[ENG21]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC SYSTEMS ENGINEERING AND ENGINEERING MANAGEMENT

SEMESTER ONE EXAMINATION 2021/2022

ADVANCED MECHATRONIC SYSTEMS

MODULE NO: MEC6002

Date: Wednesday 12th January 2022 Time: 10:00 – 12:00

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

CANDIDATES REQUIRE: **Formula Sheets attached following questions.**

School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Question 1

LG is a consumer electronic company that designs and builds white goods. In order to develop an intelligent washing machine measures the cleanliness of different washing grades of clothing against a reference clean cloth. The grades of the clean clothes have been learned from artificial intelligent model and programmed into the washing machine. Example grades are 1, 2, 3, 4, and 5. There is a PID controller installed inside the washing machine to regulate the washing grades against the choice of the user, which can be represented by K. The dirt cleaning part of the washing machine is represented as W, and a sensor that senses the output of washed cloth is depicted as S.

a) Draw a schematic diagram representing the feedback model of the novel washing machine system. **[5 marks]**

b) Determine the general transfer function of the closed-loop system. **[5 marks]**

c) Redraw the equivalent open-loop model of the system. **[5 marks]**

d) Assuming that K = 0.5, calculate output of the system if the user sets the washing grade to 1 and $G = 6$. **[5 marks]**

e) Determine the steady-state error of the washing machine, if the input is a step function. **[5 marks]**

Total 25 marks

School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Question 2

Large welding robots are widely used in automobile assembly lines. In particular, the welding head is moved to different positions on the automobile bode, thus rapid and accurate responses are required. The characteristic equation for the welding system including a controller is as shown in **Figure Q2**.

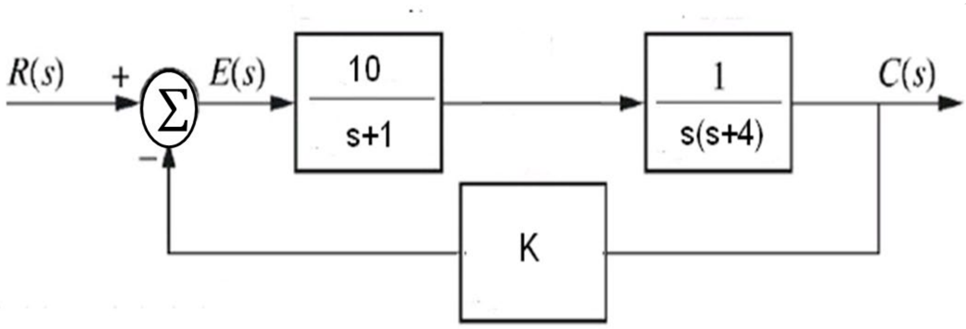

Figure Q2

a) derive the equivalent transfer function of the system **[8 marks]**

b) draw and complete the Routh Table **[7 marks]**

c) using Routh-Hurwitz stability criterion and the three-point tests, determine the direction for which the system becomes stable **[5 marks]**

d) find the maximum value of K for which the system is stable **[3 marks]**

e) express the range of values of K for the system to be stability **[2 marks]**

Total = [25 marks]

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Question 3

a) In digital control systems, digital-to-analogue convert (DAC) and analogue-to-digital converter (ADC) form a major part of the system. In converting digital signals to analogue signals, Zero-Order Hold (ZOH) filters are used. Using suitable diagrams, one for each, describe the operation of ZOH filters.

[12 marks]

b) Consider a digital control system equipped with Digital-to-Analogue Converter (DAC). The DAC compartment enables that the resulting digital signals are converted into analogue signals using the zero-order hold (ZOH) filter. The ZOH filter is connected in series with the sensor system whose transfer function is defined as:

$$G_p(s) = \frac{6}{s(s+3)}.$$

determine the discrete-time sampled-data transfer function of the control system, assume that the sampling time $T = 0.51$ seconds.

[13 marks]

Total 25 marks

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School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Question 4

Figure Q4 shows a simplified mechanical system, where M = 10 Kg; K1 = 2 N/m; K2 = 3 N/m; C = 4 Ns/m; g=0 m/s^2

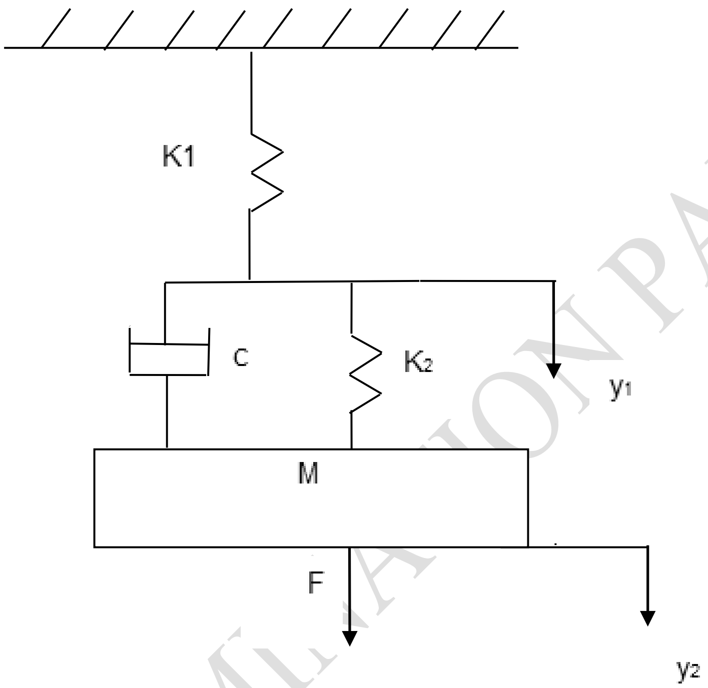

Figure Q4 - A Simplified Mechanical System

(a) Develop the differential equations for the variables y1 and y2 of the mechanical system. **[8 marks]**

(b) Determine the Laplace transforms of the differential equations obtained from Q4(a) above. Assume that the system is subjected to a unit step input and the initial conditions of the system are zeros (i.e. at time = 0, x, x', x'' are all zeros).

[4 marks]

(c) Determine the transfer function G(s) = Y2(s)/F(s) **[8 marks]**

(d) Explain the differences between open-loop and closed-loop control systems. **[5 marks]**

Total 25 marks

PLEASE TURN THE PAGE….

School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Question 5

a) An industrial robot is used for picking up and placing machined parts from a conveyor system. The transfer function of the picking up process of the robot arm is:

$$G(s) = \frac{200}{4s + 1}$$

and the system is subject to a unit step input.

i) Calculate the time taken for the output of the photovoltaic units to reach 75% of its final value. **[4 marks]**

ii) Calculate the output percentage of the photovoltaic units after 10 seconds, and determine the system output value at that time (10 seconds). **[6 marks]**

b) **Figure Q5** demonstrates a simplified block diagram of a mechanical control system.

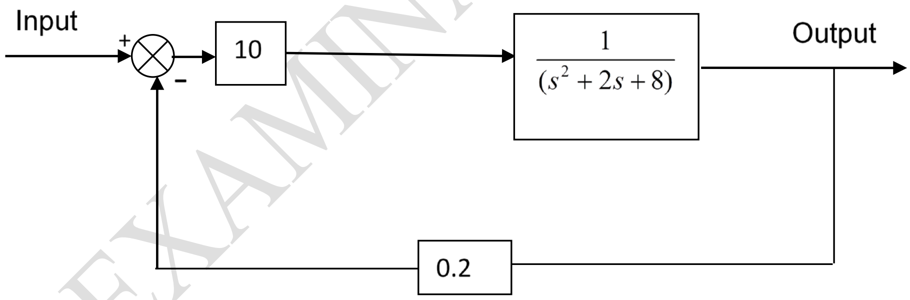

Figure Q5 Mechanical Control System

i) What is the mechanical control system's transfer function G(s) = Output/Input? **[5 marks]**

(ii) If a unit step input is applied into the system, determine the system's percentage overshoot, rise time, settling time, peak time, natural frequency, damped frequency, and damping ratio. **[10 marks]**

Total 25 marks

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Question 6

If the position control system has experienced a disturbance, Rd (s), and a DC gain, K, has been inserted into the system as shown in **Figure Q6.**

(a) Determine the overall system transfer function (G(s) = C(s)/R(s)) for the control system.

[16 marks]

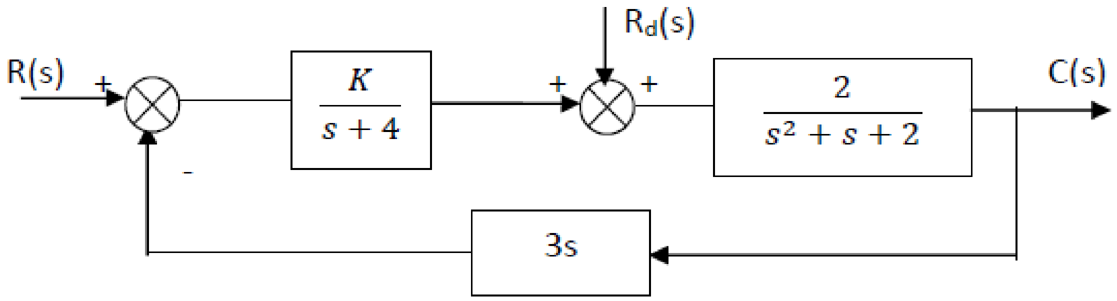

Figure Q6 - A position control system

(b) Explain the main functions of the following components which play important parts in field of mechatronic systems:

- Sensors
- Actuators
- Programmable Logic Control
- Data Communication Interfaces

[9 marks]

Total 25 marks

END OF QUESTIONS

Formula sheet follows on the next page….

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School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Formula Sheet

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)

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

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

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

Laplace Transforms

A unit impulse function 1

A unit step function $\dfrac{1}{s}$

A unit ramp function $\dfrac{1}{s^2}$

First order Systems

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

$\theta_O = AG_{ss}(1-e^{-t/\tau})$ (for a step input with size A)

School of Engineering
MSc Systems Engineering and Engineering Management
Semester One Examination 2021/2022
Advanced Mechatronic Systems
Module No MEC6002

Performance measures for second-order systems

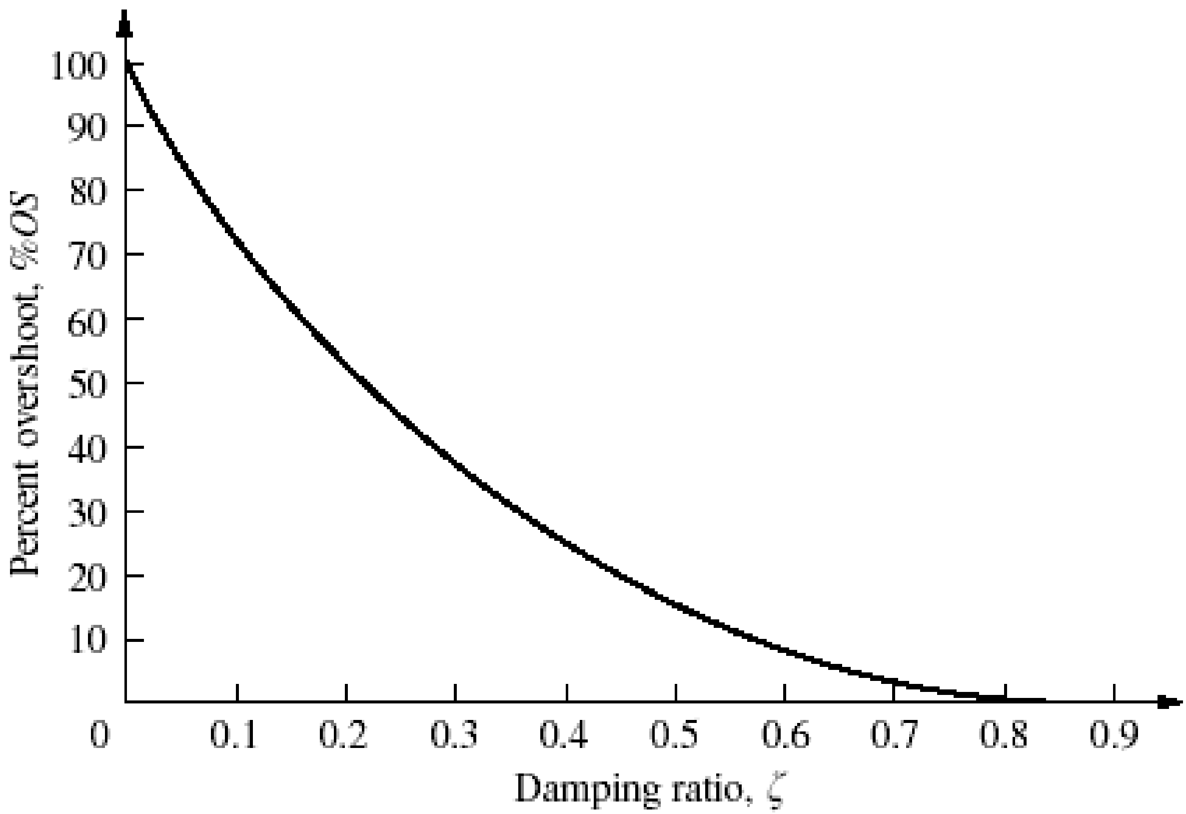
$\omega_d t_r = 1/2\pi$

$\omega_d t_p = \pi$

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

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

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



	$f(t)$	$F(s)$	
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.	$\cos \omega t\,u(t)$	$\frac{s}{s^2+\omega^2}$	

	$f(t)$	$F(s)$

$$\frac{df(t)}{dt} = sF(s)-f(0) \quad \text{(1st order)}$$

$$\frac{d^2f(t)}{dt^2} = s^2F(s) - s\,f(0) - f'(0) \quad \text{(2nd order)}$$

$$\frac{d^nf(t)}{dt^n} = s^nF(s) - \sum_{i=1}^{n} s^{n-1} f^{i-1}(0) \quad \text{(Higher order)}$$

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