Ref. No.: Ex/IEE/PC/B/T/224/2025

B.I.E.E. 2nd Yr. 2nd Semester Examination, 2025

SUBJECT: Linear Control Systems

Time: Three hours | Full Marks 100

All Modules are Compulsory. Stepwise marking will be done.

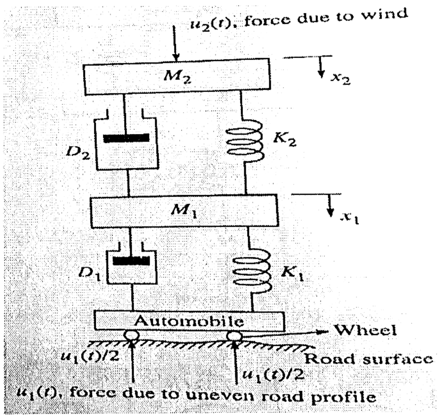
<table>
<tr><th>Q.No.</th><th></th><th>Marks</th></tr>
<tr><td></td><td><u>Module I (CO1)</u></td><td></td></tr>
<tr><td>1.</td><td>a) A speed controller for a steel rolling mill comprises of an armature controlled DC servomotor with resistance R_a, negligible L_a, motor torque constant K_T and back emf constant K_b. The motor cum load mechanical constants of the motor-mill system are J and B. The rolling mill also has a constant torque T_w applied at its input. Draw the system block diagram with input as the armature applied voltage e_a and output as motor velocity ω. Find the system TF M_o in terms of gain K and time constant T and also find the sensitivity S_K^{Mo}.
OR
A position control system driven by an armature controlled DC servomotor has the following components: i) Potentiometer with gain K_e, ii) Error amplifier with gain K_1, iii) Motor with non-zero R_a and negligible L_a, Torque constant K_T, non-zero J_m, negligible f_m (including back emf effect), iv) Gear and Load with turns ratio n, and non-zero J_L and f_L. Draw system block diagram. Determine open loop gain K, T.F. $T(s)=\theta_o(s)/\theta_i(s)$ and S_K^T.</td><td>2+2+2</td></tr>
<tr><td></td><td>

Fig. 1
b) (i) Draw the free body diagram of the automobile shown in Fig1. (ii) Derive the mechanical system ODEs.
iii) State the F-v equivalent electrical system elements.
OR
Derive the system equations for a hydraulic actuator from first principles. Determine order of system, G(s), K, T, ξ and ω_n.</td><td>2+2+2

6</td></tr>
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<tr><td>2.</td><td>Derive the transfer function for the system in Fig.2a or Fig. 2b using block diagram reduction technique. Draw the equivalent signal flow graph and use Mason's Gain Formula to find the transfer function.

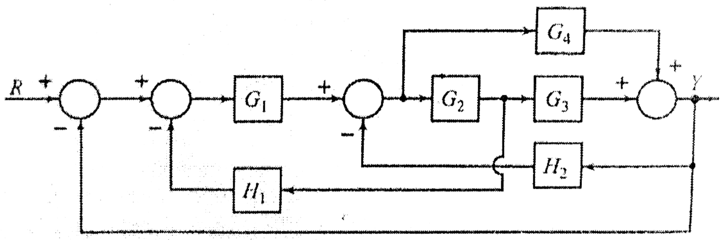

Fig.2a

OR

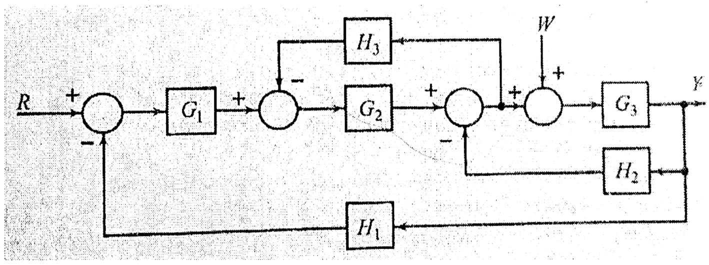

Fig. 2b</td><td>3+2+3</td></tr>
<tr><td>3.</td><td>Module 2 (CO2)
Assuming the unit step response for a 2nd order underdamped system, derive the following from first principles: a) the initial value of the transient response, b) the envelopes with their start values, c) t_p, d) M_p, and e) t_s. Draw the response illustrating all items listed in a)-e).
OR
a) Consider that a unity feedback closed loop feedback control system has the TF $G(s) = 5(s+1)/\{s^2(s+12)(s+5)\}$. Identify type of system and compute steady state errors for unit step, ramp and parabolic inputs.
b) For $GH(s)=K/s(s+2)^2$, determine the value of K that satisfies $|GH(j2)|=1$. What is the frequency of oscillation and damping of the system for this K? How does the system behavior change if K is increased?</td><td>6+4

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4</td></tr>
<tr><td>4.</td><td>Consider a unity angular position feedback system with controller K_A and $G(s)=4500/s(s+361.2)$. Determine close loop TF, ζ, ω_n, M_p, e_{ss} (in rad) for unit ramp input for $K_A = 14.5$. Replacing K_A by $(184.1+0.324s)$, determine close loop TF, ζ, ω_n, M_p, K_v, e_{ss} (in rad) for unit ramp input.
OR
Consider a unity feedback angular position servomechanism with forward gains $G_1=6.88 \times 10^4$ and $G_2(s) = 1/s\ (200s + 5\times 10^3)$. Determine close loop TF, ζ, ω_n, ω_d, M_p, t_p, t_s, e_{ss} for step input of 1 rad and e_{ss} for constant angular velocity of 1 rpm. Also determine e_{ss} if a steady torque of 1200 Nm is applied as disturbance input to $G_2(s)$.</td><td>10

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Q.No.		Marks
	Module 3 (CO3)	
5.	a) A unity feedback system with $G(s)=(s+3)/(s^2+2s+2)$ is preceded by a PI controller $K_c(s+5)/s$. Determine the range of K_c for which the closed loop poles lie to the left of (-2). OR For a feedback system with $G(s)=K/s(s+1)$ and $H(s)=(1-Ts)/(1+Ts)$, determine the combination of K and T and plot the region for the system to be stable.	5
	b) Draw the root-locus plot for a unity feedback system containing a velocity feedback loop composed of $G(s)=K/s(s+2)$ and velocity feedback 0.2s. Determine ξ, s and K for least damping. OR Draw the root-locus plot for a system with characteristic equation $F(s)=K(s+5)/(s+1)(s+2)$. Determine ξ, s and K for least damping.	10
6.	For the system having open loop TF $GH(s) = 200/(s+2)(s+4)(s+5)$ OR $GH(s)= 5000/s(s+5)(s+10)$, a) Identify Bode components and state magnitude and phase characteristics of the components, identify critical frequencies. b) Draw the Bode magnitude and phase plots using asymptotes, c) Provide table for calculated and graphically obtained gain and phase values at critical frequencies. d) Identify gain margin, phase margin in the plots and compare graphical gain and phase margins with theoretical values. e) Comment on system stability.	4+8+4+3+1
7	a) Draw Nyquist contour, polar plot and Nyquist plot of $GH(s)=1/s(s+a)(s+b)$ for (i) a=3, b=5 **OR** (ii) a=1, b=0.5. What is the real intercept at $\omega = 0$ and ω for real axis crossing? Infer stability. Determine phase and gain crossover frequencies, gain and phase margins and show on the plot.	7
	b) Illustrate how to determine M_p for a 2nd order system $G(s)=1/s(s+1)$ using the M circles? Determine M_p analytically. OR Derive from first principles the relation for N circles in terms of the real and imaginary parts of $G(j\omega)$ and illustrate them.	3

Q.No.		Marks
8.	**Module 4 (CO4)** a) For a unity feedback system with $G(s)=K/s(s+2)$, design a lead compensator that provides $\xi=0.5$ and $\omega_n=4$ rad/s and ensures $K_v=10$. For this, a) determine primary system gain and lead compensation needed, b) sketch the root locus plot c) provide reasoning and determine the pole and zero locations, d) determine the lead compensator TF and any additional gain corrections needed e) determine overall compensated system TF.	9
	OR	
	Design a lead compensator for a type 1 unity feedback system with $G(s)=K/s(s+1)$ to ensure $K_v=10$ and PM at least 45°. For this, a) determine system gain needed, b) sketch the Bode plot and determine ω_g and PM, c) determine amount of phase compensation needed, d) determine corresponding α and new ω_g, and τ and e) lead compensator TF and overall compensated system TF.	9
	b) (i) Draw the active lead=lag compensator circuit with 2 op-amps. Determine its TF and establish conditions on the parameters to obtain lead and lag compensation. (ii) Determine a balanced design of the resistors and capacitors for the compensator designed in 8a) using the compensator circuit in 8b(i).	3+3