Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	CONTROL SYSTEMS
COURSE CODE	:	BEJ 20503 / BEV 30503
PROGRAMME CODE	:	BEJ / BEV
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER ALL QUESTIONS 2.THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3.STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

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

Q1 (a) Describe the definition of marginally stable based on s-plane poles location.

(2 marks)

(b) The characteristic equation for heat-exchanger system is as shown below:

$$R(s) = 2s^5 + 4s^4 + 2s^3 + 4s^2 + 2s + 4$$

Based on Routh Hurwitz approach, identify either the system is stable or unstable.

(11 marks)

(c) Charles has developed closed loop system for hydraulic arm for stable positioning. The closed loop transfer function for the system is as shown below:

$$\frac{C(s)}{R(s)} = \frac{K(s+2)}{s^4 + 7s^3 + 15s^2 + 25s + K(s+2)}$$

Calculate the range of K for the system to stable.

(12 marks)

Q2 From the experiments of "*Elementary Identification and Design*" for a closed loop position control system, the data gathered by one of the groups is as shown below:

$n = 30$
$K_p = 3\ v/rad$
$K_g = 0.2\ v/rads^{-1}$
$T = 100\ ms$
$K_a K_s K_g = 40$

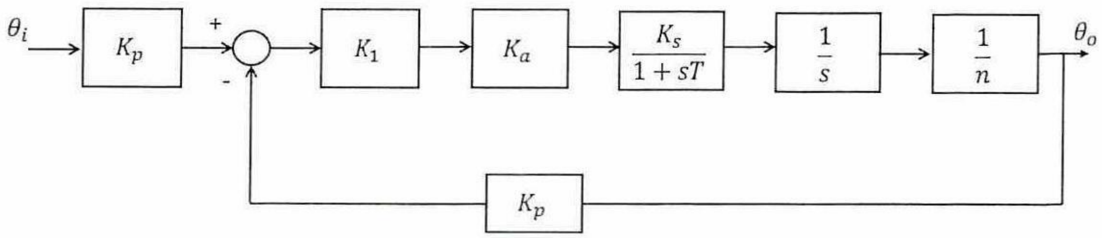

Figure Q2.1: Block diagram

(a) Using the above values and **Figure Q2.1**, solve $\frac{\theta_o}{\theta_i}$.

(8 marks)

(b) If $K_1 = 1$, by comparing the result obtain in question **Q2(a)** to a standard prototype of a second order system, calculate:

(i) Maximum overshoot (μ_S)

(3 marks)

(ii) Rise time (T_r)

(3 marks)

(iii) Peak time (T_p)

(3 marks)

(c) Calculate the value of K_1 that will give a 0.1353 of maximum overshoot (μ_S).

(8 marks)

Q3 (a) Proportional-integral-derivative (PID) controller is a type of feedback control mechanism that is applied in various examples especially that requires high accuracy.

(i) Illustrate the block diagram of a PID controller together with the plant and feedback in a closed-loop system. Clearly label the reference, error, and output signals in your diagram. Also separate the paths of proportional, derivative, and integral errors in your diagram.

(5 marks)

(ii) $K_p, K_i,$ and K_d are the proportional, integral, and derivative gains in a PID controller. Explain the typical effects of each of the gain parameters to the rise time, overshoot, and the steady state error of the response.

(6 marks)

(b) Figure **Q3.1** shows a unity-feedback configuration for the plant.

$$G(s) = \frac{1}{(s+1)(s+2)(s+10)}$$

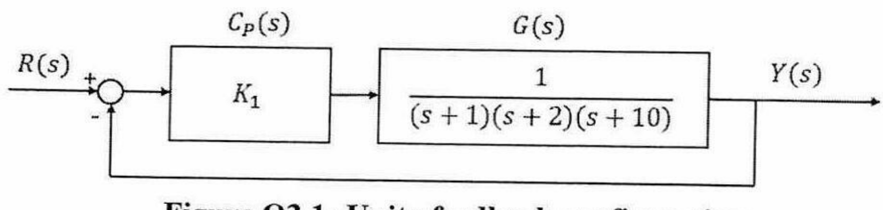

Figure Q3.1: Unity feedback configuration

(i) The root locus for this uncompensated system is as shown in **Figure Q3.2**, as well as the line of constant damping ratio $\zeta = 0.174$. From the root locus, calculate the corresponding value of K_1 that will produce a damping of $\zeta = 0.174$. It is given that for any point on the root locus, the corresponding gain, $K = \frac{\Pi\text{"finite pole lengths"}}{\Pi\text{"finite zero lengths"}}$.

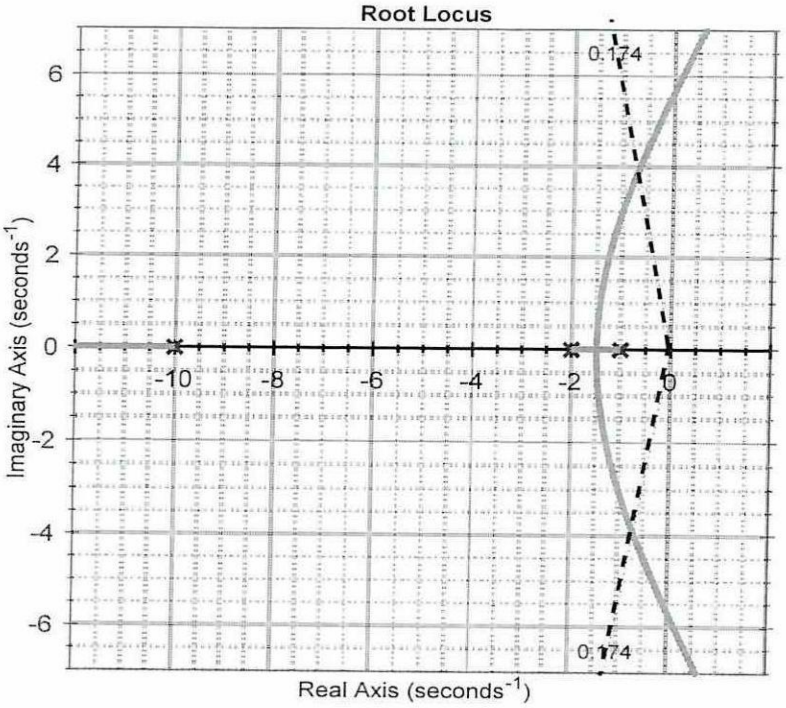

Figure Q3.2: Root locus

(3 marks)

(ii) With the value of K_1 found above in **Q3(b)(i)**, write the forward transfer function $C_p(s)G(s)$.

(2 marks)

(iii) Calculate the static error constant K_p for this forward transfer function.

(2 marks)

(iv) Examine the steady-state error for this feedback configuration for a step input.

(2 marks)

(v) To eliminate the steady-state error, a PI compensator $C_{PI}(s)$ is employed as shown in **Figure Q3.3**. Notice that the compensator is a pure integrator with a real zero component located at -0.1. The root locus for the compensated system is shown in **Figure Q3.4**. Calculate the value of K_2 that will give a similar transient response characteristic as in **Q3(b)(i)**. Confirm that K_2 is within 1%-5% of K_1.

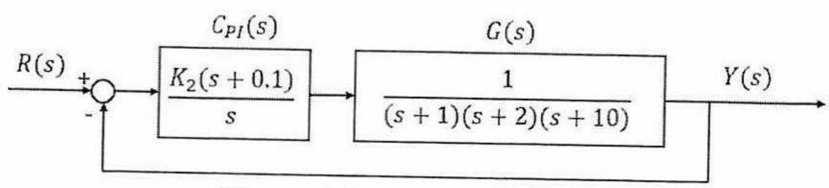

Figure Q3.3: PI compensator

(2 marks)

(vi) Shows that the steady-state error of the feedback system with PI compensator is zero.

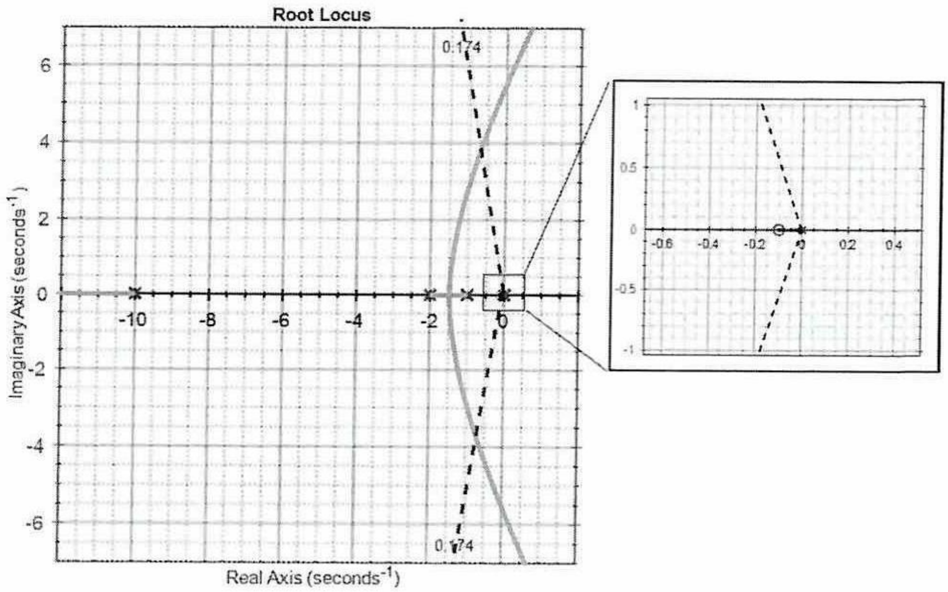

Figure Q3.4: Root locus

(3 marks)

Q4 Consider the feedback system as shown in **Figure Q4.1**.

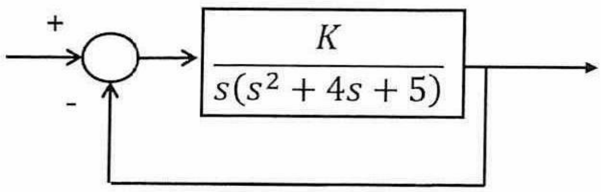

Figure Q4.1: Feedback system

(a) A root locus exists on the real axis between the origin and -infinity. Calculate the angles of asymptotes of the root-locus branches.

(3 marks)

(b) Examine the intersection of the asymptotes on the real axis.

(3 marks)

(c) Show that the closed loop characteristic equation is given by:

$$\frac{dK}{ds} = -(3s^2 + 8s + 5)$$

(4 marks)

(d) Calculate the breakaway and break-in points from $\frac{dK}{ds} = 0$.

(4 marks)

(e) Construct the root locus for this closed loop system and provide all the root locus information required.

(6 marks)

(f) Examine the range of K for the closed loop system to be underdamped.

(5 marks)

End of Questions

APPENDIX A

FORMULAE

Table A: Laplace transform table

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

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	$\mathscr{L}\left[\frac{d^n f}{dt^n}\right]=s^nF(s)-\sum_{k=1}^{n}s^{n-k}f^{k-1}(0^-)$
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: 2nd order prototype system equations

$\frac{C(s)}{R(s)}=\frac{\omega_n{}^2}{s^2+2\zeta\omega_n s+\omega_n{}^2}$	$T_r=\frac{\pi-\cos^{-1}\zeta}{\omega_n\sqrt{1-\zeta^2}}$
$\zeta=\frac{-ln\left(\frac{\%OS}{100}\right)}{\left(\sqrt{\pi^2+ln\left(\frac{\%OS}{100}\right)}\right)}$	$T_p=\frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$
$T_s=\frac{4}{\zeta\omega_n}$	$\mu_p=e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$