ENG74

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

MSC MECHANICAL ENGINEERING

SEMESTER TWO EXAMINATION 2024/25

ADVANCED THERMAL POWER AND ENERGY SYSTEMS

MODULE NO: AME7008

Date: Tuesday 13th May 2025 **Time: 10:00am – 12:00pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

School of Engineering
MSc Mechanical Engineering
Semester Two Examination 2024/25
Advanced Thermal Power and Energy Systems
Module No: AME7008

QUESTION 1

a) Servomotor is used to control the position of plotter pen as in the following **Figure Q1** below. Find the steady state error under Proportional control (Kp) and for a unit step input.

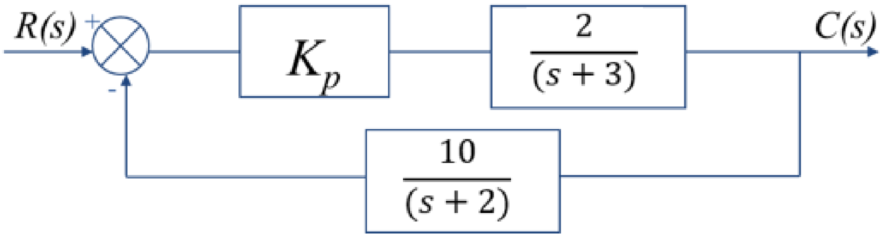

Figure Q1 Servo motor

[9 Marks]

b) Discuss with diagram, the differences between the transient state response and steady state response of control system response.

[4 Marks]

c) Explain how varying the **time constant** and **gain** of a first-order system affects its overall behavior and response.

[5 Marks]

d) The step response of a 1st order system is given below as

$$\mathbf{c(t) = 12(1 - e^{-0.5t}), \ t \geq 0}$$

Find:

- Time constant, τ
- D.C Gain, K
- Transfer function, G(s)

[7 Marks]

Total 25 marks

QUESTION 2

a) List 5 standard test signals. Describe any two of them with diagram.

[4 Marks]

Consider a DC motor with an open-loop transfer function:

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

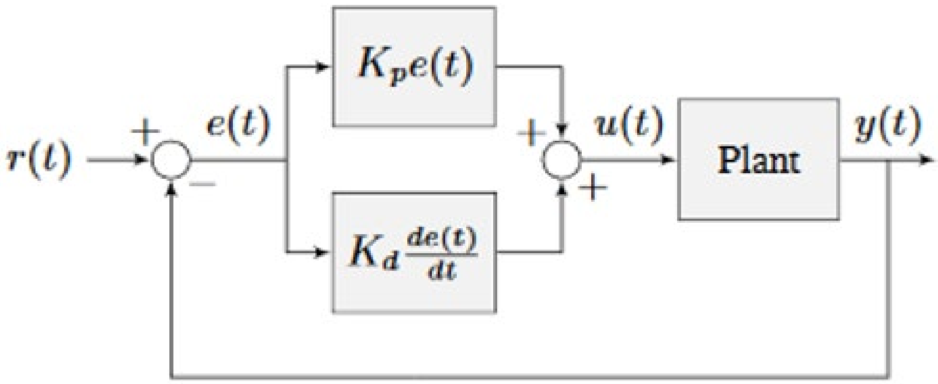

Figure Q2: DC motor controller.

A **PD** controller is added to improve the DC motor response with Kp = 4 and Kd = 1, as shown in Figure Q2.

- Evaluate the performances of closed loop DC motor system (natural frequency, damping ratio, Percentage Overshoot, peak time, rise time, settling time and steady-state error) to assess its performance without the PD controller.

[11 Marks]

- Compare the new natural frequency and damping ratio with the original system (without the PD controller).

[5 Marks]

- Explain how the PD controller affects the transient response of the system

[5 Marks]

Total 25 marks

QUESTION 3

The landing of a parachute user and his free body diagram at a landing operation is shown in Figure Q3.

Figure Q3 landing of a parachute user

a) Derive the differential equations describing the behaviour of the parachute user in Figure Q3 giving the relationship between the input force of his legs hitting the ground and the output displacement x on his body frame.

[8 Marks]

b) Write out the transfer function expression for this system using Laplace transform if m =5kg, c = 35Ns/m, k=350N/m, force F(t) = 300F(t) and assuming zero initial condition.

[8 Marks]

c) State the number of poles and zeros in the system. Give reasons for your answer.

[5 Marks]

d) Check for if the system is controllable and observable.

[4 Marks]

Total 25 marks

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QUESTION 4

a) As a mechanical engineer working within a fluid dynamics laboratory, your role involves investigating different fluid flow behaviours to inform equipment design and performance assessments. Two fundamental flow models, Poiseuille flow and Couette flow, have significant implications in various industrial applications. Using clear, labelled diagrams, compare and contrast Poiseuille flow and Couette flow. In your answer:

- Clearly illustrate each flow type with appropriate velocity profiles.
- Identify and describe the key differences between the two flow patterns, particularly in terms of driving forces, boundary conditions, velocity distribution, and shear stress behaviour.
- Discuss the relevance and practical applications of each flow type within mechanical engineering and fluid dynamics, providing examples of where each is encountered in real-world scenarios.

[17 Marks]

b) You are a mechanical engineer assigned to conduct a detailed Computational Fluid Dynamics (CFD) analysis to evaluate the aerodynamic performance of a new turbine blade design. To ensure the accuracy, reliability, and validity of your CFD results.

- Clearly outline and describe in detail the main steps involved in conducting a complete CFD analysis.

[8 Marks]

Total 25 marks

QUESTION 5

a) As a mechanical engineer at a power generation plant, you have been asked to present a detailed overview of the fundamental thermodynamic processes involved in the operation of a gas turbine cycle.

Explain the fundamental thermodynamic processes that constitute the ideal gas turbine (Brayton) cycle, clearly describing each process and how it contributes to power generation. Additionally, support your explanation by providing clearly labelled sketches of the cycle on both:

- Pressure–Volume (p-v) diagram
- Temperature–Entropy (T-s) diagram

In your answer, discuss the significance of each process stage (compression, heat addition, expansion, and heat rejection), and highlight key assumptions made when analysing an ideal Brayton cycle.

[16 Marks]

b) As a mechanical engineer working on the aerodynamic analysis of turbine blades within a thermal power plant, your role requires an in-depth understanding of aerodynamic forces acting on aerofoil-shaped components.

- Clearly explain the concepts of drag force and drag coefficient, as well as lift force and lift coefficient, and state their importance in aerodynamic analysis.
- With the aid of a clearly labelled diagram, describe the various components (features) of an aerofoil, and explain how changes in the angle of attack affect key aerodynamic parameters such as lift, drag, and flow separation. Provide practical examples of how the aerofoil concept is applied specifically within thermal power energy systems, outlining its significance in improving system efficiency and performance

[9 Marks]

Total 25 marks

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QUESTION 6

a) A Brayton cycle is operating with a pressure ratio of 7 and a maximum temperature of 100K. Air flows through the cycle at a rate of 2kg/s and enters the compressor at 1 bar and 303K. Calculate the compressor work input, turbine work output, and thermal efficiency of the cycle. Show all your work and assume ideal conditions and Cp is 1.005 KJ/Kgk.

[25 Marks]

Total 25 marks

END OF QUESTIONS

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Formula Sheet follows over the page

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FORMULA SHEET

Blocks with feedback loop

G(s) = $\frac{Go(s)}{1+Go(s)H(s)}$ (for a negative feedback)

G(s) = $\frac{Go(s)}{1-Go(s)H(s)}$ (for a positive feedback)

Steady-State Errors

$e_{ss} = \lim_{s\to 0}[s(1-G_O(s))\theta_i(s)]$ (for an open-loop system)

$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+G_o(s)}\theta_i(s)]$ (for the closed-loop system with a unity feedback)

$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+\frac{G_0(s)}{1+G_0(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \lim_{s\to 0}[-s\cdot\frac{G_2(s)}{1+G_2(s)G_1(s)}\cdot\theta_d]$ (if the system subjects to a disturbance input)

$$\frac{bo}{(s^2+a1s+ao)}$$

Laplace Transforms

A unit impulse function 1

A unit step function $\frac{1}{s}$

A unit ramp function $\frac{1}{s^2}$

First order Systems

$G(s) = \frac{\theta_o}{\theta_i} = \frac{G_{ss}(s)}{\tau s+1}$

$$\tau\left(\frac{d\theta_o}{dt}\right) + \theta_o = G_{ss}\theta_i$$

$\theta_O = G_{ss}(1 - e^{-t/\tau})$ (for a unit step input)

$\theta_O = AG_{ss}(1 - e^{-t/\tau})$ (for a step input with size A)

$\theta_o(t) = G_{ss}(\frac{1}{\tau})e^{-(t/\tau)}$ (for an impulse input)

Second-order systems

$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$G(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

The transient response has four distinct part identifiable

(a) Rise time, $T_r = \dfrac{\pi - \theta}{\omega_n\sqrt{1-\varsigma^2}}$

(b) Peak time, $T_p = \dfrac{\pi}{\omega_n\sqrt{1-\varsigma^2}}$

(c) Percentage maximum overshoot, %MP = $e^{-(\varsigma\pi/\sqrt{1-\varsigma^2})}$ x 100%

(d) Settling time (2% error), $T_s = \dfrac{4}{\varsigma\omega_n}$

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❑Output of the first order system with a unit impulse input is

$$c(t) = K(\frac{1}{\tau})e^{-(t/\tau)}$$

$$c(t) = K(1 - e^{-t/\tau}), t \geq 0$$

❑Output of the first order system with a unit ramp input is

$$c(t) = K[1 - e^{-(t/\tau)}]$$

$$G(s) = \frac{C(s)}{R(s)} = \boxed{\frac{K}{\tau s + 1}}$$

Steady state

$$e_{ss} = \lim_{t\to\infty} e(t) = \lim_{s\to 0} sE(s)$$

$$E(s) = \frac{1}{1 + G(s)} R(s)$$

$$E(s) = R(s) - C(s)$$

$$e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1 + G(s)}$$

According the value of ζ, a second-order system can be set into one of the four categories:
Overdamped - when the system has two real distinct poles (ζ >1).
Underdamped - when the system has two complex conjugate poles (0 <ζ <1).
Undamped - when the system has two imaginary poles (ζ = 0).
Critically damped - when the system has two real but equal poles (ζ = 1).

Laplace of higher derivatives

$$L\{f'(t)\} = sF(s) - f(0)$$

$$L\{f''(t)\} = s^2F(s) - sf(0) - f'(0)$$

$$L\{f'''(t)\} = s^3F(s) - s^2f(0) - sf'(0) - f''(0)$$

Therefore in general:

$$L\{f^n(t)\} = s^n L\{f(t)\} - s^{n-1}f(0) - s^{n-2}f'(0) - \ldots - f^{n-1}(0)$$

where $f(0)$ is value of $f(t)$ @ $t = 0$, $f'(0)$ is value of $f'(t)$ @ $t = 0$

$$\text{T.F.} = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s).H(s)}$$

	$f(t)$	$\mathcal{L}(f)$		$f(t)$	$\mathcal{L}(f)$
1	1	$1/s$	7	$\cos \omega t$	$\frac{s}{s^2 + \omega^2}$
2	t	$1/s^2$	8	$\sin \omega t$	$\frac{\omega}{s^2 + \omega^2}$
3	t^2	$2!/s^3$	9	$\cosh at$	$\frac{s}{s^2 - a^2}$
4	t^n $(n = 0, 1, \cdots)$	$\frac{n!}{s^{n+1}}$	10	$\sinh at$	$\frac{a}{s^2 - a^2}$
5	t^a (a positive)	$\frac{\Gamma(a+1)}{s^{a+1}}$	11	$e^{at} \cos \omega t$	$\frac{s-a}{(s-a)^2 + \omega^2}$
6	e^{at}	$\frac{1}{s-a}$	12	$e^{at} \sin \omega t$	$\frac{\omega}{(s-a)^2 + \omega^2}$

Gas turbines and Jet propulsion

$$W_c = m * c_p * (T_2 - T_1)$$

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$$W_T = m * c_p * (T_3 - T_4)$$

$$T = \left(1 + \frac{m_f}{m_a}\right) C_e - C_a$$

$$C.V = \frac{m_a}{m_f} \times q_{add}$$

END OF PAPER