MACHAKOS UNIVERSITY

University Examinations for 2021/2022

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

FIFTH YEAR SECOND SEMESTER EXAMINATION FOR

BACHELOR OF SCIENCE (MECHANICAL ENGINEERING)

EMM 514: CONTROL ENGINEERING II

DATE: 15/12/2021 **TIME: 11.00-1.00 PM**

INSTRUCTIONS

- This paper consists of Five Questions.
- **Question 1** is **Compulsory.** Attempt **Any Other Two** Questions.
- Answers to any particular question must be together.

QUESTION ONE (COMPULSORY) (30MARKS)

a) Draw the Flow Chart of the Design Algorithm of a Control System (4 marks)

b) In order to design and implement a control system, the knowledge of *Five* essential and generic elements is required. Discuss such elements. (5 marks)

c) For the unity feedback systems shown, $K_p = 20, J = 50$ and $T_d = 1$. Determine the unit step response (4 marks)

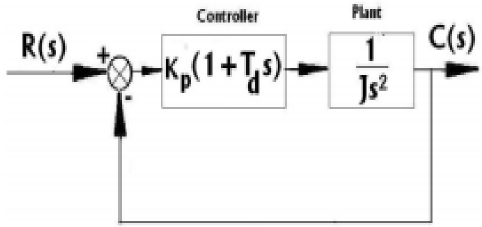

Figure Q 1 b)

d) Given the state equations(3marks)

$$\dot{x_1}(t) = x_2(t)$$
$$\dot{x_2}(t) = x_3(t)$$
$$\dot{x_3}(t) = -6x_1(t) - 11x_2(t) - 6x_3(t) + 6u(t)$$
$$y(t) = x_1(t)$$

Determine the Control Canonical Form (CCF)

e) Discuss whether the following system is completely observable or controllable (4 marks)

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} -2 & 0 \\ 3 & -5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u$$
$$y = [1 - 1\,]\, x(t)$$

f) For a system with the differential equation

$$\frac{d^3y}{dx^3} + 7\frac{d^2y}{dx^2} + 19\frac{dy}{dx} + 13y = 13\frac{du}{dt} + 26u$$

i. Determine the state space representation in CCF (2 marks)

ii. Draw the direct form realization of a block diagram (2 marks)

g) A single-input single-output plant has the transfer function

$$G(s) = \frac{4}{S(S+1)(S+4)}$$

i. Determine a state model for the system in Control Canonical Form (2 marks)

ii. Design a state feedback that will place the Closed-loop pole at $-2 \pm j\,2$ and -5 (2 marks)

iii. Obtain the closed-loop transfer function for the controlled system (2 marks)

QUESTION TWO (20MARKS)

a) For a Closed Loop System with open loop gain G(s), feedback path gain H(s), derive the closed loop gain of the system. Begin with a well labelled block diagram (3 marks)

b) A liquid level process control system is as shown in Figure Q 2a) while the Block Diagram for the same is as shown in Figure Q 2b).

i. Compute the closed loop transfer function for the system (4 marks)

ii. Derive the expressions of the natural frequency and damping ratio of the system (3 marks)

c) The system parameters are for the system described in 2b) above are $A = 2m^2, R_f = 15s/m^2$, $H_1 = 1V/m$, $K_v = 0.1m^3/sV$, $K_1 = 1$ (controller gain) and the undamped natural frequency is 0.1 rad/s.

i. Determine the Integral Action Time and Damping Ratio of the System (3 marks)

ii. Assuming zero initial conditions, find an expression for the time response of the system when there is a step change of $h_d(t)$ from 0 to 4m. Sketch such a response. (7 marks)

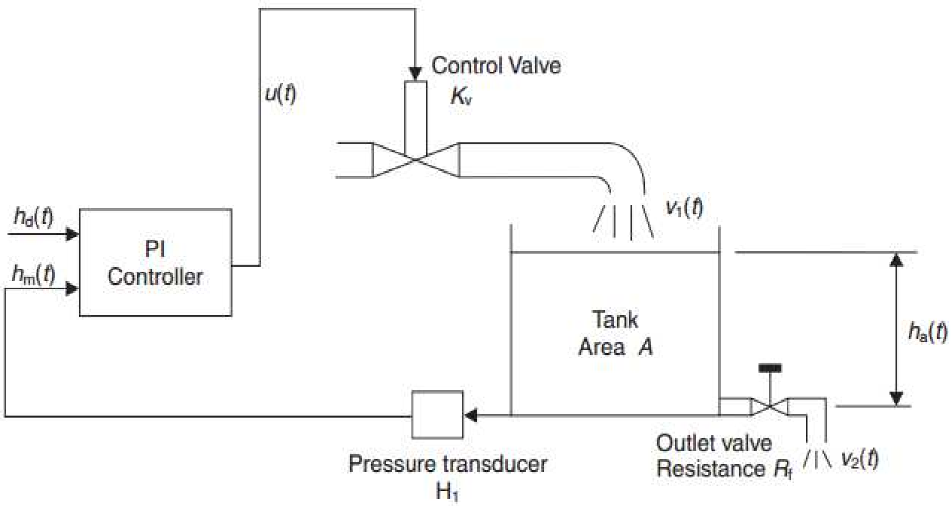

Figure Q 2a)

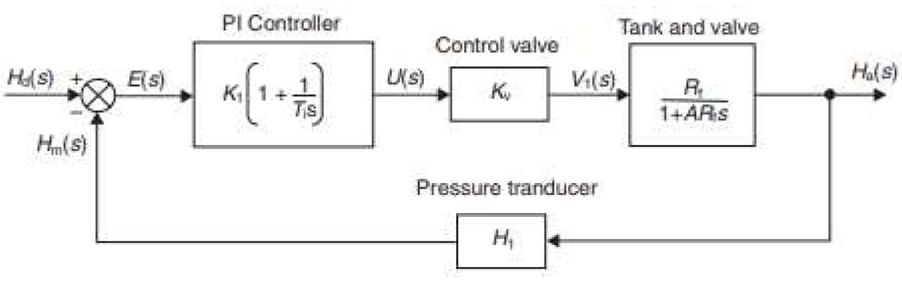

Figure Q 2b)

QUESTION THREE (20 MARKS)

a) Write the Mathematical Model of the PID Controller, in time and frequency domain. Explain all the symbols used (2 marks)

b) Derive the Transfer Function of a general closed loop PID controlled system with input R(s), output C(s), plant gain G(s) and feedback control gain H(s) (5 marks)

c) Consider the control system shown in Figure Q 3c).

i. Apply a Ziegler–Nichols tuning rule for the determination of the values of parameters $K_p, T_i \text{ and } T_d$. Hence state the controller gain (9 marks)

ii. Unit Step Response of the System (4 marks)

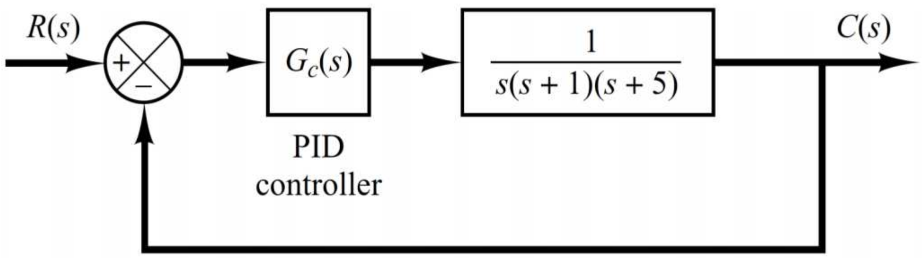

Figure Q 3c)

QUESTION FOUR (20 MARKS)

a) Define the following Terms as used in State Variable Modelling

i. State

ii. State Space

iii. State Variables

iv. State Equations (4 marks)

Figure Q 4 shows mass-spring-damper system. The states can be defined as

$$x_1 = y$$

$$x_2 = \frac{dy}{dt} = \dot{x_1}$$

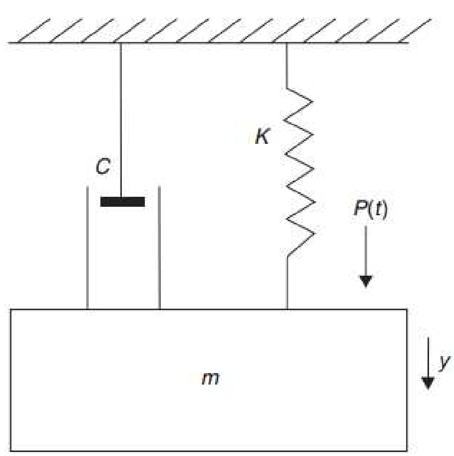

Figure Q 4

b) Derive the State *Variable Equations for the System* (4 marks)

c) Given that $m = 1kg, C = 3Ns/m, K = 2N/m$ and $u(t) = 0$. Determine the following

i. Characteristic Equation (2 marks)

ii. Un-damped natural frequency and damping ratio (2 marks)

iii. Transition matrix $\phi(t)$ (5 marks)

iv. Transient response of the state variables to a unit step input (3 marks)

QUESTION FIVE (20MARKS)

a) Using the Various Matrices in the State Equations explain the following

i. Observability

ii. Observer Canonical Form (OCF) (4 marks)

b) A Control System is defined by the transfer function

$$G(s) = \frac{Y(s)}{R(s)} = \frac{18S^2 + 5S + 3}{S^3 + 7S^2 + 4S + 13}$$

Determine the Observer Canonical Form (OCF) (3marks)

c) A Control System is defined by the State Equations

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

$$y = [1\ 0\ ]\, x(t)$$

Design a Full-Order Observer that has undamped natural frequency of 10rad/s and a damping ratio of 0.5 using the following methods

i. Direct Comparison (6 marks)

ii. Observer Canonical Form (OCF) (4 marks)

iii. Ackerman's Formula (3 marks)