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: APRIL 2025 EXAM

TIME: 2 HOURS

DATE: April 2025

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 any THREE Questions.

Do not write on the question paper.

Question ONE

(a) Figure Q1 (a) shows the block diagram of a closed-loop flow control system. Identify: the sensor, the transducer, the actuator, the transmitter, the controller, the manipulated variable, and the measured variable. (7 marks)

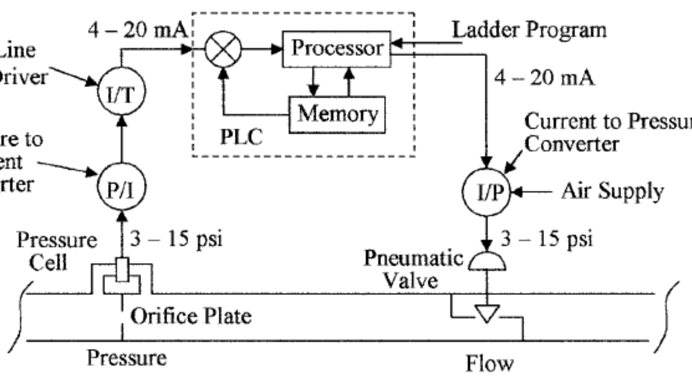

Figure (a)

(b) Draw and explain process control loops for Supervisory and Direct digital control (DDC) (4 marks)

(c) Explain what is meant by a nonlinear system (2 marks)

(d) A second-order nonlinear system given by:

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

i) Obtain the singular points

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

(8 marks)

(e) Explain bilinear transformation (2 marks)

(f) Derive the discrete-time transfer function of the following continuous-time plant. Use a zero-order hold element and assume the sampling time T to be known. (7 marks)

$$G(s)=\frac{1}{s^2+3s+2}$$

Question TWO

(a) State the effects of the following control actions on system performance.

i) Integral action and

ii) Derivative action

(4 marks)

(b) A three-term controller is described by the equation

$$\theta_c(t)=20\left[e(t)+\frac{1}{T_r}\int_0^t e(t)+T_d\frac{de(t)}{dt}\right]$$

Where e (t) = system error, $\theta_c(t)$ = controller output, T_r = reset time and T_d = derivative time. This is used to control a process with transfer function

$$G(s)=\frac{40}{10s^2+80s+800}$$. Unity feedback is used.

i) If integral action is not employed, find the derivative time required to make the closed-loop damping ratio unity.

ii) If this value of derivative time is maintained. Determine the minimum value of reset time that can be used without instability arising.

(8 marks)

(c) Closed loop control system shown in Figure Q 2(c) in which a PID controller is used to control the system.

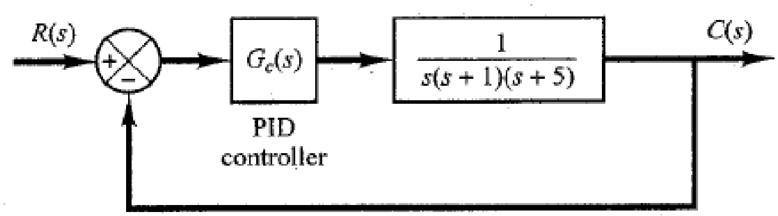

Figure Q 2(c)

The PID controller has the transfer function

$$G_c(s)=K_p\left(1+\frac{1}{T_i s}+T_d s\right)$$

Apply a Ziegler-Nichols ultimate cycle tuning rule for the determination of the values of parameters K_p, τ_i and τ_d given the following data: $K_p=0.6K_c,\ T_i=T_c/2,\ T_d=T_c/8$; The notations have the usual meanings.

(8 marks)

Question THREE

(a) Briefly describe the phase plane and the describing function techniques for nonlinear system analysis

(8 marks)

(b) Derive the expression for describing function of the non-linearity function of an ideal relay as shown in figure Q3 (b) given that the output

$$w(t)=\begin{cases}-M, & -\pi\le\omega T<0,\\ -M, & 0\le\omega T<\pi.\end{cases}$$ (6 marks)

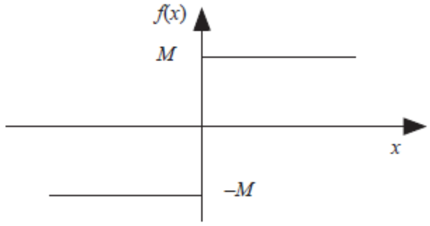

Figure Q3 (b)

(c) State what is meant by Jump phenomenon in nonlinear systems (2 marks)

(g) Explain the following nonlinear phenomena

i) Finite escape time.

ii) Limit circles.

(4 marks)

Question FOUR

(a) Explain Sampling theorem (2 marks)

(b) 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)

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

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

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

(d) Implement digital PID controller algorithm using the position and the velocity versions. (8 marks)

Question FIVE

(a) Derive the relation between s plane and z plane using Bilinear transformation technique (6 marks)

(b) The discrete time system is to have the identical time response to the continuous system. State the desired closed loop poles and characteristic equations in

i) the s plane and

ii) the z plane

(2 marks)

(c) Derive the state equations and the transfer function $H(z)=Y(z)/R(z)$ for the block diagram of Figure Q5 (c).

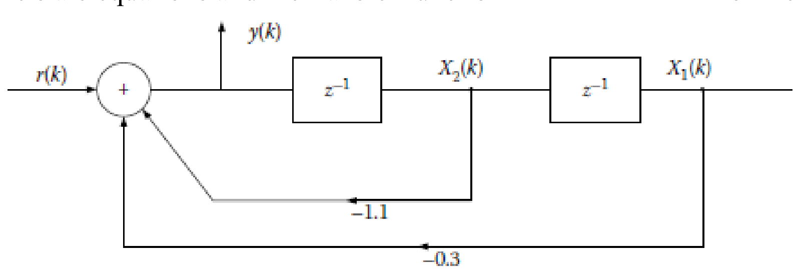

Figure Q5 (c). (8 marks)

(d) Sketch a block diagram of a discrete - time system with the state space representation as shown

$$\begin{bmatrix} x_1(k+1) \\ x_2(k+1) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 2 & 5 \end{bmatrix} \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(k)$$

$$y(k) = \begin{bmatrix} 8 & -7 \end{bmatrix} \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix}$$

(4 marks)

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.	–	–	$a^k \cos k\pi$	$\frac{1}{1+az^{-1}}$

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