MACHAKOS UNIVERSITY

SCHOOL OF ENGINEERING AND TECHNOLOGY

UNIVERSITY EXAMINATIONS – 2024

FOURTH YEAR SECOND SEMESTER EXAMINATION FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

EMM 514: CONTROL ENGINEERING II

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 1 (30marks)

a) The state representation for a control system is defined by the relation

$$\dot{x(t)} = Ax(t) + Bu(t)$$

$$y(t) = Cx(t) + Du(t)$$

The state $x(t)$ can be expressed as

$$x(t) = P\,V(t)$$

Where V(t) is the transformed state vector and P is the transformation. Show that the Similarity Tram formation can be given by (5marks)

$$\dot{V(t)} = A_V V(t) + B_V u(t)$$

$$y(t) = C_V V(t) + D_V u(t)$$

b) State and explain the Three Cases of the ST in a) above (6marks)

c) Define Observability and Controllability the respective test with respect to b) above (4marks)

d) The control system for a Manufacturing Plant is represented by

$$\dot{x(t)} = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 1 & 3 \\ 1 & 1 & 1 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix} u(t)$$

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

For the System, obtain the following:

i) Control Canonical Form (CCF) (6marks)

ii) Observer Canonical Form (OCF) (6marks)

e) Comment on the Observability and Controllability of the System in d) above (3marks)

Question 2 (20marks)

Consider the process PID control system shown in Figure Q 2 for a general process plant.

a) Derive the expression of the complete response C(s) when $R_1(s)$ and $R_2(s)$ are acting simultaneously (7marks)

b) Apply a Ziegler–Nichols tuning rule for the determination of the values of parameters $K_1, T_i\ and\ T_d$ when $T_1 = 10$ seconds and $T_2 = 20$ seconds (6marks)

c) Hence find the response of the system when $r_1(t)$ is a unit step and $r_2(t)$ is zero. Determine the ratio of successive peaks (7marks)

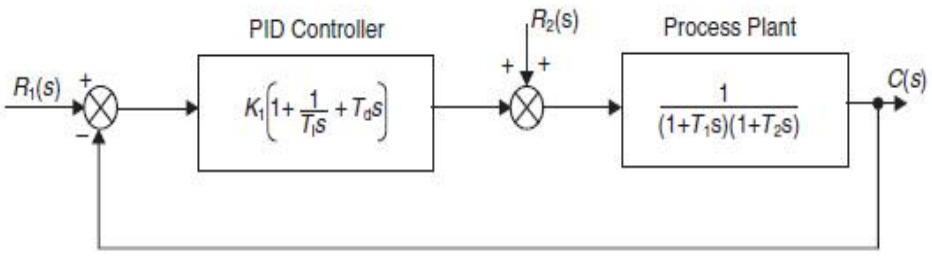


Figure Q 2

Question 3 (20marks)

a) Discuss the need for Computer Aided Design of Control Systems in the Industry (2marks)

b) In order to design and implement a control system, the knowledge of *Five* essential and generic elements is required. Discuss such elements (2.5marks)

c) By Providing a Flow Chart Diagram in each case, design the Control Algorithm for the following cases:

   i) General Control System (4marks)

   ii) PI Control (3marks)

   iii) PID Control (3marks)

   iv) PD Control (2.5marks)

d) Discuss the recent trends in *Control System* Design (3marks)

Question 4 (20marks)

a) Beginning from a well labelled Circuit Diagram, derive the closed loop gain of a PI Controller. Hence or otherwise, derive the expressions of the Natural Frequency and Damping Ratio of an Industrial PI Controller (7marks)

b) A liquid level process control system is as shown in Figure Q 3a) while the Block Diagram for the same is as shown in Figure Q 3b)

   i) Compute the closed loop transfer function for the system (2marks)

   ii) Derive the expressions of the natural frequency and damping ratio of the system (2marks)

c) The system parameters are for the system described in 3b) 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 (3marks)

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 (6marks)

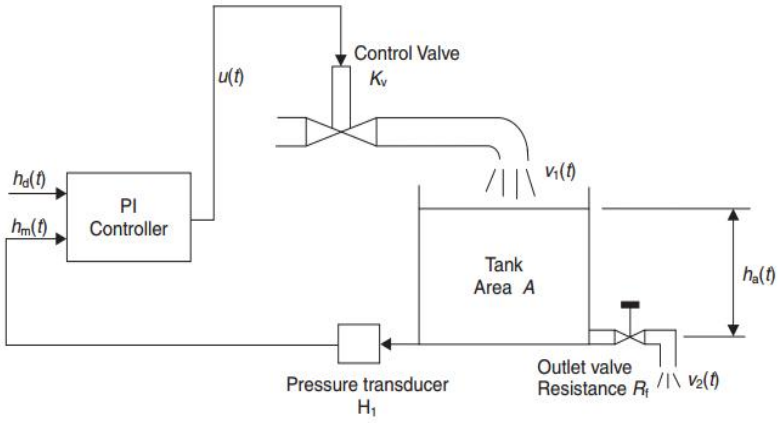


Figure Q 4a)

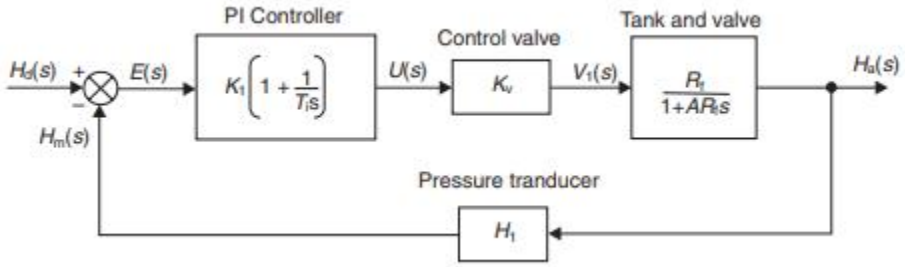


Figure Q 4b)

Question 5 (20marks)

Figure Q 5 shows mass-spring-damper system.

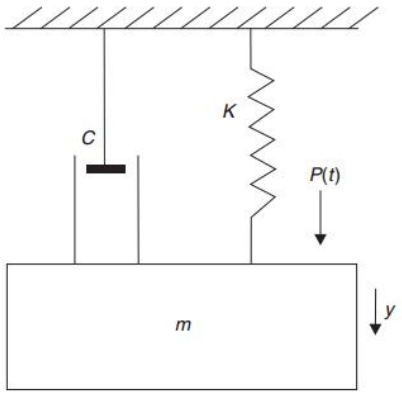


Figure Q 5

The states can be defined as

$$x_1 = y$$

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

Consequently, the State Representation can be given by

$$\dot{x(t)} = Ax(t) + Bu(t)$$

$$y(t) = Cx(t) + Du(t)$$

Where

$$A = \begin{bmatrix} 0 & 1 \\ -k/m & -c/m \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1/m \end{bmatrix}, C = [1 \quad 0] \text{ and } D = 0$$

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

a) Characteristic Equation, Un-damped natural frequency and damping ratio (4marks)

b) Transition matrixes, $\phi(s)$ and $\phi(t)$(4marks)

c) Transient response for the system due to a unit step input using Inverse Laplace Transform. Assume zero initial conditions (4marks)

d) *Discrete-time transition and control matrices* using a sampling time $T = 0.1s$ (8marks)