CONFIDENTIAL

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	CONTROL SYSTEMS
COURSE CODE	:	BEJ 20503
PROGRAMME CODE	:	BEJ
EXAMINATION DATE	:	JULY/AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWERS ALL QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSE BOOK** 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSE BOOK.

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

Q1 (a) Build the transfer function $\theta_2(s)/T(s)$ for the rotational mechanical system with gears shown in **Figure Q1 (a).**

(10 marks)

(b) Develop the equation of each motions for mechanical network shown in **Figure Q1 (b).**

(15 marks)

Q2 (a) Rozie has analyzed the stability of the system shown in **Figure Q2(a)**. Based on her analysis, the system is stable. Apply the concepts of stability in the complex s-plane and the Routh-Hurwitz criterion to verify Rozie's statement.

(12 marks)

(b) The Characteristic Equation of a system is $Ts = 2s^4 + 7$. Show either the system is stable or not by employing the Routh-Hurwitz criterion.

(11 marks)

(c) Explain what stability is and the sufficient condition for Routh-Hurwitz Stability Criterion.

(2 marks)

Q3 (a) A ship undergo motion about their roll axis as shown in **Figure Q3(a)**. Fins called stabilizers are used to reduce the rolling motion. The stabilizer can be positioned by closed–loop control system that consists of component such as fin actuators and sensors, as well as the ship's roll dynamics. Assume the roll dynamics, which relates the roll–angles output, $\theta(s)$ to a disturbance-torque input, T_D, is

$$\frac{\theta(s)}{T_D} = \frac{2.25}{s^2 + 0.5s + 2.25}$$

(i) Calculate the natural frequency ω_n, damping ratio ζ, peak time T_p, rise time T_r, and percentage of overshoot, $\%\mu_s$ of the system.

(9 marks)

(ii) Classify the characterizing response of the system.

(2 marks)

(iii) The percentage maximum overshoot obtained in Q3a(i) is reduced by 60%. Calculate the new value of damping ratio, ζ for the system.

(5 marks)

(b) A boat is circling a ship that is using a tracking radar with speed of 20 knots, and it is circling the ship at a distance of 1 nautical mile as shown in **Figure Q3(b)(i).** A simplified model of the tracking system is shown in **Figure Q3 (b)(ii)**.

(i) Classify the system type

(1.5 marks)

(ii) Given that the value of K = 200 and the system has been tested with three the system type different reference inputs, $\theta i(t)$ which are 10 $u(t)$, 10t $u(t)$ and $10t^2$ $u(t)$. Demonstrate using steady state error analysis, which $\theta_i(t)$ could give infinite (∞) steady state error?

(7.5 marks)

Q4 (a) Consider the simplified form of the transfer function for position servo mechanism used in an antenna tracking system as shown in **Figure Q4**. In this system, an electric motor is used to rotate a radar antenna which automatically tracks an aircraft. The error signal, which proportional to the difference between the pointing direction of the antenna and the line of sight to the aircraft, is amplified by controller, drives and controls the motor in the appropriate direction so as to reduce this error. Illustrate the root locus for this system.

(25 marks)

-END OF QUESTIONS

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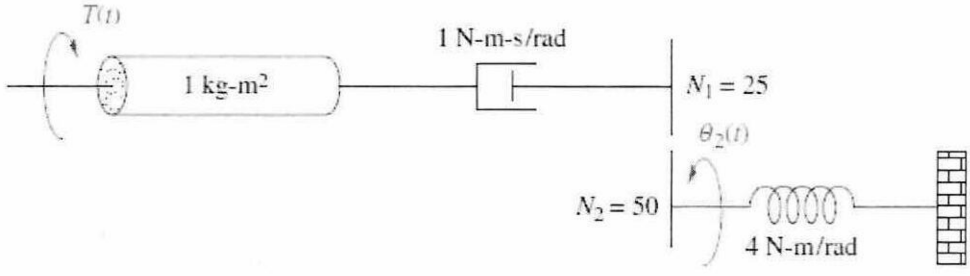

Figure Q1 (a)

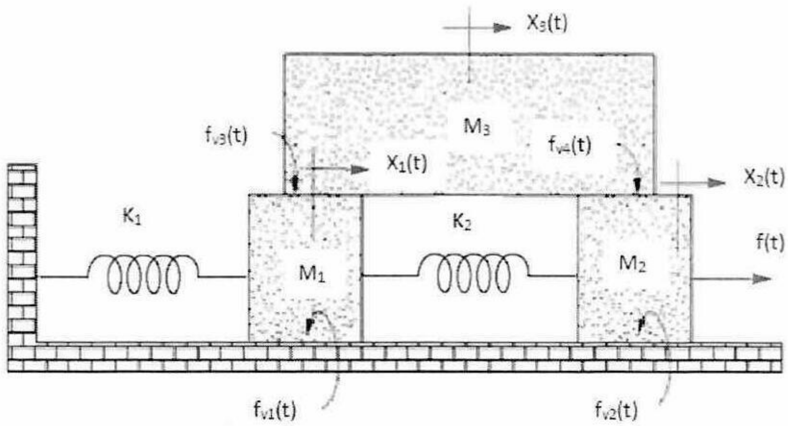

Figure Q1 (b)

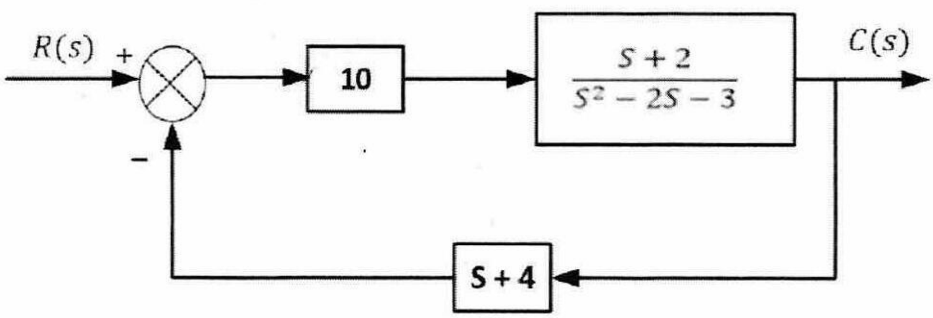

Figure Q2 (a)

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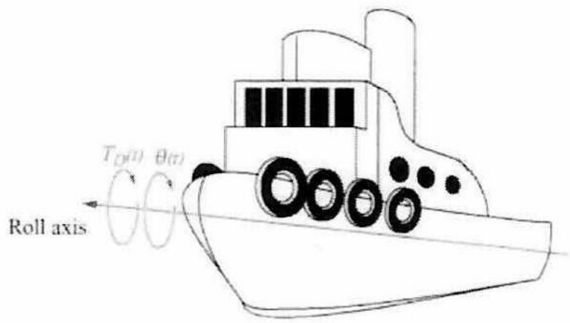

Figure Q3 (a)

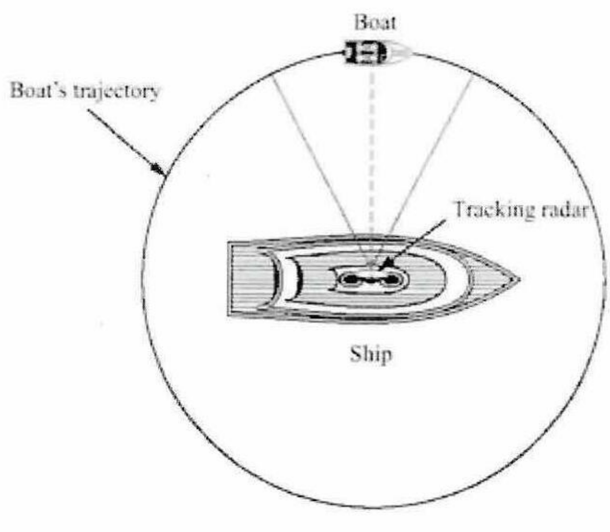

Figure Q3 (b)(i)

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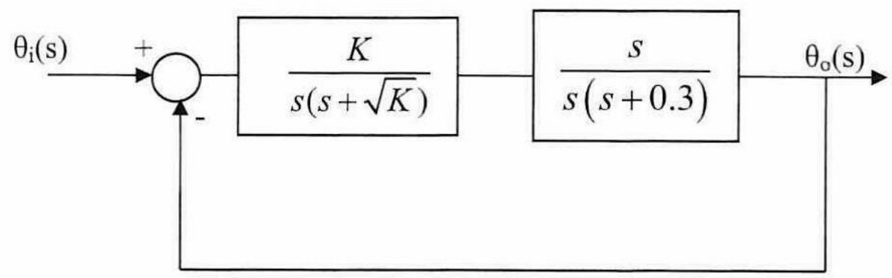

Figure Q3 (b)(ii)

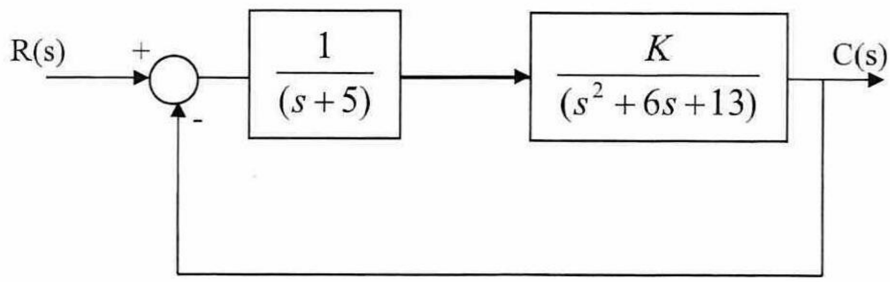

Figure Q4

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FORMULAS

Table A
Laplace transform table

$f(t)$	$F(s)$
$\delta(t)$	1
$u(t)$	$\frac{1}{s}$
$tu(t)$	$\frac{1}{s^2}$
$t^n u(t)$	$\frac{n!}{s^{n+1}}$
$e^{-at}u(t)$	$\frac{1}{s+a}$
$\sin \omega t u(t)$	$\frac{\omega}{s^2+\omega^2}$
$\cos \omega t u(t)$	$\frac{s}{s^2+\omega^2}$
$e^{-at} \sin \omega t u(t)$	$\frac{\omega}{(s+a)^2+\omega^2}$
$e^{-at} \cos \omega t u(t)$	$\frac{(s+a)}{(s+a)^2+\omega^2}$

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Table B
Laplace transform theorems

Name	Theorem
Frequency shift	$\mathscr{L}\left[e^{-at}f(t)\right]=F(s+a)$
Time shift	$\mathscr{L}\left[f(t-T)\right]=e^{-sT}F(s)$
Differentiation	$\mathscr{L}\left[\frac{d^n f}{dt^n}\right]=s^n F(s)-\sum_{k=1}^{n} s^{n-k} f^{k-1}(0^-)$
Integration	$\mathscr{L}\left[\int_{0^-}^{t} f(\tau)d\tau\right]=\frac{F(s)}{s}$
Initial value	$\lim_{t\to 0} f(t)=\lim_{s\to\infty} sF(s)$
Final value	$\lim_{t\to\infty} f(t)=\lim_{s\to 0} sF(s)$

Table C
2^{nd} Order prototype system equations

$\frac{C(s)}{R(s)}=\frac{\omega_n^{\ 2}}{s^2+2\zeta\omega_n s+\omega_n^{\ 2}}$	$T_r=\frac{\pi-\cos^{-1}\zeta}{\omega_n\sqrt{1-\zeta^2}}$
$\mu_p=e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$	$T_p=\frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$
$T_s=\frac{4}{\zeta\omega_n}$ (2% criterion)	$T_s=\frac{3}{\zeta\omega_n}$ (5% criterion)