **[3 marks]**

(v) the percentage maximum overshoot, **[4 marks]**

(vi) the 2% settling time t_s, **[6 marks]**
and the peak time t_p of the output.

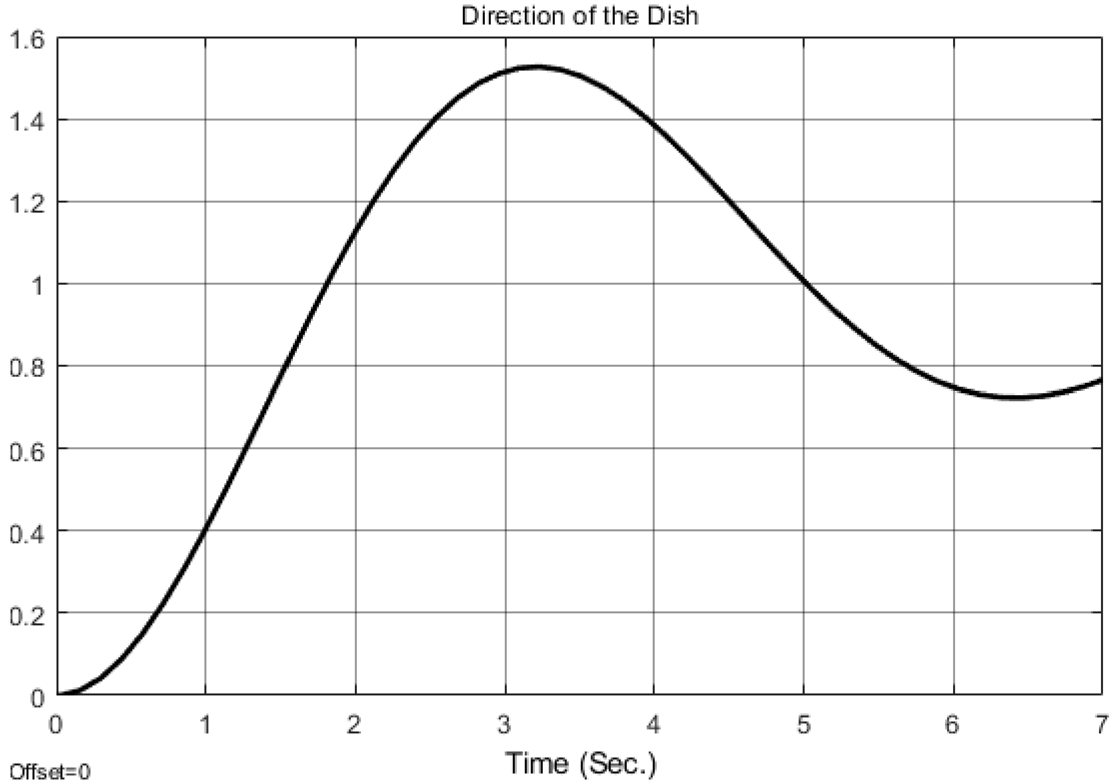

Figure Q6

Total marks 25

END OF QUESTIONS

Formula sheet follows on the next pages

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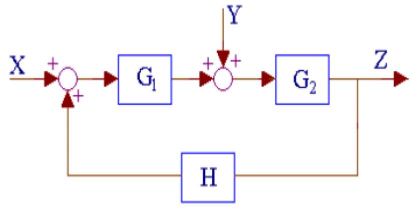
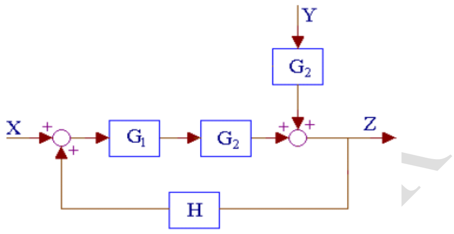
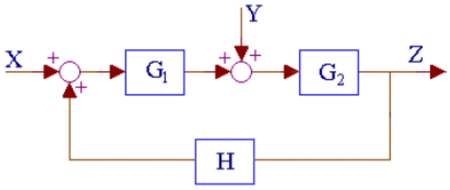
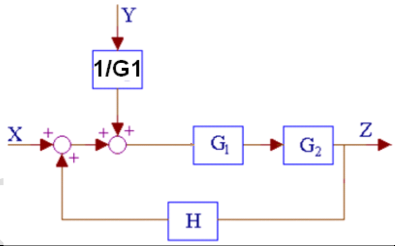
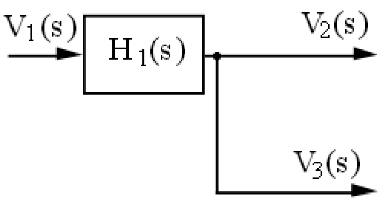
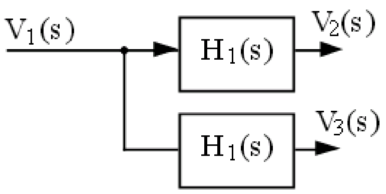
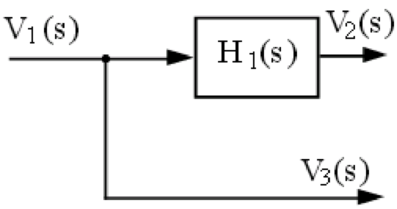
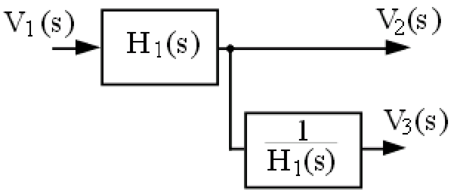
FORMULA SHEET

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

G(s) = $\frac{Go(s)}{1-Go(s)H(s)}$ (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

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

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

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

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 PAPER