[ENG26]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC MECHANICAL ENGINEERING

SEMESTER TWO EXAMINATION 2023/24

ADVANCED THERMAL POWER AND ENERGY SYSTEMS

MODULE NO: AME7008

Date: Wednesday 15th May 2024 **Time: 10:00 – 12:00**

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.

QUESTION 1

You have recently been appointed as an engineer at an innovative energy storage start-up, tasked with the development of a product that harnesses potential energy for storage purposes. In instances of surplus electricity within the grid, a motorised winch mechanism engages, drawing a mass towards a spring, subsequently immobilised by a braking system. Upon the grid's requisition for energy, the mass is disengaged, reverting to its original state, thus releasing stored energy. Your immediate superior has proposed the conceptualisation of this product through a model comprising a solid barrier, two springs characterised by stiffness constants K1 and K2, a damper endowed with a damping coefficient C, and a mass denoted as M. **Figure 1** shows the model of your product. The input to the system is the Force F acting from the winch to the mass and the outputs are displacements y_1 and y_2.

a) Drive the governing equations for the displacements y_1 and y_2 of the machine system.

[10 marks]

b) Determine the Laplace transforms of the differential equations obtained from (a) above. Assume the initial conditions of the system are zeros (i.e. at time = 0,y_1 $\dot{y}_1$, $\ddot{y}_1$ are all zeros).

[5 marks]

c) Determine the transfer function $G(s) = \frac{y_2(s)}{F(s)}$.

[10 marks]

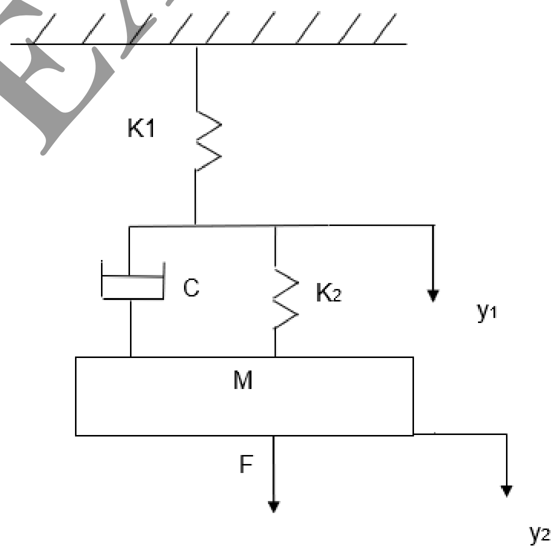

Figure 1 Energy System Mechanism

Total 25 marks

Please turn the page

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QUESTION 2

a) Consider the system used in recycling technology as shown in **Figure 2**, where V(t) is the input voltage, and i(t) is the output current. Determine the response i(t) of the system when V(t) is a unit-step input.

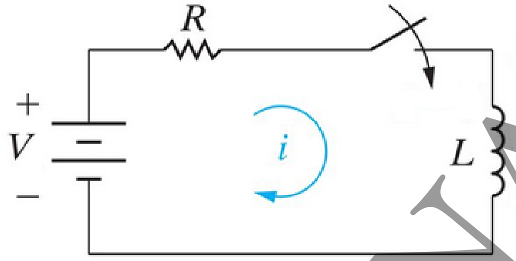

Figure 2 Linear system

[15 Marks]

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

$$C(t) = 4e^{-0.5t}$$

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

[10 Marks]

Total 25 marks

QUESTION 3

a) Determine the natural frequency and damping ratio for the system with transfer function represented by the following equation:

$$G(s) = \frac{36}{s^2 + 4.2s + 36}$$

Furthermore, find the Peak time (t_p), Maximum overshoot (M_p), Settling time (t_s), and Rise time (t_r)

[10 Marks]

b) An aerospace servomotor with a damping ratio of ζ= 0.4, is employed to regulate the displacement of a plotter pen. The block diagram to control the system is shown in **Figure 3**.

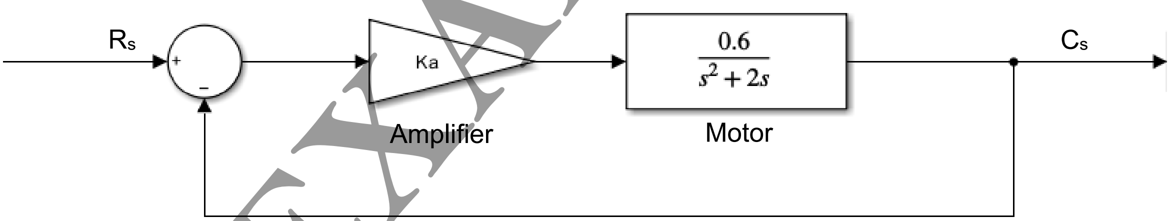

Figure 3 Servo-motor Block diagram

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).

[15 Marks]

Total 25 marks

Please turn the page

QUESTION 4

a) Explain what head loss is and identify two types of head losses experienced by liquid in pipe flow.

[4 Marks]

b) Water flows through capillary tubes A and B into tube C. If $Q_a = 2 \times 10^{-3} L/s$, what is the maximum Q_b allowable in tube B for laminar flow in tube C? The water temperature is 40°C ($\vartheta = 0.661 \times 10^{-6} \frac{m^2}{s}$). With the calculated Q_b, what type of flow exists in tubes A and B? Assume diameters in A, B, and C to be 5mm, 4mm, and 6mm respectively.

[12 Marks]

c) Calculate the head loss in a cast iron pipe with a diameter of 15cm and a length of 30m when water flows through it at a rate of 75 Litres/s at 20℃. Consider the following properties:

- Water at 20°C: $\vartheta = 1.007 \times 10^{-6} \frac{m^2}{s}$
- Cast Iron roughness: $\in = 0.15mm$

[9 Marks]

Total 25 marks

QUESTION 5

a) Derive Bernoulli's equation from the principle of work and energy.

[16 Marks]

b) If the airflow above the wing moves at a speed of $180 \frac{m}{s}$ and below the wing moves at a speed of $130 \frac{m}{s}$, calculate the force required to keep the airplane airborne. Assume the mass of the airplane is 4000 kg and the wing surface area is $50m^2$. The airplane is flying at a low altitude, so take the density as $1.10 \frac{kg}{m^3}$

[9 Marks]

Total 25 marks

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QUESTION 6

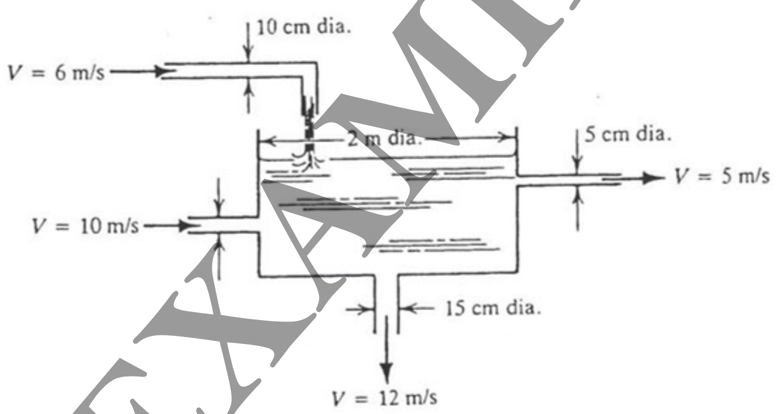
a) Explain discretisation and its necessity in a CFD simulation.

[4 Marks]

b) Approximate the derivative of a function $f(x) = x^2 + 2x \; at \; x = 3$ using forward, backward and central difference method and step size of 1. Verify the result using an analytical solution.

[13 Marks]

c) At what rate is the liquid level rising or falling in the tank shown below.



[Marks 8]

Total 25 marks

END OF QUESTIONS

Formula sheet follows over the page

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Formula Sheet

- **Block feedback**

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

G(s) = $\dfrac{Go(s)}{1-Go(s)H(s)}$ (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 $\left(\dfrac{-\zeta\pi}{\sqrt{(1-\zeta^2)}}\right)\times 100\%$

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

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

- **Laplace Transforms**

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

Please turn the page

	$f(t)$	$F(s)$
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.	$\cos\omega t\,u(t)$	$\frac{s}{s^2+\omega^2}$

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

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

Thermal Power Formula Sheet

$$\lambda = \frac{64}{Re}$$

$$H_f = \frac{\lambda L v^2}{2gd}$$

$$Re = \frac{\rho v d}{\mu}$$

$$Re = \frac{Vd}{\vartheta}$$

$$Q = VA$$

$$A_1V_1 = A_2V_2$$

$$SPG = \frac{\rho_{fluid}}{\rho_{water}}$$

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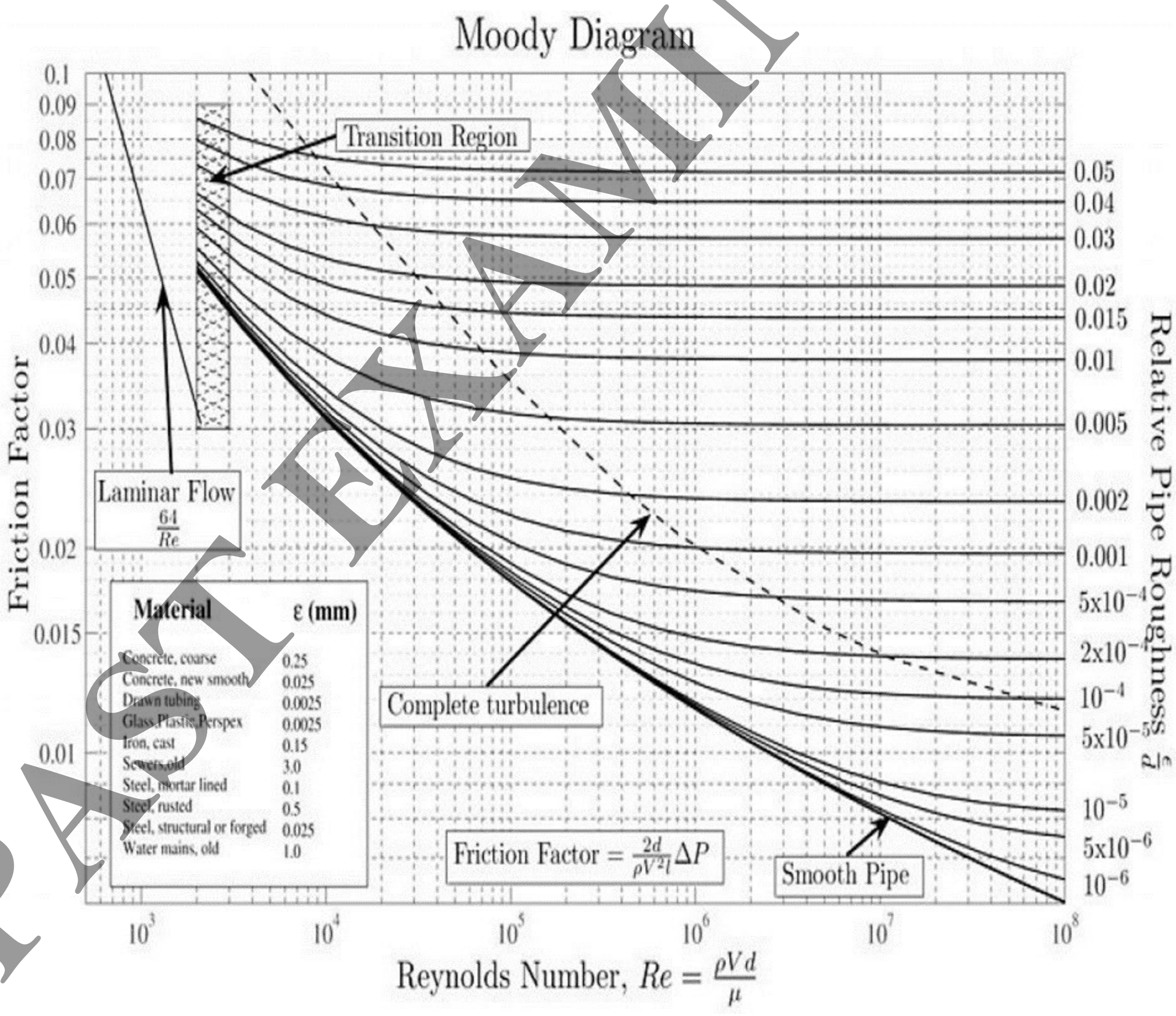
$$\rho_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = \rho_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$P = \frac{F}{A}$$

$$FD: \frac{f(x_i + 1) - f(x_i)}{h}$$

$$BD: \frac{f(x_i) - f(x_i - 1)}{h}$$

$$CD: \frac{f(x_i + 1) - f(x_i - 1)}{2h}$$



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