Ref. No.: Ex/PG/EE/T/112B/2018

M. E. ELECTRICAL ENGINEERING 1ST YEAR 1ST SEM. EXAMINATION-2018

Subject: CONTROL SYSTEM ENGINEERING (CS) Time: Three Hours Full Marks: 100

Answer ***Any Five*** questions (5×20)

Question No.			Marks
Q1	(a)	Starting from the Principle of Argument derive the Nyquist Stability Criteria.	7
	(b)	Consider the closed-loop system whose open-loop transfer function is $$G(s) = \frac{Ke^{-2s}}{s}$$ Find the maximum value of K for which the system is stable.	7
	(c)	Consider the system $$\dot{x} = Ax$$ where A is given by $$A = \begin{bmatrix} 0 & 1 & 0 \\ -b_3 & 0 & 1 \\ 0 & -b_2 & -b_1 \end{bmatrix}$$ Determine the conditions that must be satisfied for the system to be stable.	6
Q2	(a)	Define (i) Resonance Peak and (ii) Resonant Frequency of a closed-loop control system. Hence find their relationships with time domain specifications.	3+3
	(b)	Plot the root loci for a unity-feedback control system with the following feed-forward transfer function: $$G(s) = \frac{K(1-s)}{(s+2)(s+4)}$$	8
	(c)	Consider the unity-feedback system with feed-forward transfer function $$G(s) = \frac{K}{s(s+1)}$$ The constant-gain locus for the system for a given value of K is defined by the following equation: $$\left|\frac{K}{s(s+1)}\right| = 1$$ Show that the constant-gain loci for $0 \le K \le \infty$ will be given by $$[\sigma(\sigma+1)+\omega^2]^2 + \omega^2 = K^2$$ where, $s = \sigma + j\omega$.	6

Q3 (a) Consider the mechanical system shown in Figure Q3-(a). 6

Obtain the transfer function of the system taking the displacement x_i as the input and x_o as the output.

Comment whether it is a mechanical lead network or lag network?

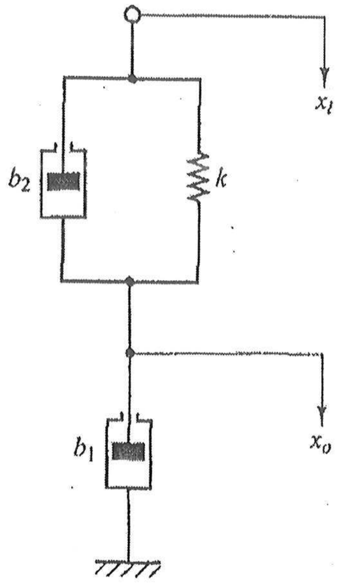

Figure Q3-(a)

(b) Consider the system shown in Figure Q3-(b), which involves velocity feedback. Determine the values of the amplifier gain K and the velocity feedback gain K_h so that the following specifications are satisfied: 14

(i) Damping ratio of the closed-loop poles is 0.5.

(ii) Settling time ≤ 2 sec.

(iii) Static velocity error constant $K_v \geq 50$ sec $^{-1}$.

(iv) $0 < K_h < 1$.

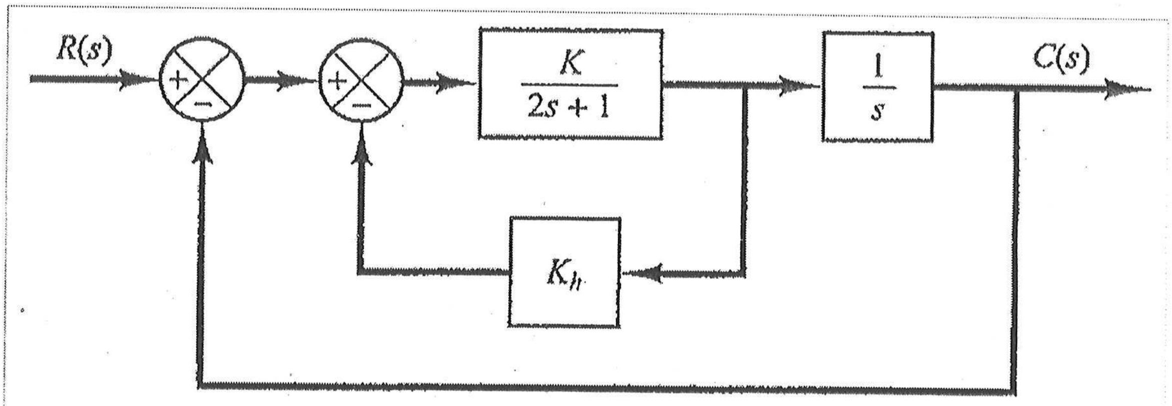

Figure Q3-(b)

Q4 (a) Referring to the system shown in Figure Q4-(a) design a compensator such that the static velocity error constant, K_v, is 20 $\sec^{-1}$ without appreciably changing the original location of a pair of the complex-conjugate closed-loop poles at $s = -2 \pm j2\sqrt{3}$. 14

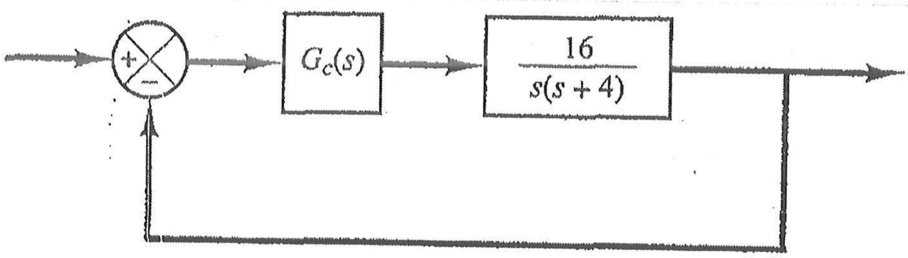

Figure Q4-(a)

(b) Consider a unity-feedback system with the closed-loop transfer function 6

$$\frac{C(s)}{R(s)} = \frac{Ks + b}{s^2 + as + b}$$

Show that the steady-state error in the ramp response is given by

$$e_{ss} = \frac{Ks + b}{K_v} = \frac{a - K}{b}$$

Q5 (a) Show that if the system matrix is of form, 6

$$\begin{bmatrix} 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 0 & 1 \\ -a_0 & -a_1 & -a_2 & \cdots & -a_{n-2} & -a_{n-1} \end{bmatrix}$$

then the modal matrix becomes Vandermonde matrix given as

$$\begin{bmatrix} 1 & 1 & 1 & \cdots & 1 & 1 \\ \lambda_1 & \lambda_2 & \lambda_3 & \cdots & \lambda_{n-1} & \lambda_n \\ \lambda_1^2 & \lambda_2^2 & \lambda_3^2 & \ddots & \lambda_{n-1}^2 & \lambda_n^2 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ \lambda_1^{n-1} & \lambda_2^{n-1} & \lambda_3^{n-1} & \cdots & \lambda_{n-1}^{n-1} & \lambda_n^{n-1} \end{bmatrix}$$

(b) Consider the following system: 8

$$\dddot{y} + 6\ddot{y} + 11\dot{y} + 6y = 6u$$

Obtain a state-space model of the system in a Diagonal Canonical Form. Comment on the Controllability and Observability of the system.

(c) Given the system equation 6

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 2 & 1 & 0 \\ 0 & 2 & 1 \\ 0 & 0 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

find the solution in terms of the initial conditions $x_1(0)$, $x_2(0)$ and $x_3(0)$.

Q6 (a) Define and explain with example (i) Stabilizability, and (ii) Detectability of a system. 3+3

(b) Given a system in state equation form 4

$$\dot{x} = Ax + Bu,$$

$$\text{with, } A = \begin{bmatrix} 0 & 1 \\ 0 & 2 \end{bmatrix} \text{ and } B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

Show that the system cannot be stabilized by state-feedback control

$$u(t) = -Kx.$$

(c) Consider the system given by 10

$$\dot{x} = Ax + Bu, \quad y = Cx$$

where

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -6 & -11 & -6 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad C = [4\ 5\ 1]$$

Show that there would be some non-zero initial states which cannot be determined from the measurement of $y(t)$.

Q7 (a) Show that a system given by 8

$$\dot{x} = Ax + Bu, \text{ and } y = Cx,$$

will be controllable *if and only if* there is no left (or row) eigenvector of A that is orthogonal to B.

(b) A regulator system has a plant 12

$$G(s) = \frac{10}{(s+1)(s+2)(s+3)}$$

By using the state-feedback control

$$u = -Kx$$

it is desired to place the closed-loop poles at $s = -2 \pm j2\sqrt{3}$ and $s = -10$. Determine the necessary state-feedback gain matrix K.

Q8 (a) State and prove the "Separation Principle" in respect of full-order observer design. 10

(b) Consider a system defined by the state equation 10

$$\dot{x} = Ax, \quad y = Cx, \text{ with } A = \begin{bmatrix} -1 & 1 \\ 1 & -2 \end{bmatrix} \text{ and } C = [1 \quad 0]$$

Design a full-order state observer.

Assume the observer poles at $s = -5$ and $s = -5$.