[ENG29]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC SYSTEMS ENGINEERING AND ENGINEERING MANAGEMENT

SEMESTER 2 EXAMINATION 2023/2024

ADVANCED CONTROL TECHNOLOGY

MODULE NUMBER: EEM7015

Date: Tuesday 14th May 2024 **Time: 10:00 – 12:00**

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.

This examination paper carries a total of 100 marks.

Formulae sheet is attached at the end of the paper.

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

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Question 1

A block diagram for a furnace temperature control system is shown in Figure Q1 below:

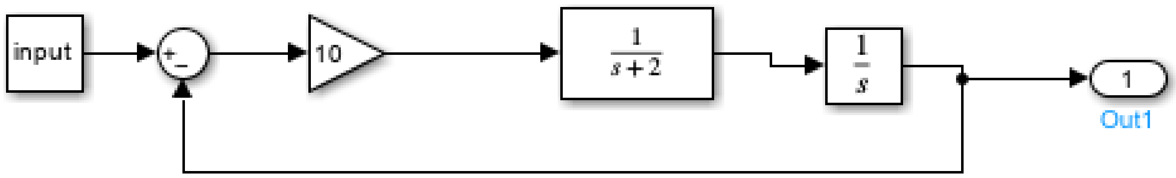

Figure Q1

a) Determine the system damping ratio, natural frequency, damped frequency, and steady state gain. **[7 marks]**

b) Determine the time domain response of the system, y(t), to a unit impulse input, r(t). **[6 marks]**

c) For a unit step input, determine the system rise time, peak time, maximum percentage overshoot, and settling time for a 2% tolerance. **[6 marks]**

d) If the input of $r(t) = 100, t \geq 0 \; and \; r(t) = \; 0 \,, t \leq 0$

is applied, analyse the system steady state error. **[6 marks]**

Total marks [25 marks]

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Question 2

A filter is shown in Figure Q2.

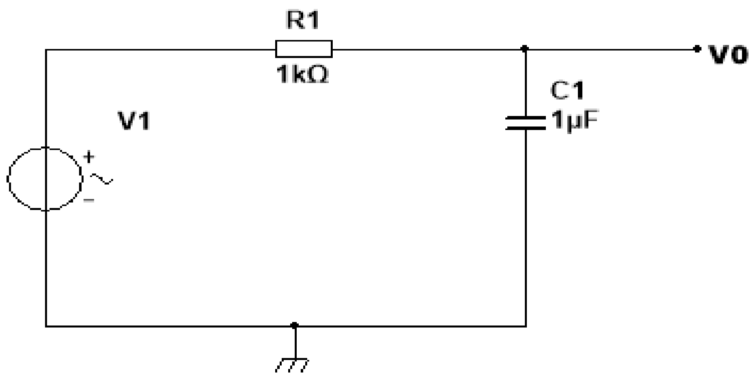

Figure Q2

Where Vo is the output and V1 is the input.

a) Determine the transfer function in the Laplace domain. **[8 marks]**

b) Sketch the pole zero map, indicating the poles and zeros. **[5 marks]**

c) Derive the equation that predicts the output voltage in the time domain. **[7 marks]**

d) Is the filter stable and what type of filter is it. **[5 marks]**

Total marks [25 marks]

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Question 3

A dynamic system is shown in the block diagram below, Figure Q3(a),

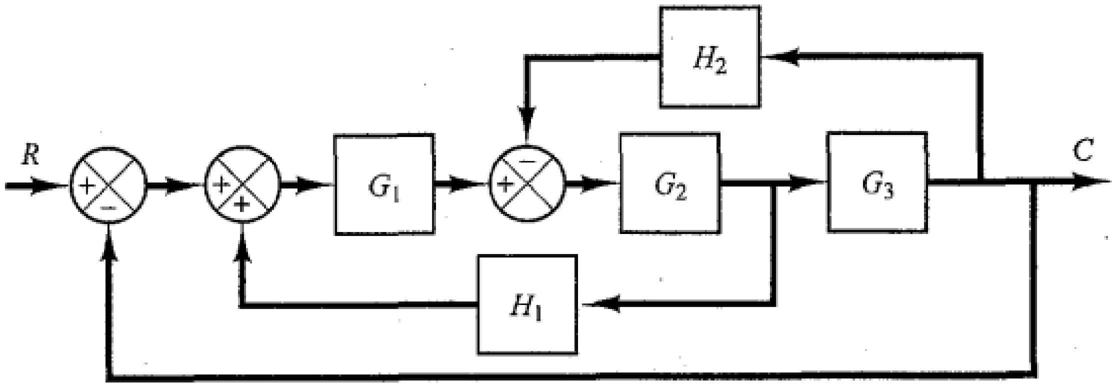

Figure Q3(a)

a) Show how the block diagram in figure Q3(a) could be reduced to describe the output over the input C/R. **[6 marks]**

b) From the Matlab graph shown in Q3(b), estimate the gain and phase margins **[6 marks]**

c) Sketch the magnitude and phase for the following functions.

(i) $G1(s) = \frac{10}{0.2s+1}$ **[2 marks]**

(ii) $G2(s) = \frac{2500}{S^2 + 80S + 2500}$ **[2 marks]**

(iii) $G3(s) = \frac{8}{S}$ **[2 marks]**

d) Sketch the final result of G1(s)*G2(s)*G(s) and estimate the phase and gain margin. **[7 marks]**

Question 3 continues over the page…

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Question 3 continued…

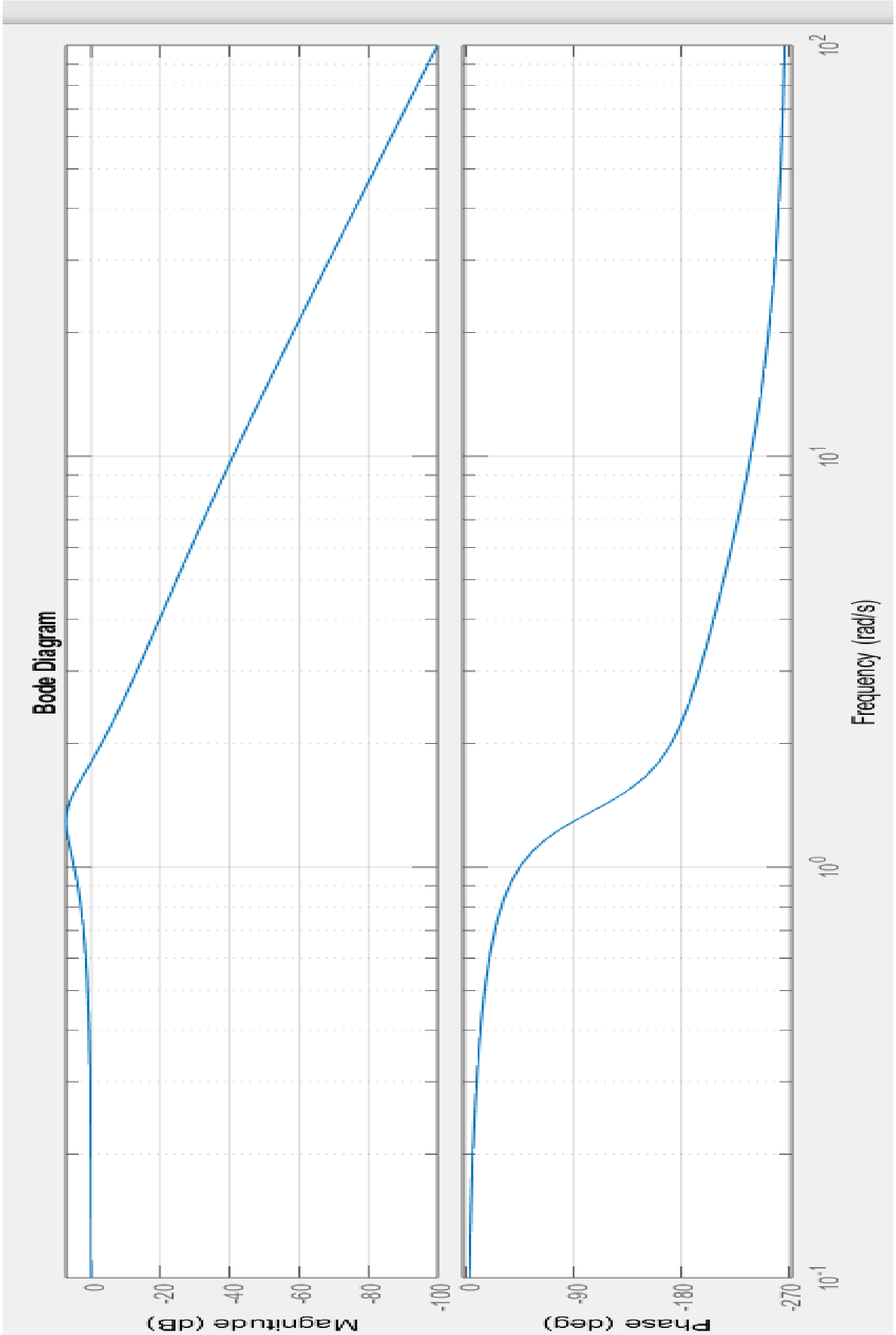

Figure 3(b)

Total marks [25 marks]

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Question 4

A suspension system for mountain bicycle is shown Figure Q4. If the input is force F(t) and the output displacement Y(t);

(a) Develop the system differential equation and transfer function. **[15 marks]**

(b) Determine the state space equations and Matrices **A,B,C** and **D** **[10 marks]**

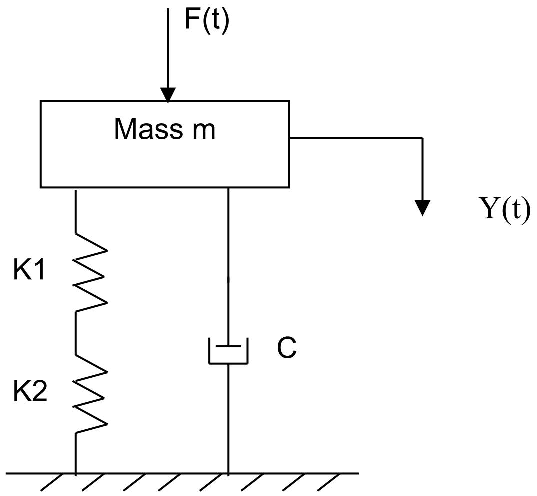

Figure Q4

Total marks [25 marks]

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Question 5

A PID controller is used to control an automation processing plant as shown in Figure Q5. The open loop transfer function of the plant is given by.

$$G_p(s) = \frac{60}{(s+2)(s+5)}$$

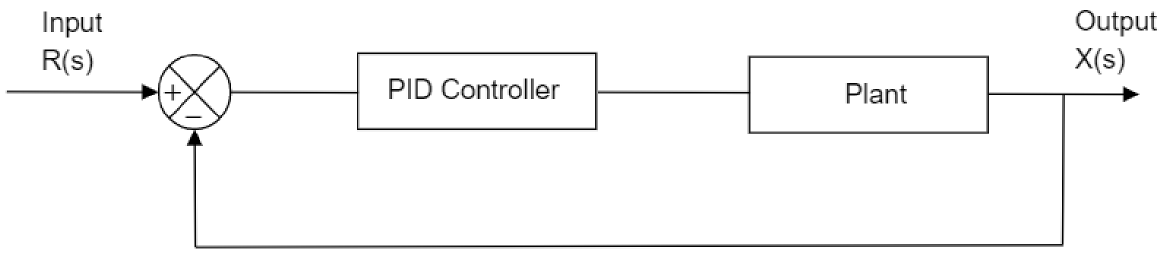

Figure Q5: Control system of the processing plant.

(a) Evaluate the performances of closed loop plant system (natural frequency, damping ratio, Percentage Overshoot, peak time, rise time, settling time and steady-state error) to assess its performance without the PID controller.

[10 marks]

(b) Design a PID controller to determine the parameter K_p, K_i and K_d, and clearly identify the design procedure if the system responses for a unit step input are required to be:

- The maximum overshoot is less than 8%.
- The settling time is 40% less than without the PID controller.
- The steady-state error is 0.

[15 marks]

Total marks [25 marks]

END OF QUESTIONS

Formulae sheets follow over the page

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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

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

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_0(s)}{1+G_0(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \dfrac{1}{1+\lim_{z\to 1} G_0(z)}$ (if a digital system subjects to a unit step 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

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

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

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

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

$\theta_o(t) = G_{ss}(\dfrac{1}{\tau})e^{-(t/\tau)}$ (for an impulse input)

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Second-order systems

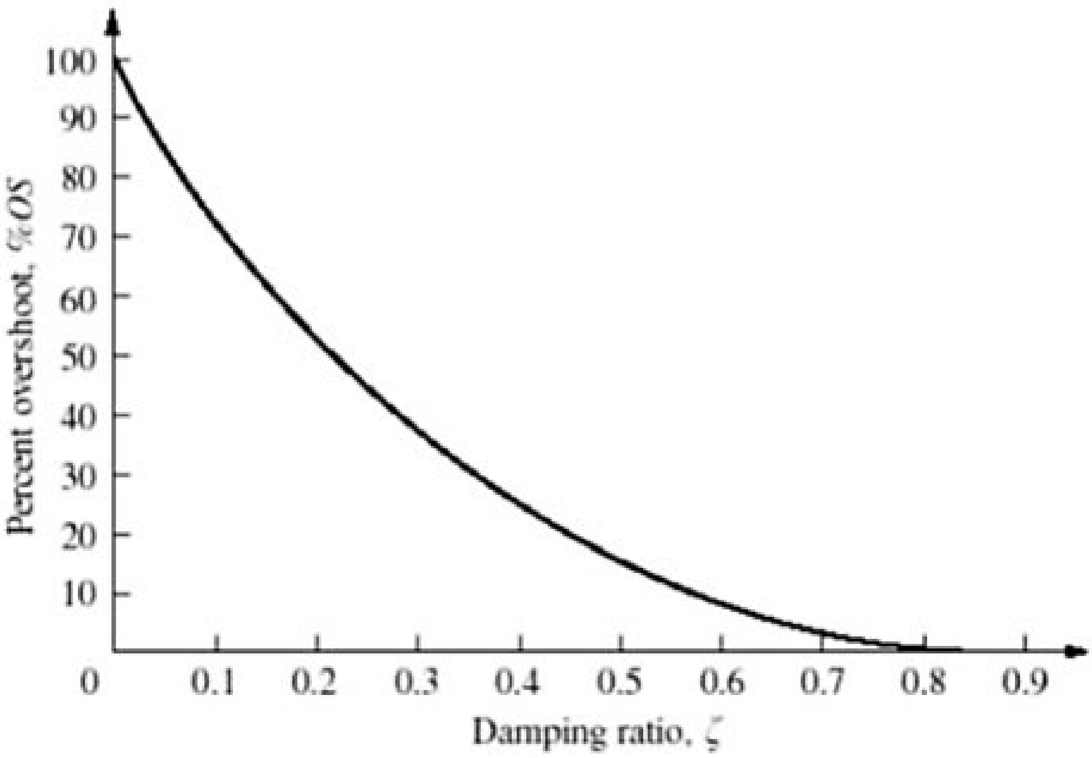
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

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

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

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

$t_s = \frac{4}{\zeta\omega_n}$ $\omega_d = \omega_n\sqrt{(1-\zeta^2)}$



Controllability: $R = [B \; AB \; A^2B \ldots\ldots A^{(n-1)} \; B]$

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Laplace transform and Z transform table

Laplace Domain	Time Domain	Z Domain
1	$\delta(t)$ unit impulse	1
$\frac{1}{s}$	$u(t)$ *unit step*	$\frac{z}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$
$\frac{1}{s+a}$	e^{-at}	$\frac{z}{z-e^{-aT}}$
$\frac{1}{s(s+a)}$	$\frac{1}{a}\left(1-e^{-at}\right)$	$\frac{z\left(1-e^{-aT}\right)}{a(z-1)\left(z-e^{-aT}\right)}$
$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$\frac{z\left(e^{-aT}-e^{-bT}\right)}{a\left(z-e^{aT}\right)\left(z-e^{-bT}\right)}$
$\frac{b}{(s+a)^2+b^2}$	$e^{-at}\sin(bt)$	$\frac{ze^{-aT}\sin(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$
$\frac{s+a}{(s+a)^2+b^2}$	$e^{-at}\cos(bt)$	$\frac{z^2-ze^{-aT}\cos(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$

Laplace Transforms of common functions

Functions		
Unit pulse (Dirac delta distribution)	$\delta(t)$	$F(s)=1$
Unit step function	$1(t)$	$F(s)=\frac{1}{s}$
Ramp function	$f(t)=at$	$F(s)=\frac{1}{s^2}$
Sine function	$f(t)=\sin at$	$F(s)=\frac{a}{s^2+a^2}$
Cosine function	$f(t)=\cos at$	$F(s)=\frac{s}{s^2+a^2}$
Exponential function	$f(t)=e^{at}$	$F(s)=\frac{1}{s-a}$
Operations		
Differentiation	$L(f'(t))$	$sF(s)-f(0)$
Integration	$L\left(\int f(t)dt\right)$	$\frac{1}{s}F(s)$
Time shift	$Lf(t-a)$	$e^{-as}F(s)$

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