UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC SYSTEMS ENGINEERING AND ENGINEERING MANAGEMENT

SEMESTER TWO EXAMINATION 2021/2022

ADVANCED CONTROL TECHNOLOGY

MODULE NO: EEM7015

Date: Tuesday 17th May 2022 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions.

Answer ANY THREE questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

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

Q1. The differential equations for a nonlinear dynamic system are given by (Equations 1 and 2):

$$\frac{d^2L}{dt^2} = \frac{Px^2}{L} \quad \textbf{......(1)}$$

$$V = H\frac{dx}{dt} + Kx \quad \textbf{.....(2)}$$

The input of the system is ΔV, and outputs of the system are ΔL, Δx, and dΔL/dt.

(a) Using Taylor's series approximation to linearise this nonlinear system. **(12 marks)**

(b) Select the state variables and transfer the differential equations obtained from (a) above to the relevant first-order differential equations. **(7 marks)**

(c) Determine the system matrices A, B, C and D, where A, B, C, and D have their usual meaning. **(10 marks)**

(d) Explain system controllability and system observability **(4 marks)**

Total 33 marks

Q2. (a) Consider three fuzzy subsets of the set X,

X = {a, b, c, d, e, f, g} = {-3, -2, -1, 0, 1, 2, 3}

referred to as A1, A2 and A3

A1 = {0.1/a, 0.4/b, 0.8/c, 1.0/d, 0.5/e, 0.2/f, 0/g}

A2 = {0.3/a, 0.9/b, 0.1/c, 0.3/d, 0.6/e, 0.4/f, 0.1/g} and

A3 = {1.0/a, 0.8/b, 0.6/c, 0.4/d, 0.3/e, 0.2/f, 0.1/g}

Conduct the following Fuzzy Set Operations:

(i) The **support** of A1, A2 and A3 **(2 marks)**

(ii) The **core** of A1, A2 and A3 **(2 marks)**

Question 2 continued over page….
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Question 2 continued….

(iii) The **cardinality** of A1and A3 **(2 marks)**

(iv) The **complement** of A2 and A3 **(2 marks)**

(v) The **union** of A1, A2 and A3 **(1 mark)**

(vi) The **intersection** of A1, A2 and A3 **(1 mark)**

(vii) The new set B, if B = $A1^2$ **(1 mark)**

(viii) The new set C, if C = 0.5A2 **(1 mark)**

(ix) The new set D, for an alpha cut at $A3_{0.8}$ **(1 mark)**

(x) Defuzzyfication of the set A1 by using the central of gravity (COG) technique. **(2 marks)**

(xi) Defuzzyfication of the set A3 by using the Sugeno method. **(2 marks)**

(b) Identify, using examples, the Mamdani-style fuzzy inference with Sugeno-style fuzzy inference in

i) Fuzzy rules **(4 marks)**

ii) Aggregation of rule outputs **(4 marks)**

iii) Defuzzification **(2 marks)**

iv) Discuss the advantages and disadvantages of these two Fuzzy inferences **(6 marks)**

Total 33 marks

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Question 3

You were just hired as an engineer in Keating Supercars. You are asked to model the suspension of the new car model. Your line manager suggested that the vehicle body can be simulated as a solid wall, the wishbone as a spring with stiffness K1, the suspension spring as a spring with stiffness K2, the suspension damper as a damper with damping coefficient C and the wheel as a mass with mass M. Figure Q3 shows the model of your suspension. The input to the system is the Force F acting from the road to the wheel and the outputs are displacements y_1 *and* y_2.

a) Develop the differential equations for the displacements y_1 *and* y_2 of the machine system.

(11 marks)

b) Determine the Laplace transforms of the differential equations obtained from Q4(a) above. Assume the initial conditions of the system are zeros (i.e. at time = 0, y, y', y'' are all zeros).

(11 marks)

c) Determine the transfer function G(s) = $y_2(s)/F(s)$

(11 marks)

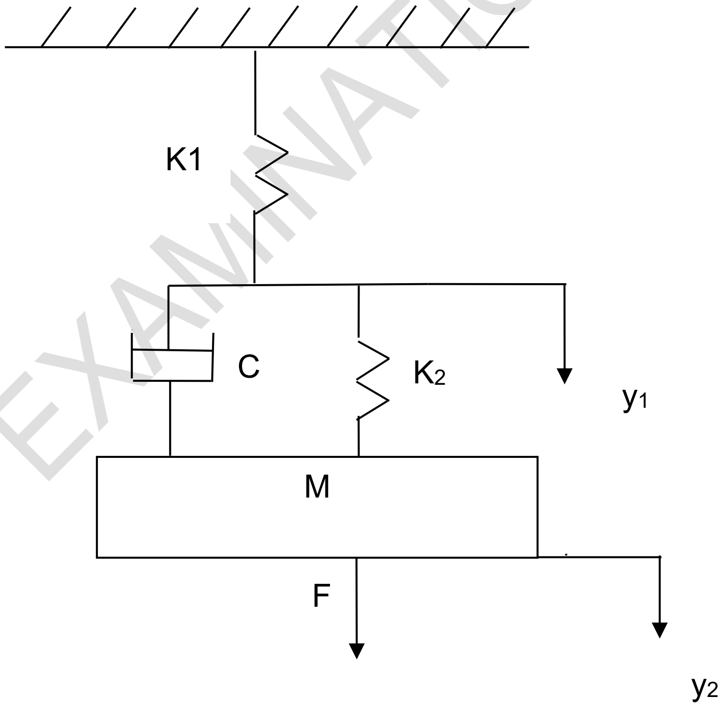

Figure Q3

Total 33 marks

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Question 4

A mechatronic system in Fig.Q4 shows an open-loop output response of the system, where the system experiences a unit step input. As a system design engineer,

(a) (i) Comment on the performance of the system design. **(4 marks)**

(ii) Suggest, with reasons, two possible approaches to improve the performance of the system. **(4 marks)**

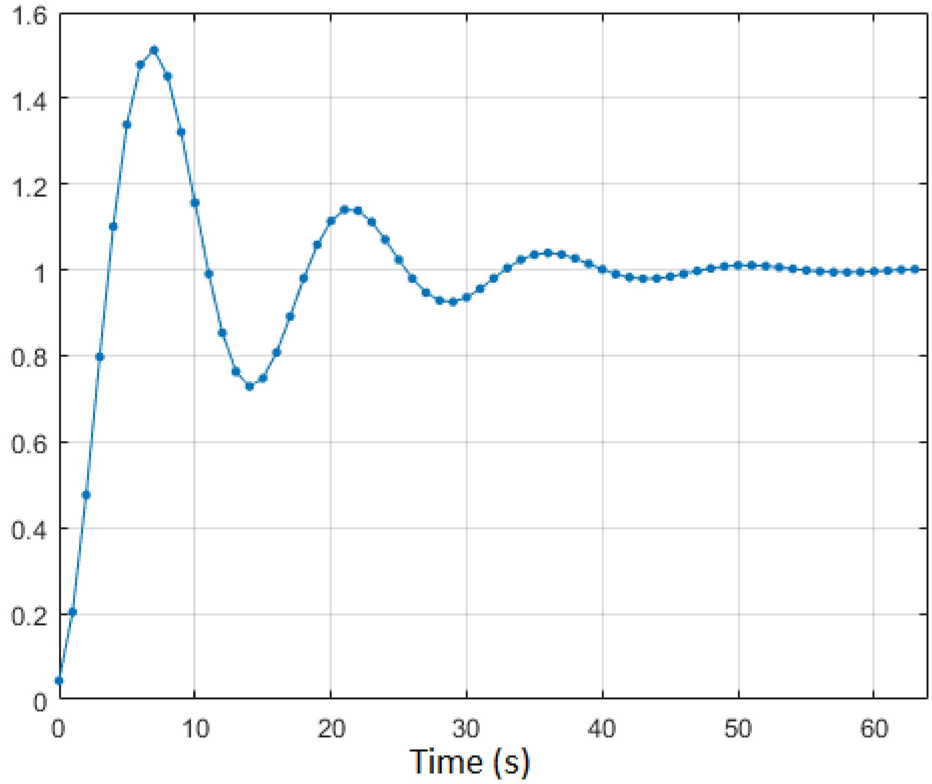

Fig. Q4 An Open-loop Output Response of a Mechatronic System

(b) If a PID controller will be applied into this mechatronic system:

(i) Draw a closed-loop control system, with the help of a block diagram, and clearly identify all blocks and signals, and explain how the whole closed-loop control system works. **(6 marks)**

(ii) Suggest, with reasons, the procedure that you will use to select the three terms of the PID controller K_p, K_i, and K_d. **(10 marks)**

Question 4b continues over the page….
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Question 4b continued….

(iii) In a PID controller, clearly explain with diagrams:

- For which purpose a P is needed
- For which purpose an I is needed
- For which purpose a D is needed **(9 marks)**

Total 33 marks

END OF QUESTIONS

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School of Engineering
MSc Systems Engineering and Engineering Management
Semester Two Examination 2021/2022
Advanced Control Technology
Module No. EEM7015

Formula Sheet

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

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

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

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Performance measures for second-order systems

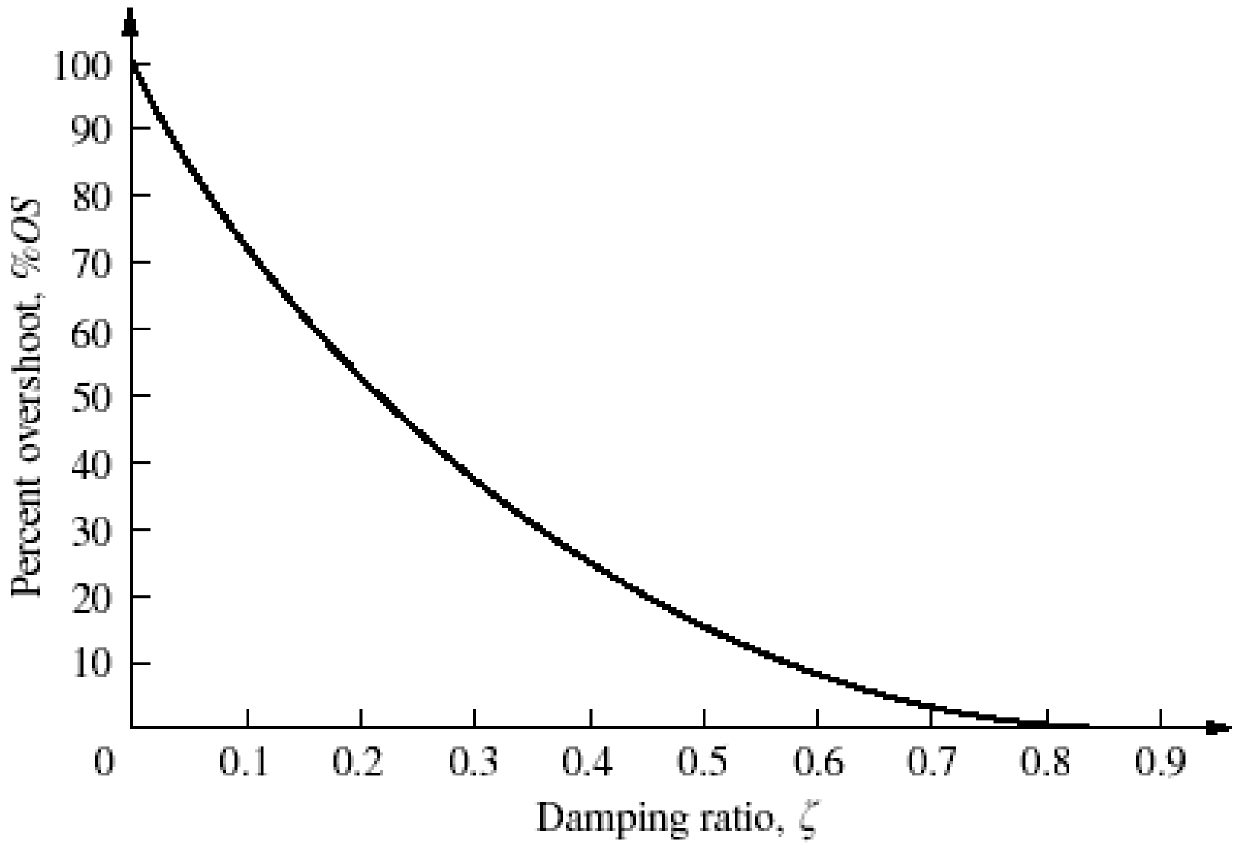
$\omega_d t_r = 1/2\pi$

$\omega_d t_p = \pi$

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

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

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



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