



MACHAKOS UNIVERSITY

University Examinations for 2019/2020 Academic Year

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

FIFTH YEAR SECOND SEMESTER EXAMINATION FOR

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING

EMM 514: CONTROL ENGINEERING II

DATE: 26/10/2020

TIME: 2.00-4.00 PM

INSTRUCTIONS

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

QUESTION ONE (30 MARKS)

SECTION A: STATE SPACE REPRESENTATION

Figure Q 1 shows mass-spring-damper system. The states can be defined as

$$x_1 = y$$

$$x_2 = \frac{dy}{dt} = \dot{x}_1$$

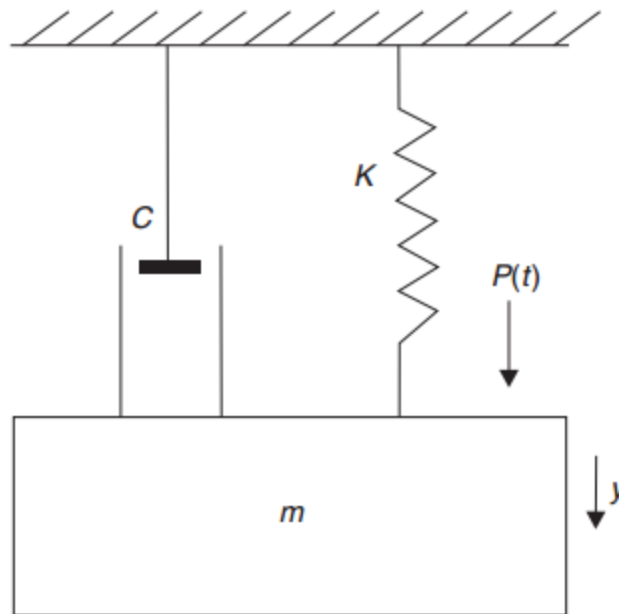
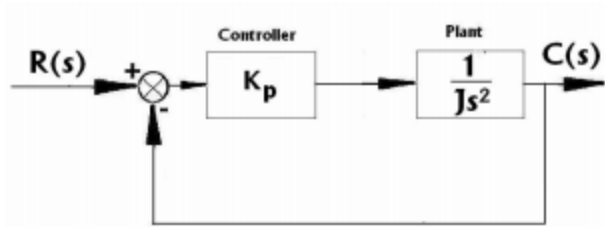


Figure Q 1

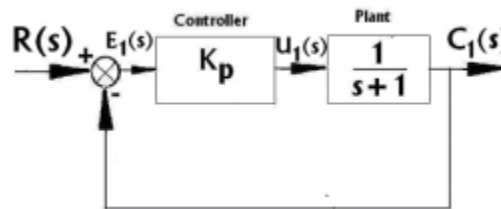
- a) Derive the state space representation of the system (4 marks)
- b) Given that $m = 1\text{ kg}$, $C = 3\text{ Ns/m}$, $K = 2\text{ N/m}$ and $u(t) = 0$. Evaluate the following
 - i. Characteristic equation, its roots, un-damped natural frequency and damping ratio (5 marks)
 - ii. Transition matrices $\phi(s)$ and $\phi(t)$ (4 marks)
 - iii. Transient response of the state variable from the set of initial conditions
 $y(0) = 1$ and $\dot{y}(0) = 0$ (2 marks)
 - iv. Transient response of the state variables to a unit step input (3 marks)

SECTION B: CONTROLLER ANALYSIS AND DESIGN

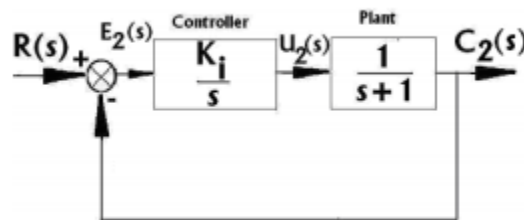
- c) Using a well labelled diagram, explain the structure details of an *Industrial Control System* (4 marks)
- d) For the unity feedback systems shown, $K_p = 20$, $J = 50$, $T_d = 1$ and $K_p = 1$. Determine the unit step response and the steady state error in each case (8 marks)



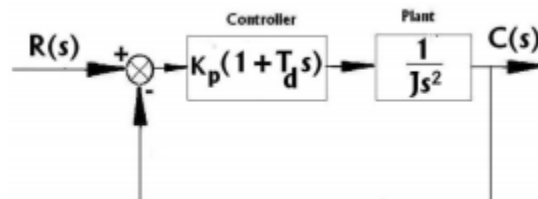
i) Figure Q 1 e i)



ii) Figure Q 1 e ii)



iii) Figure Q 1 e iii)



iv) Figure Q 1 e iv)

QUESTION TWO (20 MARKS)

A liquid level process control system is as shown in Figure Q 2.

- Draw a block diagram for the liquid-level process control system (3 marks)
- Compute the closed loop transfer function for the system, hence derive the expressions of the natural frequency and damping ratio of the system (6 marks)

The system parameters are $A = 2\text{m}^2$, $R_f = 15\text{s/m}^2$, $H_1 = 1\text{V/m}$, $K_v = 0.1\text{m}^3/\text{sV}$ and $K_1 = 1$ (controller gain).

- c) Determine the integral action time and the damping ratio when the un-damped natural frequency is 0.1 rad/s (3 marks)
- d) 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 (8 marks)

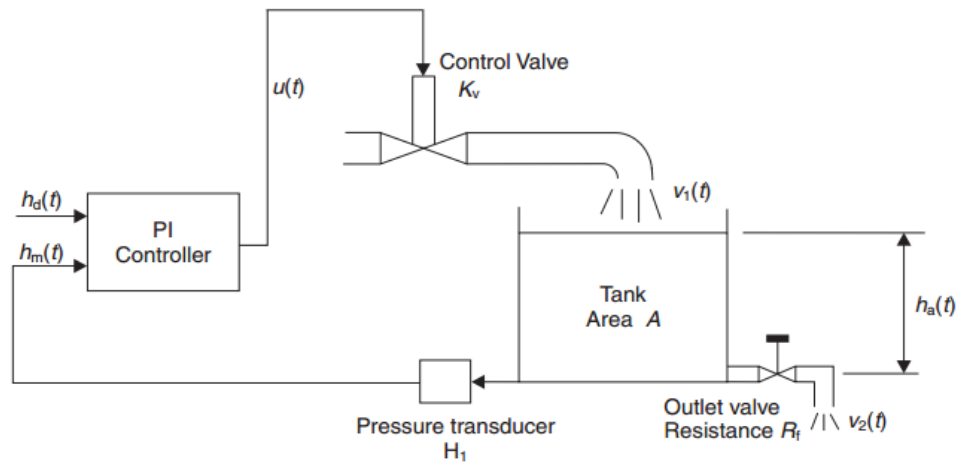


Figure Q 2

QUESTION THREE (20 MARKS)

A Room Temperature control system is as shown in Figure Q 3 a). The block diagram for such a system is as shown in Figure Q 3b). The system variable are as follows:

$$\theta_d(t) = \text{Desired Temperature } (^{\circ}\text{C})$$

$$\theta_m(t) = \text{Measured Temperature } (^{\circ}\text{C})$$

$$\theta_0(t) = \text{Actual Temperature } (^{\circ}\text{C})$$

$$\theta_s(t) = \text{Temperature of the surroundings } (^{\circ}\text{C})$$

$$u(t) = \text{Control signal } (V)$$

$$\dot{v}(t) = \text{Gas flowrate } (\text{m}^3/\text{s})$$

$$Q_i(t) = \text{Heat flow into room } (\text{J per s or W})$$

$$Q_o(t) = \text{Heat flow through walls } (\text{J per s or W})$$

The block diagram with the system equations is as shown in Figure Q 3c).

- a) Derive the expression of the actual temperature in terms of the desired and surrounding temperatures and forward path gain (10 marks)
- b) The system parameters are defined as follows: $K_2 K_3 = 5 \text{ W/V}$, $R_T = 0.1 \text{ Ks/J}$,

$C_T = 0.1J/K$, $H_1 = 1V/K$ and $T_1 = 4seconds$. Determine the following:

- PID controller settings using the Ziegler-Nicholas Process Reaction method with
 $R = 0.0396$ and $D = 1.55$ (3 marks)
- Forward path gain (1 mark)
- Actual temperature $\theta(s)$ for a unit step input and constant surrounding temperature (6 marks)

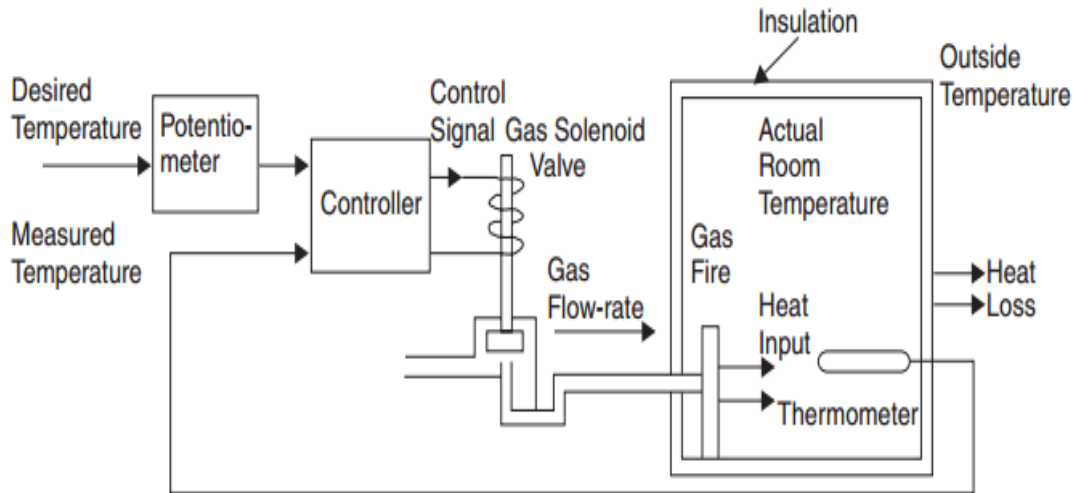


Figure Q 3a)

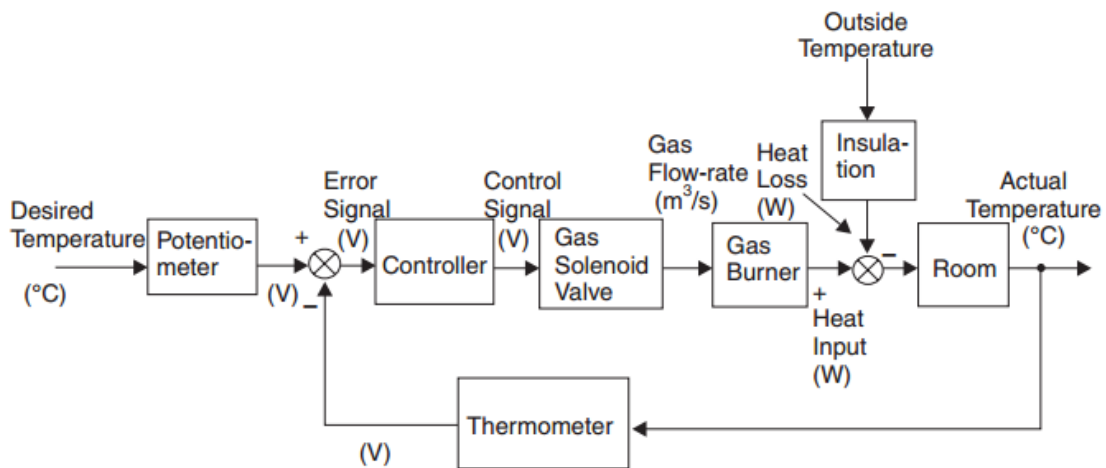


Figure Q 3b)

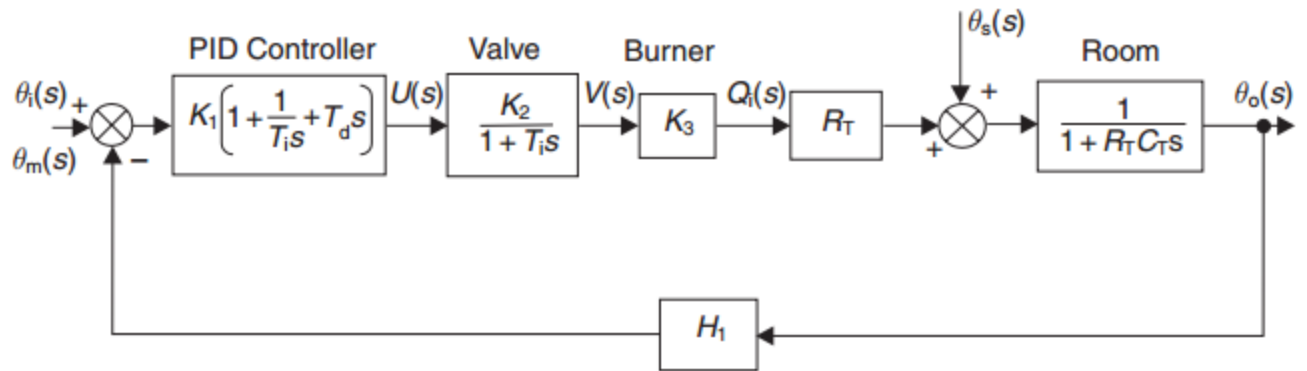


Figure Q 3c)

QUESTION FOUR (20 MARKS)

- a) 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 (4 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 (4 marks)

- b) Given the state equations

$$\dot{x}_1(t) = -x_2(t) + x_3(t) + 4u(t)$$

$$\dot{x}_2(t) = -3x_1(t) + 2u(t)$$

$$\dot{x}_3(t) = -5x_1(t) + x_2(t) + u(t)$$

$$y(t) = x_1(t)$$

Determine the Observer Canonical Form (3 marks)

- c) Given the state equations

$$\dot{x}_1(t) = x_2(t)$$

$$\dot{x}_2(t) = x_3(t)$$

$$\dot{x}_3(t) = -6x_1(t) - 11x_2(t) - 6x_3(t) + 6u(t)$$

$$y(t) = x_1(t)$$

Determine the Control Canonical Form (3 marks)

QUESTION FIVE (20 MARKS)

a) A control system is defined by the state representation. Determine the following

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

i. State transition matrix $\phi(t)$ (4 marks)

ii. $x(t)$ for a non-homogenous system (5 marks)

b) For a Control Systems defined by the transfer functions , determine the following

$$G(s) = \frac{Y(s)}{R(s)} = \frac{8}{s^3 + 7s^2 + 14s + 8}$$

i. Matrix differential equations for the system (3 marks)

ii. State transition matrix $\phi(t)$ using the (1,1) element of $\phi(s)$ (4 marks)

c) 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 (2 marks)

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