TECHNICAL UNIVERSITY OF MOMBASA

School of Engineering and Technology

Department of Electrical and Electronic Engineering

UNIVERSITY EXAMINATION FOR:

Bachelor of Science in Electrical and Electronic Engineering

EEE 4517: CONTROL ENGINEERING IV

END OF SEMESTER EXAMINATION

SERIES: AUGUST 2024 EXAM

TIME: 2 HOURS

DATE: Pick DateSelect MonthPick Year

Instructions to Candidates

You should have the following for this examination

-*Answer Booklet, examination pass and student ID*

This paper consists of five Questions; Attempt Question ONE and any other TWO Questions.

Do not write on the question paper.

Question ONE

(a) Figure Q1 (a) illustrates process control to regulate the temperature of liquid in a tank. Identify the controlled variable, the manipulated variable and any two disturbances for this process. State the function of 'x' represented in the diagram.

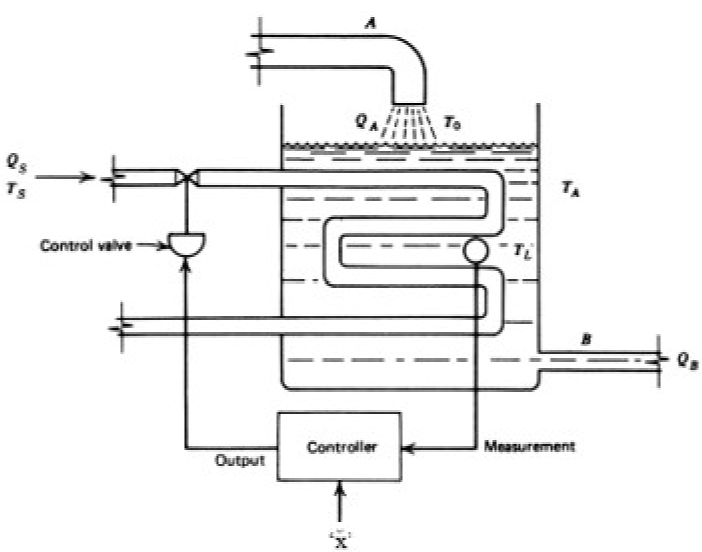

Figure Q 1 (a) (5 marks)

(b) Show how the flow control system of Figure Q 1 (b) can be modified to use the following:

(i) Supervisory control

(ii) Direct digital control (DDC)

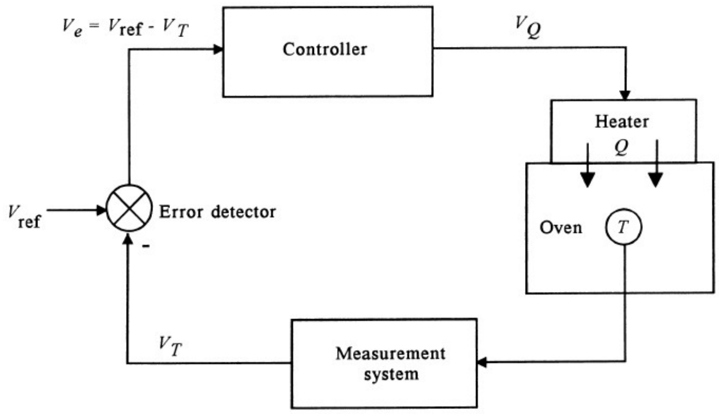

Figure Q 5 (b) (6 marks)

(c) Distinguish between linear and nonlinear systems (2 marks)

(d) Explain the following nonlinear phenomena

i) Finite escape time.
ii) Multiple isolated equilibria.
iii) Limit circles.
iv) Bifurcation

(4 marks)

(e) A first order system is described by $\dot{x} = -4x + x^3$. Determine the singular points and hence sketch the phase trajectory (4 marks)

(f) Briefly, explain the sampling theorem (2 marks)

(g) Compute the z-transform of unit-step function $u[n]=\begin{Bmatrix} 1 & \text{when } n \geq 0 \\ 0 & \text{when } n < 0 \end{Bmatrix}$ (3 marks)

(h) Define the initial and final value of the system's impulse when

$$Y(z)=\frac{2z^2}{(z-1)(z-\alpha)(z-\beta)}, |\alpha|, |\beta| > 1$$

(4 marks)

Question TWO

(a) Linearize the nonlinear equation $z = xy$ in the region $5 \leq x \leq 7; 10 \leq y \leq 12$ using Taylor series (7 marks)

(b) Briefly explain what is meant by phase plane analysis (2 marks)

(c) Consider a second-order nonlinear system given by:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} x_2 \\ -x_2 - 2x_1 + x_1^2 \end{bmatrix}$$

i) Obtain the singular points
ii) Find the Linearized system matrix A for the singular points and the Eigen values

(9 marks)

(d) State any TWO advantages of phase plane analysis (2 marks)

Question THREE

(a) Give any two reasons why derivative control action is never used alone (2 marks)

(b) Briefly explain the Transition response method of digital PID controller tuning (8 marks)

(c) Explain the merits of describing function technique for the analysis of nonlinear systems (3 marks)

(d) The characteristics of a hardening spring are given by:

$$f(x) = x + \frac{x^3}{2}$$

Given the input $x=A\sin(\omega t)$ obtain the describing function of the spring (7 marks)

Question FOUR

(a) Figure Q4 (a) shows a closed loop temperature control of a room. The temperature θ(s) of the room depends on the heat energy input Φ(s) and the transfer function relating them which is:

$$\frac{\theta(s)}{\Phi(s)}=\frac{8}{s^2+8s+800}$$

A PID controller is used with unity gain position feedback. The heater transfer function is 5. The proportional controller gain is set to 2.

i) Calculate the value of derivative time control required to give a closed loop damping ratio of unity if there is no integral action.

ii) Calculate the limiting value of integral time that may be used together with the derivative time already found before instability occurs.

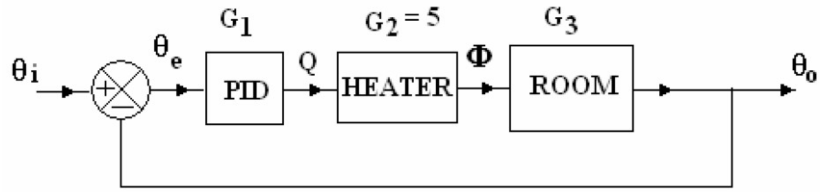

Figure Q 4 (a) (14 marks)

(b) Implement digital PID controller algorithm using the position and the velocity versions. (6 marks)

Question FIVE.

(a) Derive the difference equations of the systems with transfer functions:

i) $G(z)=\dfrac{z^4+3z^3+2z^2+z+1}{z^4+4z^3+5z^2+3z+2}$ and

ii) $H(z)=\dfrac{z}{5z^2-1.7z+0.72}$ (6 marks)

(b) For the system of figure Q 5 (b) with $G(s)=\dfrac{1}{s(s+1)}$:

i) Derive the transfer function of the digital controller $D(z)$ when the desired transfer function of the closed system is

$$G_{CL}(z)=\frac{z+1}{z^2-1.14+z0.403}$$

ii) Derive and design the discrete-time response $y(kT)$ of the closed system when the input is a unit step signal. Let $T=0.1s$ (14 marks)

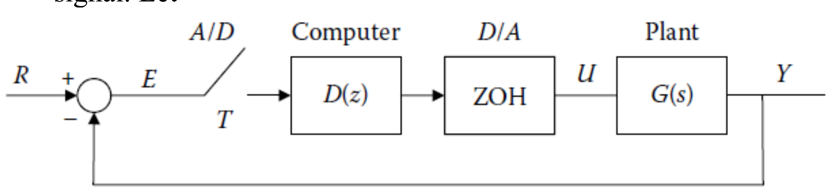

Figure Q 5 (b)

Table of Laplace and Z-transforms

	$X(s)$	$x(t)$	$x(kT)$ or $x(k)$	$X(z)$
1.	–	–	Kronecker delta $\delta_0(k)$ 1 $\quad k = 0$ 0 $\quad k \neq 0$	1
2.	–	–	$\delta_0(n-k)$ 1 $\quad n = k$ 0 $\quad n \neq k$	z^{-k}
3.	$\frac{1}{s}$	$1(t)$	$1(k)$	$\frac{1}{1-z^{-1}}$
4.	$\frac{1}{s+a}$	e^{-at}	e^{-akT}	$\frac{1}{1-e^{-aT}z^{-1}}$
5.	$\frac{1}{s^2}$	t	kT	$\frac{Tz^{-1}}{\left(1-z^{-1}\right)^2}$
6.	$\frac{2}{s^3}$	t^2	$(kT)^2$	$\frac{T^2z^{-1}\left(1+z^{-1}\right)}{\left(1-z^{-1}\right)^3}$
7.	$\frac{6}{s^4}$	t^3	$(kT)^3$	$\frac{T^3z^{-1}\left(1+4z^{-1}+z^{-2}\right)}{\left(1-z^{-1}\right)^4}$
8.	$\frac{a}{s(s+a)}$	$1-e^{-at}$	$1-e^{-akT}$	$\frac{\left(1-e^{-aT}\right)z^{-1}}{\left(1-z^{-1}\right)\left(1-e^{-aT}z^{-1}\right)}$
9.	$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$e^{-akT}-e^{-bkT}$	$\frac{\left(e^{-aT}-e^{-bT}\right)z^{-1}}{\left(1-e^{-aT}z^{-1}\right)\left(1-e^{-bT}z^{-1}\right)}$
10.	$\frac{1}{(s+a)^2}$	te^{-at}	kTe^{-akT}	$\frac{Te^{-aT}z^{-1}}{\left(1-e^{-aT}z^{-1}\right)^2}$
11.	$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	$(1-akT)e^{-akT}$	$\frac{1-(1+aT)e^{-aT}z^{-1}}{\left(1-e^{-aT}z^{-1}\right)^2}$
12.	$\frac{2}{(s+a)^3}$	t^2e^{-at}	$(kT)^2e^{-akT}$	$\frac{T^2e^{-aT}\left(1+e^{-aT}z^{-1}\right)z^{-1}}{\left(1-e^{-aT}z^{-1}\right)^3}$
13.	$\frac{a^2}{s^2(s+a)}$	$at-1+e^{-at}$	$akT-1+e^{-akT}$	$\frac{\left[\left(aT-1+e^{-aT}\right)+\left(1-e^{-aT}-aTe^{-aT}\right)z^{-1}\right]z^{-1}}{\left(1-z^{-1}\right)^2\left(1-e^{-aT}z^{-1}\right)}$
14.	$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$	$\sin \omega kT$	$\frac{z^{-1}\sin\omega T}{1-2z^{-1}\cos\omega T+z^{-2}}$
15.	$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	$\cos \omega kT$	$\frac{1-z^{-1}\cos\omega T}{1-2z^{-1}\cos\omega T+z^{-2}}$
16.	$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin \omega t$	$e^{-akT}\sin \omega kT$	$\frac{e^{-aT}z^{-1}\sin\omega T}{1-2e^{-aT}z^{-1}\cos\omega T+e^{-2aT}z^{-2}}$
17.	$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	$e^{-akT}\cos \omega kT$	$\frac{1-e^{-aT}z^{-1}\cos\omega T}{1-2e^{-aT}z^{-1}\cos\omega T+e^{-2aT}z^{-2}}$
18.	–	–	a^k	$\frac{1}{1-az^{-1}}$
19.	–	–	a^{k-1} $k = 1, 2, 3, \ldots$	$\frac{z^{-1}}{1-az^{-1}}$
20.	–	–	ka^{k-1}	$\frac{z^{-1}}{\left(1-az^{-1}\right)^2}$
21.	–	–	k^2a^{k-1}	$\frac{z^{-1}\left(1+az^{-1}\right)}{\left(1-az^{-1}\right)^3}$
22.	–	–	k^3a^{k-1}	$\frac{z^{-1}\left(1+4az^{-1}+a^2z^{-2}\right)}{\left(1-az^{-1}\right)^4}$
23.	–	–	k^4a^{k-1}	$\frac{z^{-1}\left(1+11az^{-1}+11a^2z^{-2}+a^3z^{-3}\right)}{\left(1-az^{-1}\right)^5}$
24.	–	–	$a^k \cos k\pi$	$\frac{1}{1+az^{-1}}$

$x(t) = 0 \quad$ for $t < 0$
$x(kT) = x(k) = 0 \quad$ for $k < 0$
Unless otherwise noted, $k = 0, 1, 2, 3, \ldots$