ENG39

UNIVERSITY OF BOLTON

NATIONAL CENTRE FOR MOTORSPORT ENGINEERING

BEng (HONS) AUTOMOTIVE PERFORMANCE ENGINEERING (MOTORSPORT)

SEMESTER 2 EXAMINATION 2023/2024

ADVANCED VEHICLE SYSTEMS

MODULE NUMBER MSP6011

Date Tuesday 14th May 2024 **Time: 2:00 – 4:00pm**

INSTRUCTIONS TO CANDIDATES

This paper has FIVE questions
The marks for each question are shown in brackets
Attempt ALL questions

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

Mobile telephones or cellular telephones may-not be used as calculators

Formula sheet attached

Question 1

Figure Q1 shows a quarter car model of a vehicle suspension system with masses m_1 and m_2 which represent the unsprung and sprung masses; springs k_1 and k_2 which represent the stiffness of the tyre and suspension; and damper b, which represents the damping rate of the suspension.

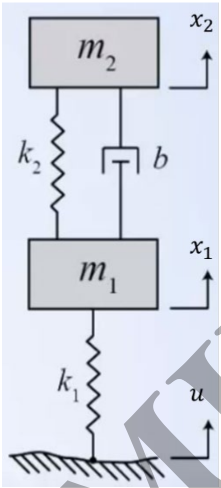

Figure Q1

(a) Develop a system of differential equations describing the motion of the system.

(8 marks)

(b) Develop a state space model of the system with input u, and outputs F_1 and F_2 (where F_1 and F_2 are the forces produced by springs k_1 and k_2).

(12 marks)

Total 20 marks

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Question 2

A DC motor can be represented as a first order system with a time constant of 0.25s and a gain of 100. The input voltage is subjected to a step increase from 0v to 5v.

a) Develop a transfer function which describes the time response of the motor. **(5 marks)**

b) Calculate the steady-state speed after 0.5s. **(7.5 marks)**

c) Calculate the time taken for the speed of the motor to reach 98% of its final value. **(7.5 marks)**

Total 20 marks

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Question 3

Figure Q3 shows a block diagram representation of a linear automotive control system where R(s) is the input, D(s) is a disturbance and Y(s) is the output.

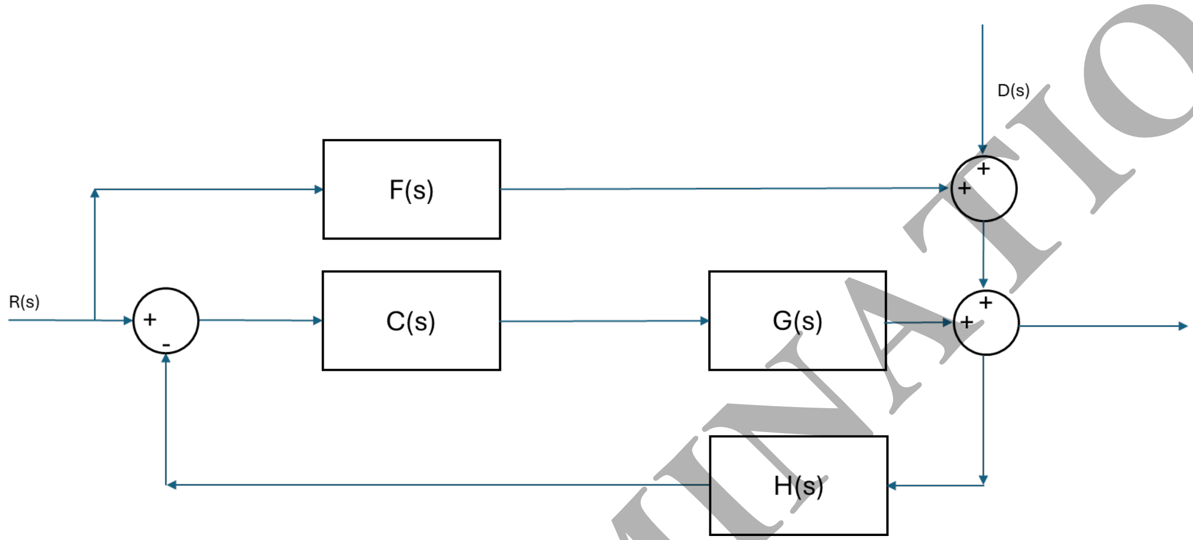

Figure Q3

a) Using block diagram reduction techniques, find the following transfer functions for the system:

I. $\frac{Y(s)}{R(s)}$ **(10 marks)**

II. $\frac{Y(s)}{D(s)}$ **(10 marks)**

Total 20 marks

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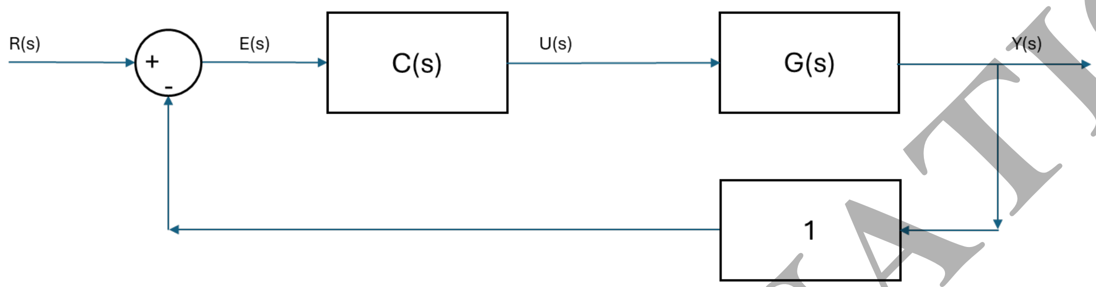
Question 4

Figure Q4 shows a mechatronic system $G(s)$, and PID controller $C(s)$, in a closed loop system.



The transfer function for the mechatronic system is:

$$G(s) = \frac{1}{s^2+10s+20}$$

and the PID controller follows the control law (written in the frequency or s-domain):

$$U(s) = \left(K_p + K_i\frac{1}{s} + K_d s\right)E(s)$$

where K_P, K_i *and* K_d are the proportional, integral and derivative gains.

a) Determine the transfer function of the closed loop system if the controller gains are $K_p = 30,\ K_i = 0,\ K_d = 0$

(7.5 marks)

b) Determine the transfer function of the closed loop system if the controller gains are $K_p = 30,\ K_i = 70,\ K_d = 0$

(7.5 marks)

c) Explain the operation of a PID controller in a closed loop system, including a description of the operation and function of the proportional, integral, and derivative terms.

(5 marks)

Total 20 marks

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Question 5

A vehicle suspension system is modelled using a quarter car model. The model consists of a single mass, with a spring and damper in parallel, which represent the sprung mass of one corner of the car, the effective spring rate of the suspension, and the effective damping rate of the suspension.

Figure Q5 **(on page 7)** shows the output time response of a system when subjected to an input unit step.

Using the data in the figure:

a) Determine the natural frequency and damping ratio of the system.
(5 marks)

b) Develop a transfer function which describes the time response of the system.
(5 marks)

c) If the sprung mass of the quarter car is 350kg, determine the effective spring rate and effective damping rate of the system.
(10 marks)

Total 20 marks

END OF QUESTIONS

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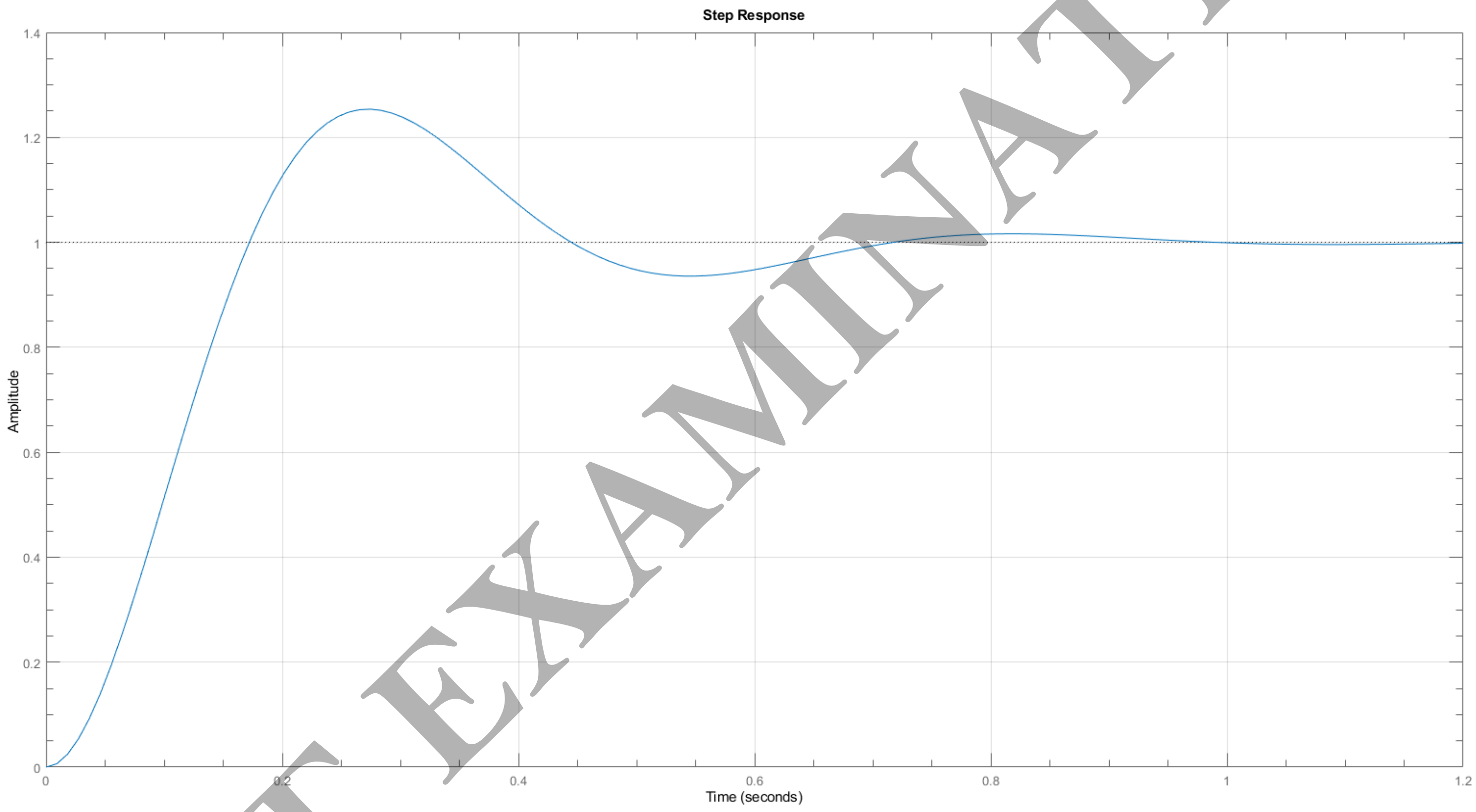
Step Response
Amplitude
Time (seconds)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2

Figure Q5

FORMULA SHEET

1st Order Systems:

$$\tau\dot{y}(t) + y(t) = ku(t)$$

$$G(s) = \frac{Y(s)}{U(s)} = \frac{k}{\tau s + 1}$$

2nd Order Systems:

$$\ddot{y}(t) + 2\zeta\omega_n\dot{y}(t) + {\omega_n}^2 y(t) = {\omega_n}^2 u(t)$$

$$G(s) = \frac{Y(s)}{U(s)} = \frac{{\omega_n}^2}{s^2 + 2\zeta\omega_n s + {\omega_n}^2}$$

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

$$t_s \approx \frac{4}{\zeta\omega_n}$$

$$t_p = \frac{\pi}{\omega_d}$$

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

END OF PAPER