[ENG09]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC MECHANICAL ENGINEERING

SEMESTER TWO EXAMINATION 2022/23

ADVANCED THERMAL POWER AND ENERGY SYSTEMS

MODULE NO: AME7008

Date: Tuesday 9th May 2023 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are FIVE 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 2022/23
Advanced Thermal Power and Energy Systems
Module No: AME7008

QUESTION 1

a) Consider the mechanical system used in submarine technology as shown in Figure 1(a), where x(t) is the input displacement, and θ(t) is the output angular displacement. Assume that the masses involved in the system are negligibly small. Also, the motions of the system are restricted to be small. Therefore, the system can be considered as a mechanical linear system. The initial conditions for x and θ are zero.
Determine the response θ(t) of the system when x(t) is a unit-step input.

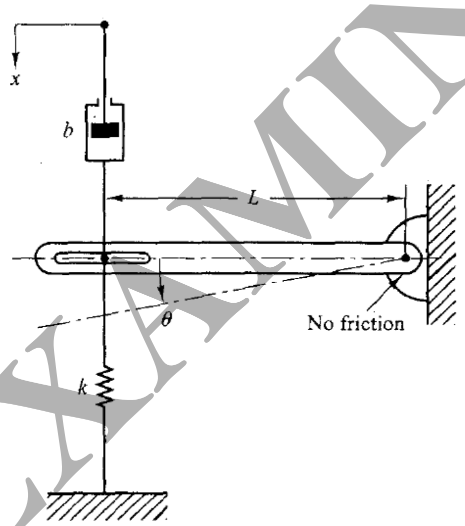

Figure 1(a) Mechanical linear system

[15 Marks]

Question 1 continues over the page…

…Question 1 continued

b) An aerospace servomotor with a damping ratio of $\zeta = 0.4$, is employed to regulate the displacement of a plotter pen. The block diagram to control the system is shown in Figure 1(b).

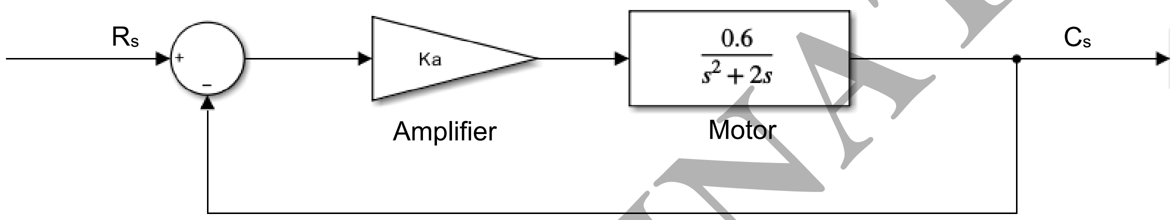

Figure 1(b) Servo-motor Block diagram

Determine the following parameters of the control system: The transfer function, Peak time (t_p), Maximum overshoot (M_p), Settling time (t_s), and Rise time (t_r).

[10 Marks]

Total 25 marks

QUESTION 2

a) Determine the governing equation that describes the correlation between the input torque T and the angular displacement θ of a driveline with a locked wheel, as shown in Figure 2(a).
Find the Laplace transforms of the derived equations, assuming that the system receives a unit step input at an initial condition taken to be zero overall.

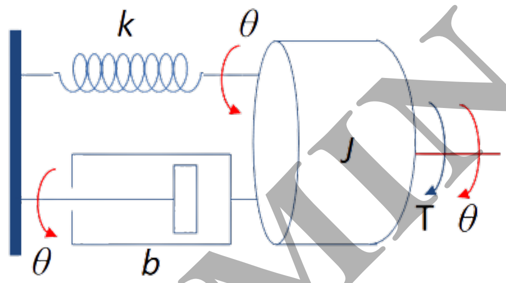

Figure 2(a) Schematical diagram of locked wheel

Your answers should provide with enough details to demonstrate your understanding of mechanical control systems and their analysis.

[16 Marks]

b) The response of a first-order mechanical system to an impulse is represented by the following equation,

$$C(t) = 3e^{-0.5t}$$

Determine its time constant (τ), DC gain (K), transfer function (G_s), and step response.

[9 Marks]

Total 25 marks

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QUESTION 3

a) A nuclear power plant gas turbine unit has a pressure ratio of 15/1 and a maximum cycle temperature of 950°C. The isentropic efficiencies of the compressor and turbine are respectively 0.79 and 0.91.

Calculate the power output of the electric generator connected to the turbine assuming that the air enters the compressor at a rate of 9.99 kg/s and a temperature of 17°C.

Use the following values for your numerical calculation;

Compression process; C_p = 1.005 kJ/kg.K and γ = 1.4.

Expansion process; C_p = 1.11 kJ/kg.K and γ = 1.333.

[16 Marks]

b) Explain the fundamental thermodynamic process of the cycle involved in the operation of a gas turbine. Additionally, provide a visual representation of the cycle through p-v and T-s diagrams.

[9 Marks]

Total 25 marks

QUESTION 4

a) An innovative military jet engine having a dynamic fluid system, consist of a steady laminar flow of a viscous and incompressible fluid between two parallel plates of a long length separated by a distance of "b" as shown in Figure 4(a). At a significant distance from the channel entrance, the fluid velocity components along the y and z axis are negligible, and the upper plate remains fixed. The fluid flow is driven by a pressure gradient $\frac{\partial p}{\partial x}$ in the x-direction, and the lower plate moves at a constant velocity (U).

Derive an expression for the fluid velocity, u(y), by using the Navier stokes equations and neglecting the effect of gravity.

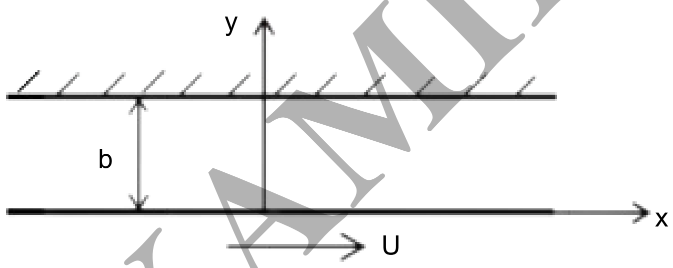

Figure 4(a) Dynamic fluid system scheme

[19 Marks]

b) Compare and contrast Poiseuille flow and Couette flow using relevant diagrams to support your argument. Additionally, describe the main differences between the two flows and explain their relevance in fluid dynamics.

[6 Marks]

Total 25 marks

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QUESTION 5

a) The following problem pertains to a jet propulsion engine, which involves a compressor with a pressure ratio of 4. The compressed air is then directed to a combustion chamber, where combustion takes place, producing a temperature of 500°C at the turbine inlet.
The actual temperature at the combustion chamber inlet is 10% higher than the temperature rise that occurs in an isentropic compressor. The exhaust gas from the turbine is expanded until it reaches a pressure of 1 bar, and the ambient temperature is 285 K. Your task is to provide the following information based on the given scenario:

i. Determine the power required to drive the compressor.

ii. Calculate the air-fuel ratio, given that the fuel has a calorific value of 43.1 MJ/kg.

iii. Find the static thrust developed per kilogram of air per second.

To solve this problem, you may use appropriate assumptions and equations as required. Ensure that you provide clear and concise explanations of all taken steps.

[16 Marks]

b) Consider the incompressible steady flow of a Newtonian fluid with the following velocity field:

$$V = (-2xy)i + (y^2 - x^2)j + (0)k$$

Neglecting the gravitational force, determine whether this velocity field satisfies the conservation of momentum or Navier-Stokes equation.

[9 Marks]

Total 25 marks

END OF QUESTIONS

Formula Sheet follows over the page

Formula Sheet

- **Navier Stokes Equations**

For a Newtonian incompressible fluid in cartesian coordinates:

$$\rho.\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{\partial u}{\partial t}\right) = \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho g$$

$$\rho.\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + \frac{\partial v}{\partial t}\right) = \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + \rho g$$

$$\rho.\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} + \frac{\partial w}{\partial t}\right) = \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + \rho g$$

The simplified motion equation for an incompressible Newtonian fluid with uniform viscosity:

$$\rho\frac{D\vec{u}}{Dt} = -\nabla p + \mu\nabla^2\vec{u} + \rho\vec{g}$$

- **Block feedback**

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

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

- **Performance measurement for second-order systems**

$\omega_d t_r = 1/2\pi$

$\omega_d t_p = \pi$

$$M.O\ (\%) = \exp\left(\frac{-\zeta\pi}{\sqrt{(1-\zeta^2)}}\right) \times 100\%$$

$$t_s = \frac{4}{\zeta\omega_n}$$

$\omega_d = \omega_n\sqrt{(1-\zeta^2)}$

- **Laplace Transforms**

$f'(t)$	$sF(s) - f(0)$
$f''(t)$	$s^2F(s) - sf(0) - f'(0)$

	$f(t)$	$F(s)$
1.	$\delta(t)$	1
2.	$u(t)$	$\frac{1}{s}$
3.	$t\,u(t)$	$\frac{1}{s^2}$
4.	$t^n\,u(t)$	$\frac{n!}{s^{n+1}}$
5.	$e^{-at}\,u(t)$	$\frac{1}{s+a}$
6.	$\sin \omega t\,u(t)$	$\frac{\omega}{s^2+\omega^2}$
7.	$\cos \omega t\,u(t)$	$\frac{s}{s^2+\omega^2}$

$$\tau\dot{y}(t) + y(t) = Ku(t)$$

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

- **Gas turbines and Jet propulsion**

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

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

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

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

END OF PAPER