ENG36

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG MECHANICAL ENGINEERING

SEMESTER 2 EXAMINATION 2023-24

THERMOFLUIDS AND CONTROL SYSTEMS

MODULE NO: AME5013

Date: Wednesday 15th May 2024 **Time: 2:00 – 4:00pm**

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.

QUESTION 1

a) Briefly explain what you understand by volume flow rate and the continuity equation?

[4 Marks]

b) What depth of oil, with a specific gravity of 0.8, will generate a pressure of $120\frac{kN}{m^2}$? What would be the equivalent depth of water to produce the same pressure?

[8 Marks]

c) A U-tube manometer is set up as depicted in figure Q1c to gauge the pressure disparity between two points, A and B, in a water-conveying pipeline with a density of 1000 kg/m^3. The density of the manometric liquid, Q, is 13600 kg/m^3, and point B is situated 0.3 m higher than point A. Determine the pressure difference when h = 0.7 m.

[13 Marks]

[Total: 25 Marks]

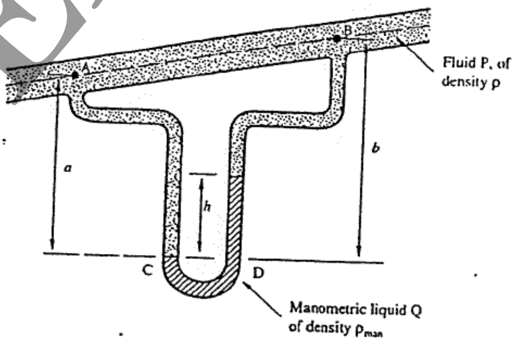

Figure Q1(c): U-Tube manometer connected to water-conveying pipeline

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QUESTION 2

a) Water (density = 1000 kg / m^3) is in steady motion in a pipe inclined downwards, at the upper end A the pipe is 100 mm in diameter and the pressure as shown by a gauge is 55 kPa. At B which is 3m below A the diameter is 62.5 mm and pressure is 35 kPa. Determine the volume flow rate.

[13 Marks]

b) Water (density = 1000 kg/m^3) is flowing down a vertical tapering pipe 6 m long as shown in Figure Q2(b). The diameters of the pipe at the top and the bottom sections are 10 cm and 5 cm respectively. If the discharge through the pipe is 100 litre/s. Find the difference of pressure between the top and bottom ends of the pipe.

[12 Marks]

[Total: 25 Marks]

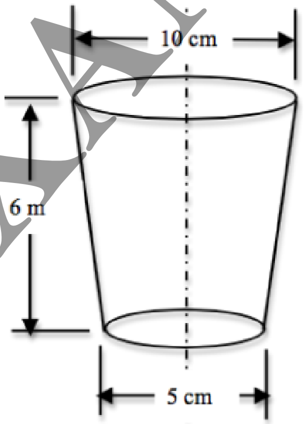

Figure Q2(b): Vertical tapered pipe

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QUESTION 3

a) The area under the curve on a p-v diagram represents the work done during a polytropic process governed by the equation $pv^n = c$. Derive an equation for the work done during this polytropic process

[15 Marks]

b) During actual expansion and compression processes in piston-cylinder devices, gases have been observed to satisfy the relationship $pv^n = c$. Let's calculate the work done when a gas expands from a state of 100 kPa and 0.05 m^3 to a final volume of 0.3 m^3 for the case where n=1.2. **[10 Marks]**

[Total: 25 Marks]

QUESTION 4

a) Compare and contrast first-order and second-order systems. Provide examples illustrating the differences between these two types of systems.

[5 Marks]

b) Explain how variations in system parameters such as damping ratio and natural frequency affect its dynamic behaviour and performance.

[5 Marks]

c) Define the following:

I. Zero-order system
II. First-order system
III. Second-order system

Give examples of each of the systems above and write out the general form of a first and second-order system.

[5 Marks]

d) The step response of a 1st order system is given below as $c(t) = 50(1 - e^{-0.5t})$, $t \geq 0$

Find:

(i) Time constant, τ

(ii) D.C Gain, K

(iii) Transfer function, G(s)

[10 Marks]

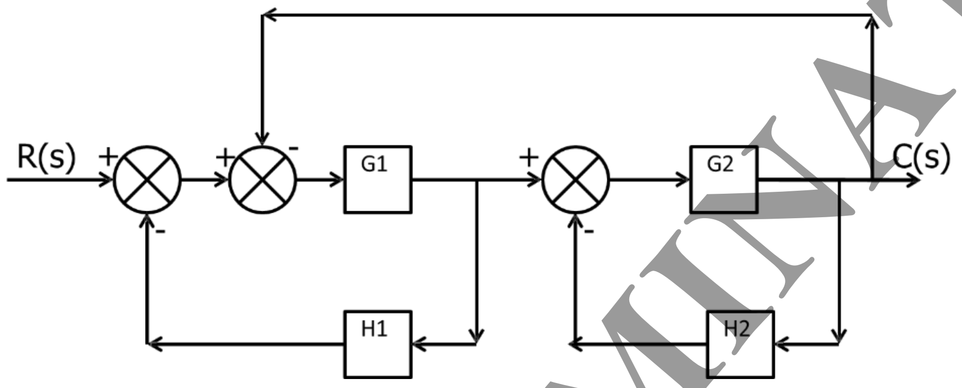
[Total: 25 Marks]

QUESTION 5

a) Describe the fundamental components that make up any closed loop control system. Give examples of each of these components in real life systems.

[5 marks]

b) Simplify the block diagram below and write out the effective transfer function.



[10 marks]

c) Given that the closed loop Transfer Function of the control system of the Heat control unit in the boiler room in University of Bolton.

$$G(s) = \frac{2000}{20s^2 + 160s + 2000}$$

Find the following

I. Peak time, Tp
II. %OS,
III. Settling time, Ts
IV. Rise time, Tr
V. Determine the nature of the damping and draw the pole locations.

[10 marks]

[Total Marks: 25]

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QUESTION 6

a) Define the following;

I. Stable system
II. Unstable system
III. Steady state error

[5 marks]

b) Find the values of controller gain K_c that make the feedback control system of the following transfer function stable.

$$T(s) = \frac{K_c}{s^2 + 2s + 3 + K_c}$$

[10 marks]

c) Consider a closed-loop control system with a transfer function G(s) given by:

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

Determine the steady-state error when the system is subjected to a unit step input (r(t)=1

[10 marks]

[Total Marks: 25]

END OF QUESTIONS

FORMULA SHEET FOLLOWS ON NEXT PAGE

Thermofluids Formula Sheet

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$p = \rho g h$$

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

$$A_1 V_1 = A_2 V_2$$

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

$$Q = VA$$

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

$$pv^n = c$$

$$P_{abs} = P_G + P_{atm}$$

$$W = \frac{P_1 V_1 - P_2 V_2}{n - 1}$$

$$W = P_1 V_1 ln \frac{V_2}{V_1}$$

$$W = nRT ln \frac{V_2}{V_1}$$

$$W = P(V_2 - V_1)$$

$$Q = C_d A \sqrt{2gh}$$

$$V = \sqrt{\frac{2(\rho_w - \rho_a)gh}{\rho_a}}$$

$$P_s = P_0 + \frac{1}{2}\rho V^2$$

$$W = \int P dv$$

$$F = \rho Q v$$

$$F = \rho Q (V_{fluid} - V_{plate})$$

$$F = \rho a v^2$$

Control Systems Formula Sheet

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

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

The transient response has four distinct part identifiable

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

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

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

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

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

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

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

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

❑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

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

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

$$E(s) = R\ (s) - C(s) \qquad e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1+G(s)}$$

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 ($\zeta > 1$).

Underdamped - when the system has two complex conjugate poles ($0 < \zeta < 1$).

Undamped - when the system has two imaginary poles ($\zeta = 0$).

Critically damped - when the system has two real but equal poles ($\zeta = 1$).

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

END OF FORMULA SHEET

END OF PAPER