Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2022/2023

COURSE NAME	:	CONTROL ENGINEERING
COURSE CODE	:	BDA 30703
PROGRAMME CODE	:	BDD
EXAMINATION DATE	:	FEBRUARY 2023
DURATION	:	3 HOURS
INSTRUCTIONS	:	(1) ANSWER **ALL** QUESTIONS IN **PART A** ANSWER **TWO (2)** QUESTIONS IN **PART B** (2) THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK** (3) STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY TYPE OF EXTERNAL RESOURCES DURING THE EXAMINATION

THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

PART A: ANSWER ALL QUESTIONS

Q1 (a) Explain the compensation characteristics of cascade PI and PD compensators.

(5 marks)

(b) What is the significance of integral and derivative terms in a PID controller?

(5 marks)

(c) Consider the control system shown in **Figure Q1(c).** Examine a Ziegler-Nichols tuning rule for the determination of the values of parameters Kp, Ti and Td.

(10 marks)

Q2. (a) State **two (2)** advantages and **two (2)** disadvantages of Nyquist diagram.

(4 marks)

(b) For the unity feedback system with a forward transfer function of

$$G(s) = \frac{5}{(s+1)(s+2)}$$

Solve the following:

(i) Plot the Nyquist diagram.

(To simplify the process of drawing the Nyquist diagram, sets the scale for the x-axes and y-axes on the polar graph paper to [xmin, xmax] which is [-1.5, 1.5] and [ymin, ymax] which is [-1.5, 1.5]. The mapping of the points should start at frequency, $\omega = 1$ Hz)

(14 marks)

(ii) Use your Nyquist diagram to find the phase margin for which the magnitude is unity.

(2 marks)

Q3. (a) **Figure Q3(a)** shows a translational mechanical system. $X_1(s)$ is the displacement input and $X_2(s)$ is the displacement output. There is no friction between wheels and floor. Find the transfer function $X_2(s)/X_1(s)$ of the system.

(5 marks)

(b) Referring to question Q3(a), if the input signal is a unit step,

(i) determine the value of k and a to yield 16.3% overshoot and a settling time of 8 seconds for a system.

(4 marks)

(ii) determine the value of rise time T_r, peak time T_p and steady-state error e_{ss} of the system step response.
(A precise analytical relationship between a normalized rise time versus damping ratio for a second-order underdamped response can be referred from the **Figure Q3(b)**)

(5 marks)

(iii) determine the value of the system's poles.

(2 marks)

(iv) plot the system's poles is the s-plane.

(1 mark)

(v) sketch the time response graph of the system, indicate the location and value of rise time T_r, peak time T_p, percent overshoot $\%OS$, settling time T_s and steady-state error e_{ss} in the graph.

(3 marks)

PART B: ANSWER TWO (2) QUESTIONS ONLY

Q4 (a) (i) Illustrates and describes the general structure of measurement system.

(5 marks)

(ii) Explain and illustrates the difference between zero order instrument and first order instrument. Provide example for each of the stated instrument.

(5 marks)

(b) (i) You are required to step down the voltage from 10 volts to 5 volts of a circuit to power up the component X with the following operational amplifiers (Op-amp):

- Non-inverting Op-amp
- Inverting Op-amp

(4 marks)

(ii) Prove that the transfer function for the following Op-amp in **Figure Q4(b)** is equal to:

$$\frac{V_o(s)}{V_i(s)} = \frac{-(s+1000)}{2(s+4000)}$$

(6 marks)

Q5 (a) (i) Name **three (3)** primary objectives of control system analysis and design.

(3 marks)

(ii) An aircraft's orientation can be expressed in terms of roll, pitch, and yaw angles, as shown in **Figure Q5(a).** Draw a block diagram for a closed-loop system that stabilizes pitch angle as follows: The control system measures the actual pitch angle using a gyro and compares the actual pitch angle with the desired pitch angle. The elevator responds to the pitch angle error by performing elevator angular deflection. The aircraft responds to this angular deflection by producing a pitch angle rate. Identify the input and output transducers, the controller, and the plant.

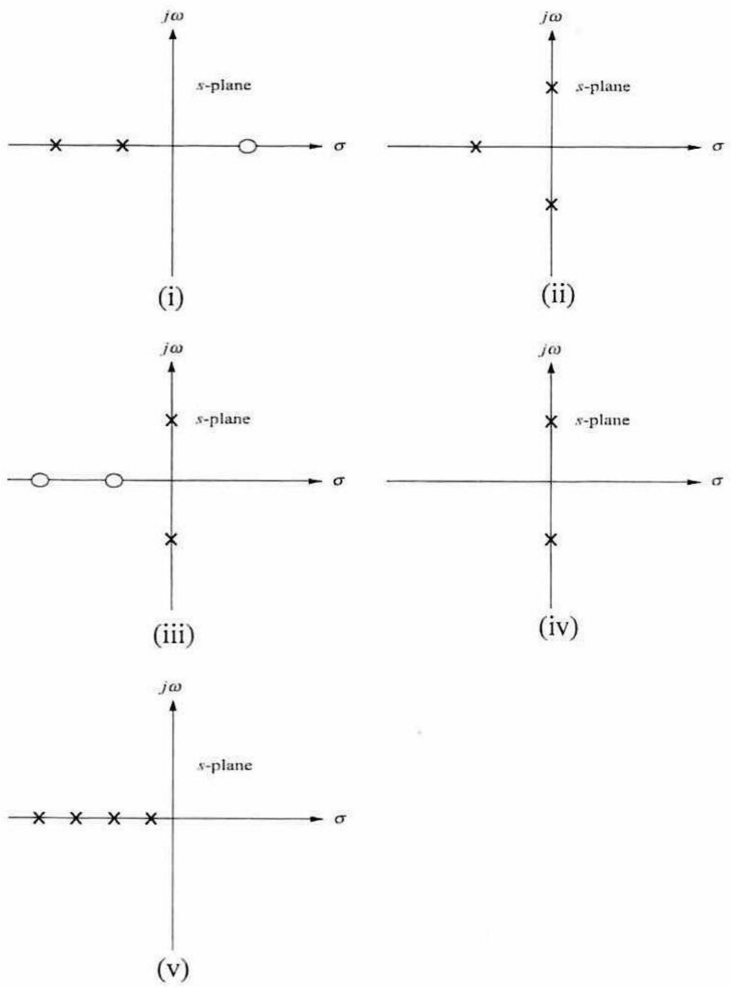
(7 marks)

(b) An innovative ship steering system was invented for the US Navy in the 1930s by a Russian-American control theory mathematician named Nicolas Minorsky. The simplified version of the control system block diagram is given in **Figure Q5(b)**. Convert the control system into an equivalent signal flow diagram and determine the transfer function for the ship's steering system using Mason's rule method.

(10 marks)

Q6 (a) Sketch the root locus for the system shown below.

(10 marks)



(b) A translational mechanical system as shown in **Figure Q6(b)**. The system consists of external force, a parallel damper and spring attached together in series with other spring. B is damping coefficient, k_1 and k_2 are spring coefficients and F is external force. The system moves with two displacements x_1 and x_2 as shown. The input and output of the system is external force F and displacement x_2 respectively.

Using the block diagram reduction, find the transfer function for the system.

(10 marks)

-END OF QUESTIONS-

FINAL EXAMINATION

SEMESTER/SESSION	: SEM I 2022/2023	PROGRAMME CODE	: BDD
COURSE NAME	: CONTROL ENGINEERING	COURSE CODE	: BDA 30703

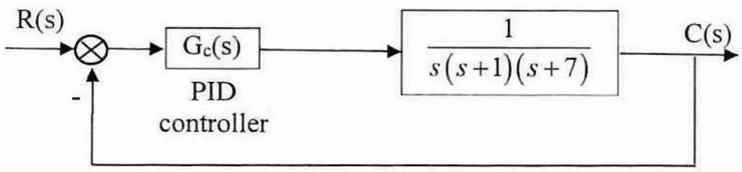


Figure Q1(c): A simple PID control system

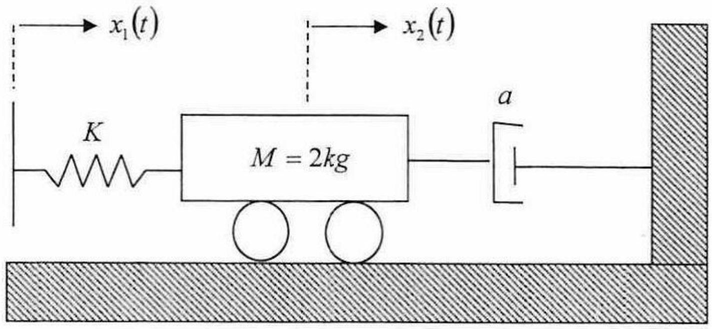
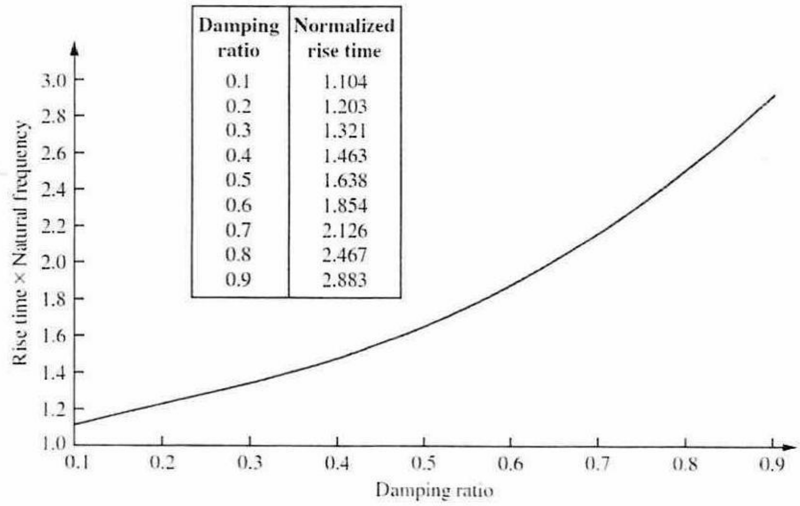


Figure Q3(a): A translational mechanical system



Damping ratio	Normalized rise time
0.1	1.104
0.2	1.203
0.3	1.321
0.4	1.463
0.5	1.638
0.6	1.854
0.7	2.126
0.8	2.467
0.9	2.883

Figure Q3(b): Normalized rise time versus damping ratio for a second-order underdamped response

FINAL EXAMINATION			
SEMESTER/SESSION	: SEM I 2022/2023	PROGRAMME CODE	: BDD
COURSE NAME	: CONTROL ENGINEERING	COURSE CODE	: BDA 30703

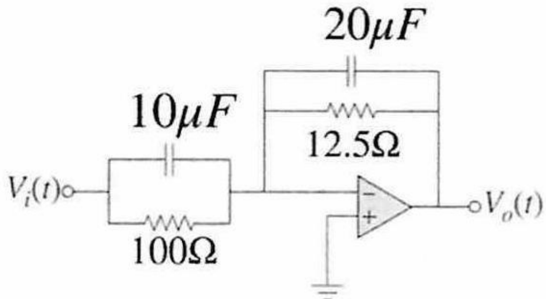


Figure Q4(b) : Operational amplifier

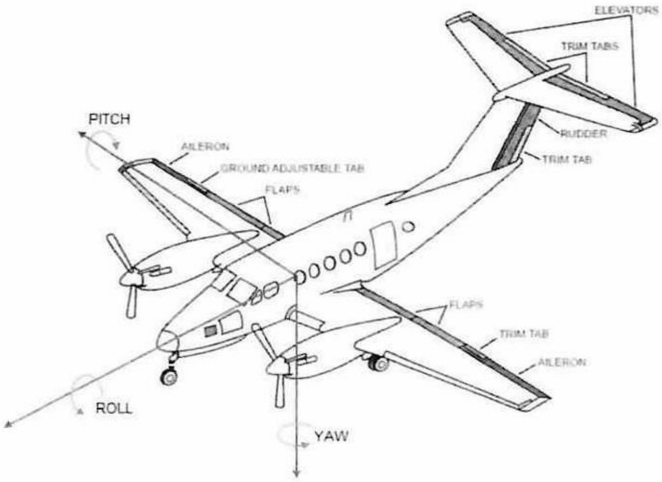


Figure Q5(a): Aircraft attitude definition.

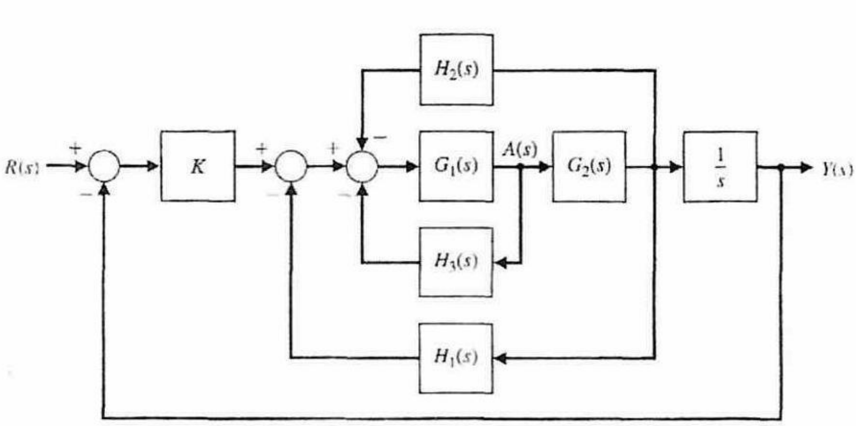


Figure Q5(b): The ship steering system

FINAL EXAMINATION

SEMESTER/SESSION	: SEM I 2022/2023	PROGRAMME CODE	: BDD
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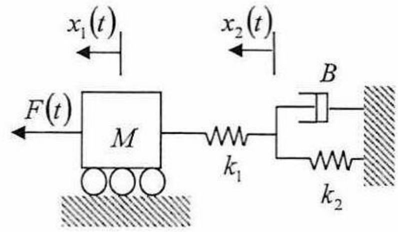

Figure Q6(b): A mechanical system

Key Equations

Time Response	Steady-state Error
$T_r = \frac{2.2}{a} \quad T_s = \frac{4}{a}$	$e(\infty) = e_{step}(\infty) = \frac{1}{1+\lim_{s\to 0} G(s)}; \quad K_p = \lim_{s\to 0} G(s)$
$G(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$	$e(\infty) = e_{ramp}(\infty) = \frac{1}{\lim_{s\to 0} sG(s)}; \quad K_v = \lim_{s\to 0} sG(s)$
$\%OS = e^{-\left(\zeta\pi/\sqrt{1-\zeta^2}\right)\times 100}$	$e(\infty) = e_{parabola}(\infty) = \frac{1}{\lim_{s\to 0} s^2G(s)}; \quad K_a = \lim_{s\to 0} s^2G(s)$
$\zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}}$	Root Locus
$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} \quad T_s = \frac{4}{\zeta\omega_n}$	$\angle KG(s)H(s) = -1 = 1/(2k+1)180°$
	$\sigma_a = \frac{\sum \text{finite poles} - \sum \text{finite zeros}}{\#\text{finite poles} - \#\text{finite zeros}}$
	$\theta_a = \frac{(2k+1)\pi}{\#\text{finite poles} - \#\text{finite zeros}}$
	$\theta = \sum \text{finite poles} - \sum \text{finite zeros}$
	$K = \frac{1}{\lvert G(s)H(s)\rvert} = \frac{1}{M} = \frac{\prod \text{finite poles lengths}}{\prod \text{finite zero lengths}}$