Program: B. Sc. Engg (IPE)
Semester: 6^{th} Semester

Date: 22 May, 2024
Time: 10:00 AM – 01:00 PM

ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)
ORGANISATION OF ISLAMIC COOPERATION (OIC)
DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

Semester Final Examination
Course Number: IPE 4607
Course Title: Control Engineering and Industrial Automation

Summer Semester: 2022-2023
Full Marks: 150
Time: 3 Hours

There are **6 (SIX)** questions. Answer **6 (SIX)** questions. The symbols have their usual meanings. Marks of each question and the corresponding CO and PO are written in brackets. A formula sheet is provided at the end of this question paper. Show all steps and calculations.

1. a) Figure 1 shows a closed loop transfer function relating input $R(s)$ to output $C(s)$. Determine and analyse the stability of the following closed-loop transfer function. Identify all pole locations in the complex plane. (15) (CO 2) (PO 2) (K4)

$R(s)$ → $$\frac{s^4+6s-5}{s^5+7s^4+6s^3+42s^2+8s+56}$$ → $C(s)$

Figure 1: A closed-loop transfer function

b) Consider the following Routh Hurwitz shows Table 1, analyse the stability by identifying the locations of the poles in the complex plane. Note that the s^5 row is initially a row of zeros. (10) (CO 2) (PO 2) (K4)

Table 1: A Routh Hurwitz table for a certain transfer function

s^7	1	2	-1	-2
s^6	1	2	-1	-2
s^5	3	4	-1	0
s^4	1	-1	-3	0
s^3	7	8	0	0
s^2	-15	-21	0	0
s^1	-9	0	0	0
s^0	-21	0	0	0

2. a) A unity feedback system has the following forward transfer function. Compute the steady-state errors for the following step inputs: (CO 2) (PO 2) (K4)

$$G(s)=\frac{1500}{s(s+50)}$$

i. $15u(t)$ (3)
ii. $15tu(t)$ (3)
iii. $15t^2u(t)$ (4)

b) Figure 2 shows a feedback control system. Solve for the value of gain, K that will yield a 0.025 error in steady-state for an input $150tu(t)$ for the following system. (15) (CO 2) (PO 2) (K4)

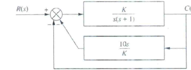

Figure 2: A feedback control system

3. a) A unity feedback system has the following forward transfer function, (CO 2) (PO 2) (K4)

$$G(s) = \frac{1}{25s^2 + 50s + 50}$$

Solve the:

i. Frequency of oscillation, ω_n (3)
ii. Damping ratio, ζ (2)
iii. Percentage overshoot, $\%OS$ (2)
iv. Settling time, T_s (2)
v. Peak time, T_p (2)
vi. Sketch the step response of this transfer function. (4)

b) Figure 3 shows a unity second-order feedback control system with a gain K and a constant β is shown below. Solve for the values of gain K and β that will result in a 30% overshoot and a settling time of 2.5 seconds to a step input. (10) (CO 2) (PO 2) (K4)

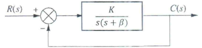

Figure 3: A unity second-order feedback control system

4. a) Find the equivalent transfer function, $T(s)$ for the system shown in Figure 4. Convert and simplify the block diagram to a signal-flow graph. (15) (CO 2) (PO 2) (K4)

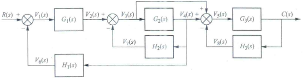

Figure 4: Block diagram for a transfer function

b) Find the transfer function $G(s) = \theta_L(s)/E_a(s)$ for the given system and torque-speed curve shown in Figure 5 below. (10) (CO 2) (PO 2) (K4)

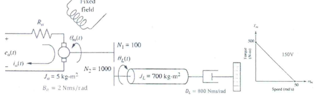

Figure 5: A DC motor and load

5. a) Consider the following schematic diagram of the industrial robotics system as in Figure 5. The system is to be applied in a manufacturing and control system process activity as a means of improving production efficiency and performance. Suggest the type of sensors FIVE (5) desirable features of sensors to be implemented in such applications. (15) (CO 3) (PO 2) (K4,P1,P3)

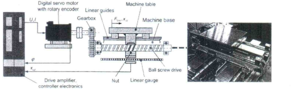

Figure 5: An industrial robotics system for manufacturing and control system engineering process

b) Figure 6 shows a pick-and-place robotics system. Discuss FIVE (5) desirable features of modern manufacturing and technologies approaches to be implemented in such applications. (10) (CO 3) (PO 2) (K4,P1,P3)

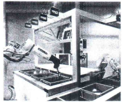

Figure 6: A pick-and-place robotics system

6. Figure 7 shows a block diagram with forward gain, K representing motion control of a CNC milling machine positioning table ball screw-driven system. Figure 8 then shows the current step response for this system. Design a suitable controller using the root locus technique that will improve the system transient performance in a way that halves the settling time while maintaining the percentage overshoot value. Compare the step response results of both the uncompensated and the compensated system. (25) (CO 4) (PO 3) (K4,P1,P2)

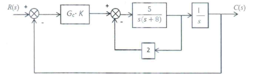

Figure 7: Block diagram of a CNC milling machine control system

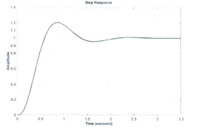

Figure 8: A step response of a CNC milling machine control system

FORMULA SHEET

$$\%OS = e^{-(\zeta\pi/\sqrt{1-\zeta^2})} \times 100 \qquad \zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}} \qquad s_{1,2} = -\sigma_d \pm j\omega_d$$

$$e_{step}(\infty) = \frac{1}{1 + \lim_{s\to0} G(s)} \qquad e_{ramp}(\infty) = \frac{1}{\lim_{s\to0} sG(s)} \qquad e_{parabola}(\infty) = \frac{1}{\lim_{s\to0} s^2 G(s)}$$

$$\omega_n = \sqrt{\omega_d^{\,2} + \sigma_d^{\,2}} \; ; \qquad \varsigma = \cos\theta; \Rightarrow \theta = \cos^{-1}\zeta \;@\; \theta = \tan^{-1}(\omega_d / \sigma_d)$$

$$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} = \frac{\pi}{\omega_d} \; ; \qquad T_s = \frac{4}{\varsigma\omega_n} = \frac{4}{\sigma_d}$$

$$\frac{\theta_m(s)}{E_a(s)} = \frac{\frac{K_t}{R_a}\cdot\frac{1}{J_m}}{s\left[s + \frac{1}{J_m}\left(B_m + \frac{K_t}{R_a}\cdot K_b\right)\right]} \qquad \frac{K_t}{R_a} = \frac{T_{stall}}{e_a} \qquad K_b = \frac{e_a}{\omega_{no-load}}$$