**ELIZADE UNIVERSITY, ILARA-MOKIN, ONDO STATE**

**FACULTY OF ENGINEERING**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING**

**FIRST SEMESTER EXAMINATION, 2020/2021 ACADEMIC SESSION**

**COURSE TITLE:** Control Engineering

**COURSE CODE: EEE 515**

**EXAMINATION DATE:** March 23, 2021

**COURSE LECTURER:** Prof Dr. M.J.E. Salami

**HOD's SIGNATURE**

**TIME ALLOWED:** 3 Hours

**INSTRUCTIONS:**

1. ATTEMPT ANY FIVE **QUESTIONS**
2. SEVERE PENALTIES APPLY FOR MISCONDUCT, CHEATING, POSSESSION OF UNAUTHORIZED MATERIALS DURING EXAM.
3. YOU ARE <u>NOT</u> ALLOWED TO BORROW CALCULATORS AND ANY OTHER WRITING MATERIALS DURING THE EXAMINATION.

## QUESTION 1 [12 Marks]

a) Consider the control system shown in Fig. Q1a, use the Mason gain formula to determine the transfer function, $\frac{Y(s)}{R(s)}$. (6 marks)

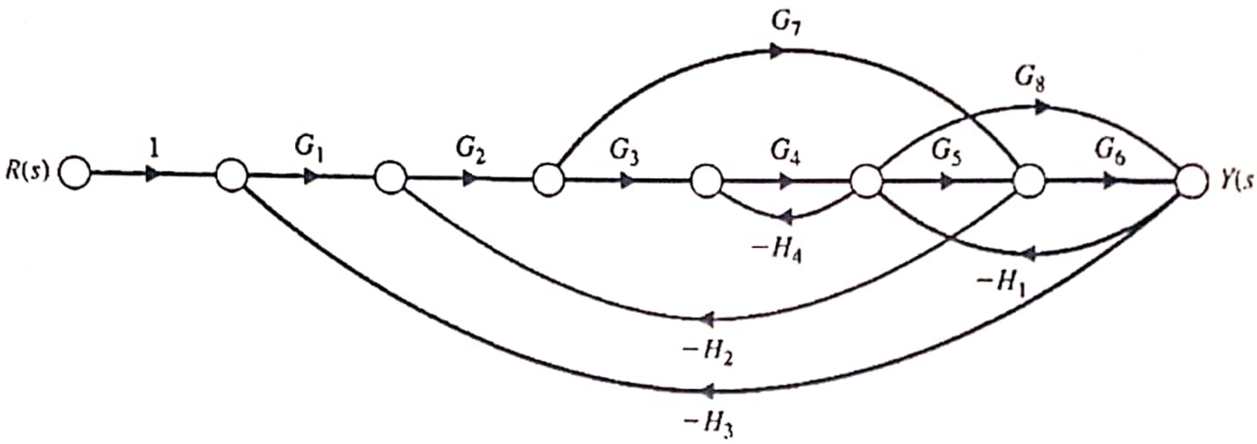



Fig. Q1a

b) The two-mass system shown in Fig. Q1b has a constant rolling friction, denoted as $b$. Determine a state variable matrix representation of the system when the output variable is $y_2(t)$, that is, $y(t) = y_2(t)$. (6 marks)

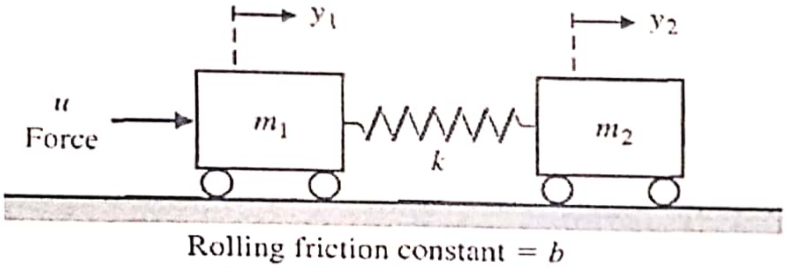



Fig. Q1b

## Question 2 [12 Marks]

a) The space telescope control system is shown in Fig. Q2a. Assume that $\tau_1 = 1\ s, \tau_2 = 0$ (as an approximation).

(i) Determine the gain $K = K_1K_2$ required so that the response to a step command is as rapid as reasonable with an overshoot of less than 5%. (3 marks)

(ii) Determine the stead-state error of the system for a step and ramp input. (2 marks)

(iii) Determine the value of $K$ for an ITAE optimal systems for a (3 marks)

1. Step input
2. Ramp input

b) The transfer function of a closed-loop control system is given as

$$T(s) = \frac{108(s+3)}{(s+9)(s^2+8s+36)}$$

(i) Determine the steady-state error for a unit step input. (1 mark).

(ii) Assume that the complex poles dominate, determine the overshoot and settling time to within 2% of the final value. (3 marks)

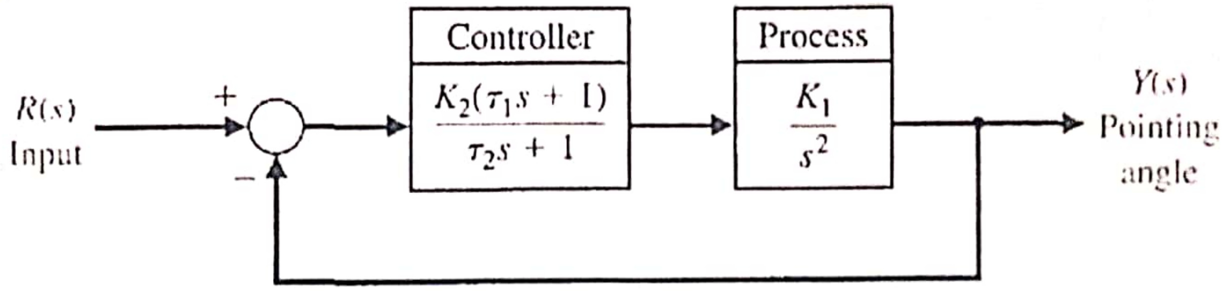



**Fig. Q2a**

**Question 3 [12 Marks]**

a) The attitude control of a space shuttle rocket is shown in Fig. Q3a. Determine the range of gain $K$ and parameter $m$ so that the system is stable and ploit the region of stabllity. (4 marks)

b) The feedback control system shown in Fig. Q3b is marginally stable. A proportional-derivative controller of the form

$$G_c(s) = K_P + sK_D$$

is used as compensator for the system.

i) Determine whether it is possible to find the values of $K_P$ and $K_D$ such that the closed-loop system is stable. (4 marks)

ii) Compute the values of the controller parameters such that the steady-state tracking error for a unit step input is less than or equal to 0.1 and the damping of the closed-loop system, $\xi = 0.5\sqrt{2}$. (4 marks)

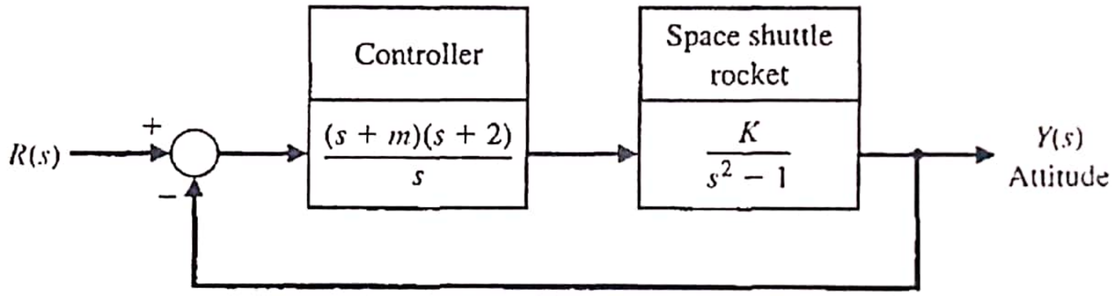



Fig. Q3a

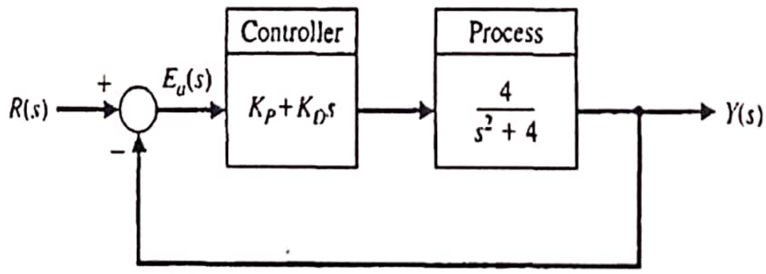



Fig. Q3b

**Question 4 [12 Marks]**

a) Use appropriate mathematical expressions to justify the statement "the locus of the roots of the characteristic equation $1 + KP(s) = 0$ begins at the poles of $P(s)$ and terminates at the zeros of $P(s)$ as $K$ increases from zero infinity". (2 marks)

b) Consider a unity feedback control system with a loop transfer function

$$L(s) = G_c(s)G(s) = \frac{K(s+10)(s+2)}{s^3}$$

(i) Plot the root locus and determine the range of $K$ for which the system is stable. (3 marks)

(ii) Predict the steady=state error of the system for a ramp input. (2 marks)

b) A unity feedback control system has a loop transfer function

$$L(s) = G_c(s)G(s) = \frac{K}{(s+2)(s^2+2s+2)}$$

(i) Determine the angle of departure of the root at the complex poles. (1 mark)

(ii) Sketch the root locus. (2 marks)

(iii) Determine the gain $K$ when the roots are on the $j\omega - axis$. (2 marks)

**Question 5 [12 Marks]**

a) The asymptotic log-magnitude plot of data acquired during system identification studies is shown in Fig. Q5a.

(i) Sketch the corresponding asymptotic phase shift plot. (2 marks)

(ii) Determine the transfer function of the system. (3 marks)

b) Obtain the Bode diagrams (magnitude and phase plots) of the transfer function (4 marks)

$$G(s) = \frac{50(s+2)}{s(s^2+4s+100)}.$$

c) Consider the feedback control system shown in Fig. Q6c with the process transfer function $G(s) = \frac{1}{s(s+1)}$. The controller is the proportional type, that is, $G_c(s) = K_p$.

(i) Determine a value of $K_p$ so that the phase margin (PM) is approximately 45°. (2 marks)

(ii) Using the PM obtained, predict the percentage overshoot of the closed-loop system to a unit step Input (1 mark)

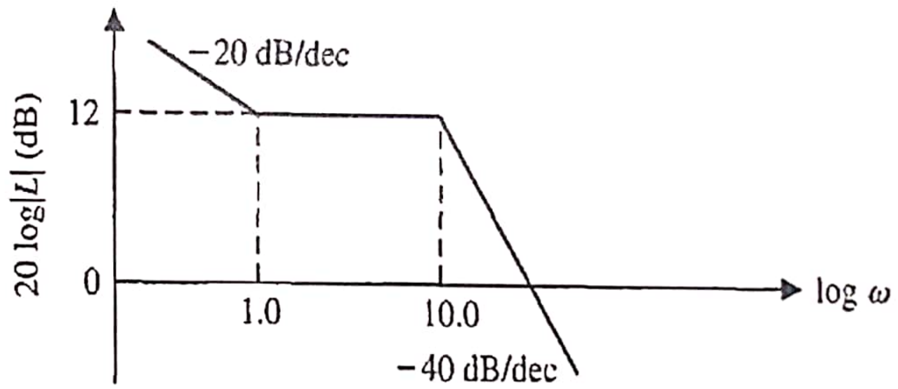



**Fig. Q5a**

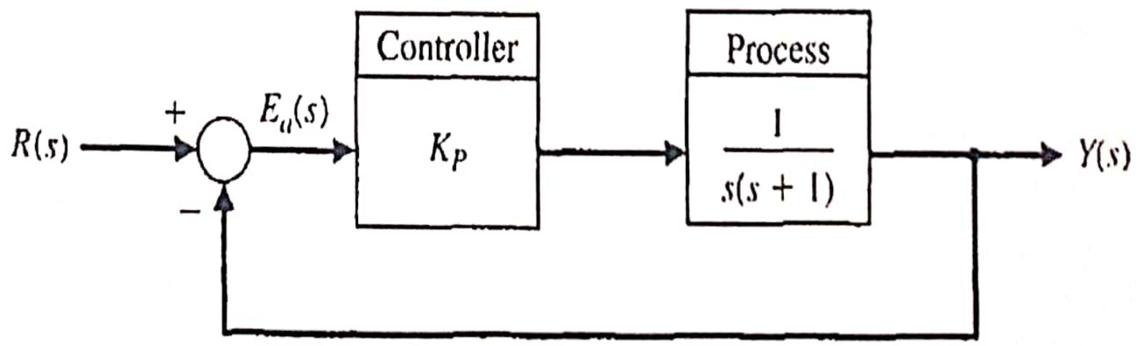



**Fig. Q5c**

**Question 6 [12 Marks]**

a) A negative feedback control system has a transfer function

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

It is required to select a compensator of the form

$$\frac{s+a}{s}$$

in order to achieve zero steady-state error for a step input. Select $K$ and $a$ so that the overshoot to a step input is approximately 5% and the settling time (with a 2% criterion) is approximately one second.

(4 marks)

b) The design of a lunar excursion module (LEM) is an interesting control problem. The attitude control system for the lunar vehicle is shown in Fig. Q6b. The torque as a first approximation will be considered to be proportional to the signal $V(s)$ so that $T(s) = K_2 V(s)$. The loop gain may be selected by the designer in order to provide a suitable damping. A damping ratio of $\xi = 0.6$ with a settling time (with 2% criterion) of less than 2.5 seconds is required. Design a phase lead compensator to satisfy the above specifications using

(i) Bode diagrams method. (4 marks)

(ii) Root locus method. (4 marks)

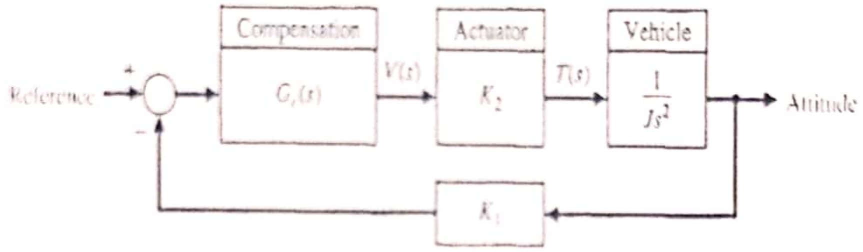



Fig. Q6b

**Question 7 [12 Marks]**

a) (i) Obtain a state variable representation for the control system shown in Fig. Q7a. (2 marks)

(ii) Determine if the system is both controllable and observable. (4 marks)

b) Hydraulic power actuators were used to derive the dinosaurs of the movie "Jurassic Park". The motion of the large monsters used high-power actuators requiring 1200 *watts*. One specific limb motion has its dynamics

$$\dot{\mathbf{x}} = \begin{bmatrix} -4 & 0 \\ 1 & -1 \end{bmatrix}\mathbf{x} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}u$$

$$y = [0 \quad 1]\mathbf{x} + [0]u.$$

It is required to place the closed-loop poles at $s = -1 \pm 3j$. Determine the required state variable feedback using Ackerman's formula. Assume that the complete state vector is available for feedback.

(6 marks)

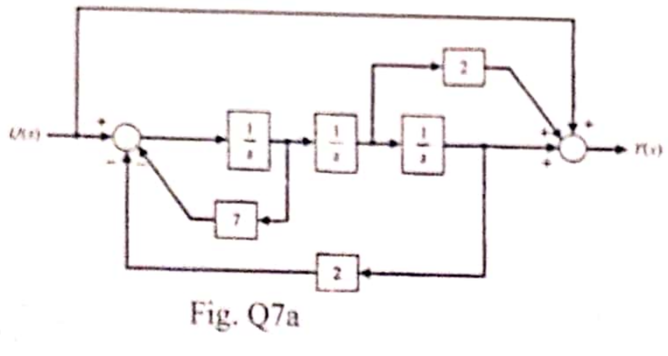
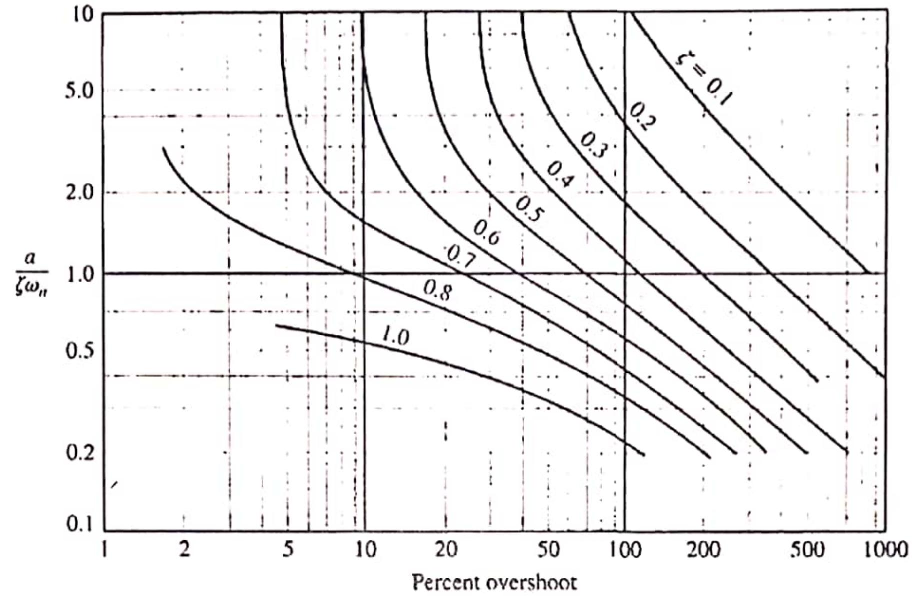



Fig. Q7a

**Table 5.4 The Response of a Second-Order System with a Zero and $\zeta = 0.45$**

| $a/\zeta\omega_n$ | Percent Overshoot | Settling Time | Peak Time |
|---|---|---|---|
| 5 | 23.1 | 8.0 | 3.0 |
| 2 | 39.7 | 7.6 | 2.2 |
| 1 | 89.9 | 10.1 | 1.8 |
| 0.5 | 210.0 | 10.3 | 1.5 |

*Note:* Time is normalized as $\omega_n t$, and settling time is based on a 2% criterion.




(a)

**Table 5.6 The Optimum Coefficients of *T*(s) Based on the ITAE Criterion for a Step Input**

$$s + \omega_n$$
$$s^2 + 1.4\omega_n s + \omega_n^2$$
$$s^3 + 1.75\omega_n s^2 + 2.15\omega_n^2 s + \omega_n^3$$
$$s^4 + 2.1\omega_n s^3 + 3.4\omega_n^2 s^2 + 2.7\omega_n^3 s + \omega_n^4$$
$$s^5 + 2.8\omega_n s^4 + 5.0\omega_n^2 s^3 + 5.5\omega_n^3 s^2 + 3.4\omega_n^4 s + \omega_n^5$$
$$s^6 + 3.25\omega_n s^5 + 6.60\omega_n^2 s^4 + 8.60\omega_n^3 s^3 + 7.45\omega_n^4 s^2 + 3.95\omega_n^5 s + \omega_n^6$$

**Table 5.7 The Optimum Coefficients of *T*(s) Based on the ITAE Criterion for a Ramp Input**

$$s^2 + 3.2\omega_n s + \omega_n^2$$
$$s^3 + 1.75\omega_n s^2 + 3.25\omega_n^2 s + \omega_n^3$$
$$s^4 + 2.41\omega_n s^3 + 4.93\omega_n^2 s^2 + 5.14\omega_n^3 s + \omega_n^4$$
$$s^5 + 2.19\omega_n s^4 + 6.50\omega_n^2 s^3 + 6.30\omega_n^3 s^2 + 5.24\omega_n^4 s + \omega_n^5$$