MACHAKOS UNIVERSITY

University Examinations for 2019/2020Academic 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

$$x_1 = y$$

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

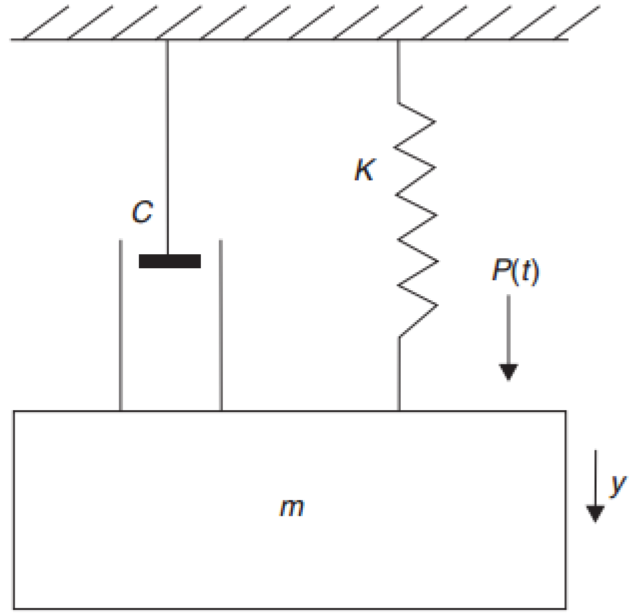


Figure Q 1

a) Derive the state space representation of the system (4 marks)

b) Given that $m = 1kg, C = 3Ns/m, K = 2N/m$ 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)

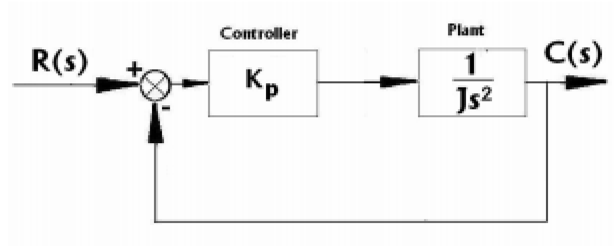
iii. Transient response of the state variable from the set of initial conditions $y(0) = 1 \; and \; \dot{y}(0) = 0$ (2 marks)

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

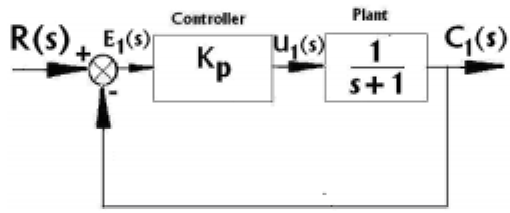
SECTION B: CONTROLLER ANALYSIS AND DESIGN

c) Using a well labelled diagram, explain the structure details of an *Industrial Control System* (4 marks)

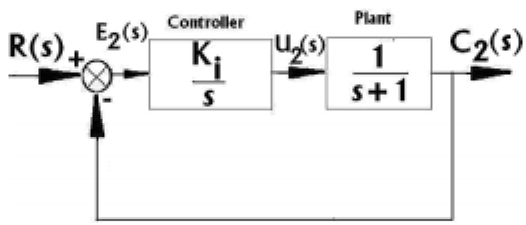
d) For the unity feedback systems shown, $K_p = 20, J = 50, T_d = 1 \; and \; K_p = 1$. Determine the unit step response and the steady state error in each case (8 marks)



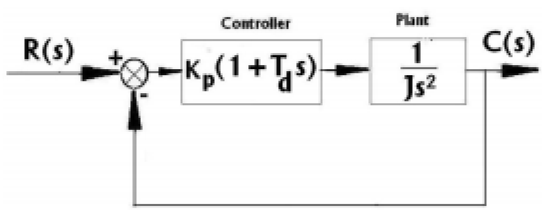
i) Figure Q 1 e i)



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.

a) Draw a block diagram for the liquid-level process control system (3 marks)

b) 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 $A = 2m^2, R_f = 15s/m^2$, $H_1 = 1V/m$, $K_v = 0.1m^3/sV$ and $K_1 = 1$ (controller gain).

c) Determine the integral action time and the damping ratio when the un-damped natural frequency is 0.1rad/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)

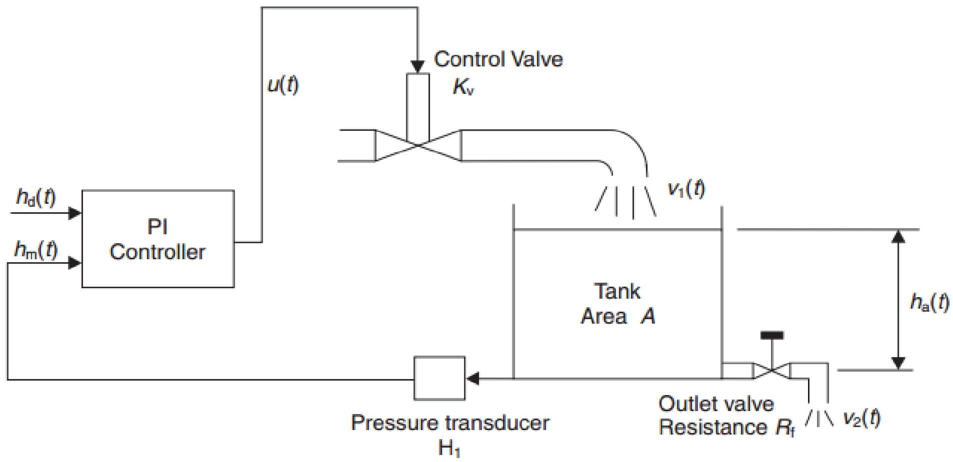


Figure Q 2

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:

$$\theta_d(t) = Desired\ Temprature\ (°C)$$

$$\theta_m(t) = Measured\ \ Temprature\ (V)$$

$$\theta_0(t) = Actual\ \ Temprature\ (°C\ )$$

$$\theta_s(t) = \ Temprature\ of\ the\ sorroundins\ (°C)$$

$$u(t) = Control\ signal\ (v)$$

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

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

$$Q_0(t) = Heat\ flow\ through\ walls\ \ (J\ per\ s\ or\ W)$$

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: $K_2K_3 = 5W/V$, $R_T = 0.1Ks/J$,

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

i. PID controller settings using the Ziegler-Nicholas Process Reaction method with $R = 0.0396\ and\ D = 1.55$ (3 marks)

ii. Forward path gain (1 mark)

iii. Actual temperature $\theta(s)$ for a unit step input and constant surrounding temperature (6 marks)

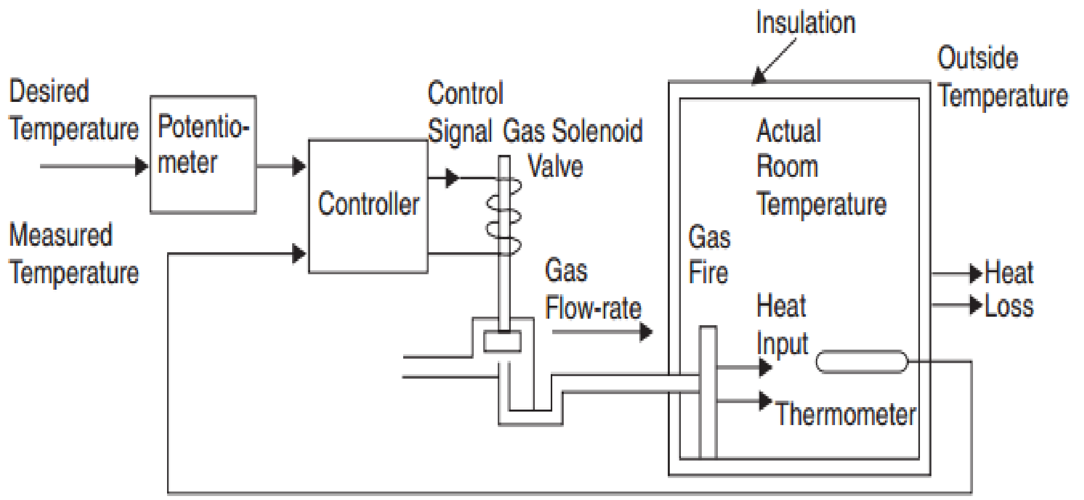


Figure Q 3a)

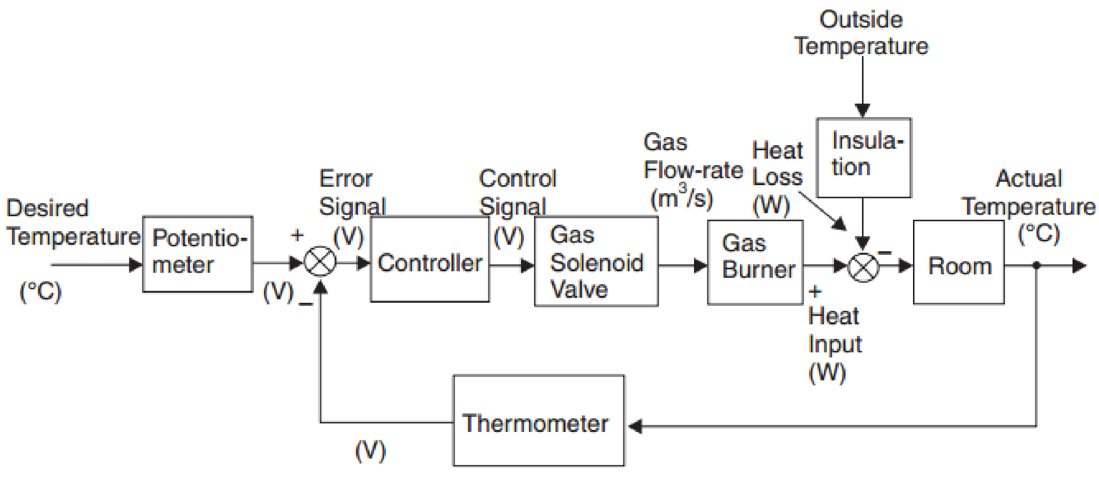


Figure Q 3b)

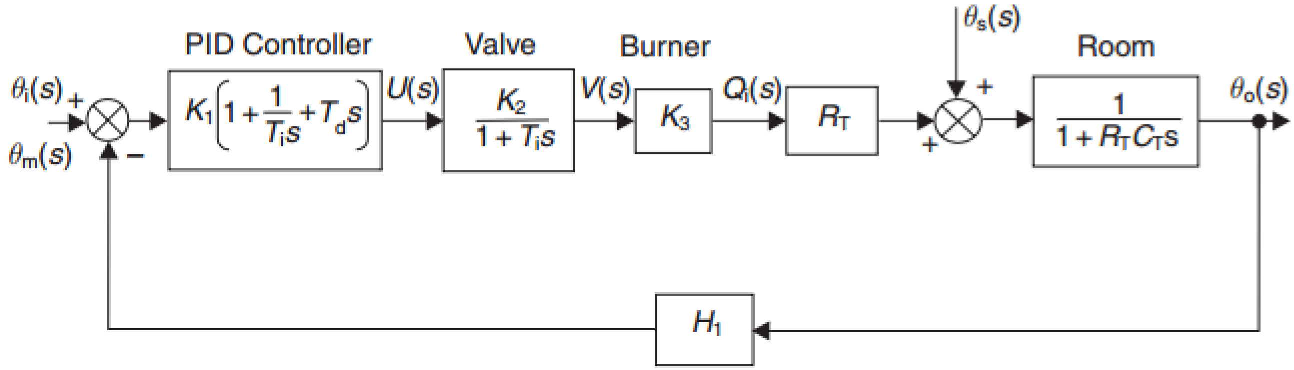


Figure Q 3c)

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)