UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2023/24

ADVANCED THERMOFLUIDS & CONTROL SYSTEM

MODULE NO: AME6015

Date: Wednesday 10 January 2024 **Time: 10:00 AM – 12:00 PM**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer FOUR questions.

All questions carry equal marks.
Attempt TWO questions from PART A and TWO questions from PART B

Marks for parts of questions are shown in brackets.

CANDIDATES REQUIRE:

Thermodynamic properties of fluids tables are provided

Take density of water = 1000 kg/m^3
Formula sheets provided

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PART A

Question 1

a) For the laminar flow through a circular pipe of radius R as shown in **Figure Q1a.**, prove the following:

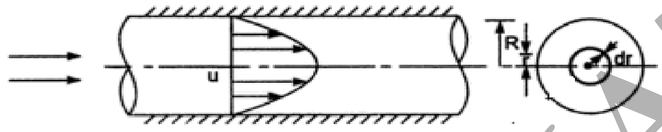

Figure Q1a. Circular pipe

The shear stress variation across the section of the pipe is linear.

(12 marks)

b) A pipe 240 mm in diameter and 10000 m long is laid at a slope of 1 in 180. An oil of specific gravity 0.85 and viscosity 1.5 poise is pumped up at the rate of 0.02 m^3/s. Find:(i) Head lost due to friction, and (ii) Power required to pump the oil.

(7 marks)

c) The space between two square flat parallel plates is filled with oil. Each side of the plate is 720 mm. The thickness of the oil film is 15 mm. The upper plate, which moves at 3 m/s requires a force of 120 N to maintain the speed. Determine:

(i) The dynamic viscosity of the oil.

(ii) The kinematic viscosity of oil if the specific gravity of oil is 0.95.

(6 marks)

Total 25 marks

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Question 2

a) The diameter of a horizontal pipe which is 300 mm is suddenly enlarged to 600 mm. The rate of flow of water through this pipe is 0·4 m^3/s. If the intensity of pressure in the smaller pipe is 125 kN/m^2, determine.

(i) Loss of head, due to sudden enlargement,

(ii) Intensity of pressure in the larger pipe, and

(iii) Power lost due to enlargement.

(13 marks)

b) Find the velocity and acceleration at a point (1, 2, 3) after 1 sec. for a three-dimensional flow given by $u = yz + t,\ v = xz - t,\ w = xy$ m/s.

(12 marks)

Total 25 marks

Question 3

a) Steam enters an engine at an absolute pressure of 10bar and at a temperature of 400°C.It is exhausted at a pressure of 0.2 bar. The steam at exhaust is 0.9 dry. Using the datas from the steam table determine the following:

i) Drop in enthalpy

(5 marks)

ii) Change in entropy

(5 marks)

iii) Sketch the process in T-S diagram

(2 marks)

b) A closed system contains air at pressure 1.5 bar, temperature 350K and volume 0.05 m^3. This system undergoes a thermodynamic cycle consisting of the following three processes in series:

Question 3 continued over…

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Question 3 continued…

Process 1-2: Constant volume heat addition till pressure is 5 bar.
Process 2-3: Constant pressure cooling.
Process 3-1: Isothermal heating to initial state

i. Evaluate the work done for each process (3 marks)
ii. Evaluate the heat transfer for each process (3 marks)
iii. Evaluate the change in entropy for each process (3 marks)
iv. Represent the cycle on T-S and p-v plot. (4 marks)

Take Specific heat capacity at constant volume, C_v =0.718kJ/kg-K and gas constant, R= 287 J/kg-K

Total 25 marks

PART B

Question 4

A closed-loop control system is shown in **Figure Q4.**

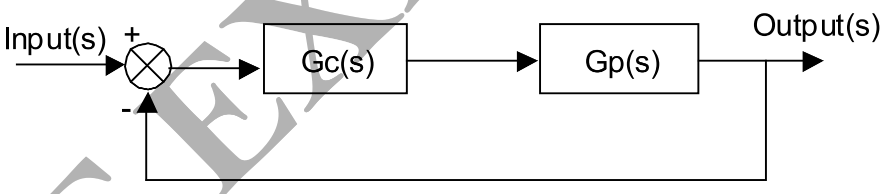

Figure Q4.

Given Gc forward path gain of controller $Gc(s) = 10(1 + \frac{Ki}{s} + sKd)$

Where K_i is integral gain and K_d is derivative gain.

G_p forward path gain of plant $Gp(s) = \frac{4}{s^2 + 6}$

Question 4 continued over…

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Question 4

(i) Determine the value of Kd (derivative gain) to achieve critical damping in a PD controller. (5 Marks)

(ii) With Kd as determined in the previous step, design the maximum allowable value of Ki (integral gain) to maintain stability in a PID controller. (4 Marks)

(iii) Design a PID controller by determining Kp (Proportional gain) and Kd (Derivative gain) using the Ki obtained previously, to achieve a maximum overshoot Mp of less than 20% and a settling time ts of less than 4 seconds. (11 marks)

(iv) For a PI controller, design the K_i for a ramp input and the steady state error is less than 2%. (5 Marks)

Total 25 marks

Question 5

(a) Develop the state space model of a simplified industrial robotic system shown in **Figure Q5a** K= spring constant; B= Damping Coefficient; M= mass; y=displacement; u=Force applied.

Question 5 continued over…
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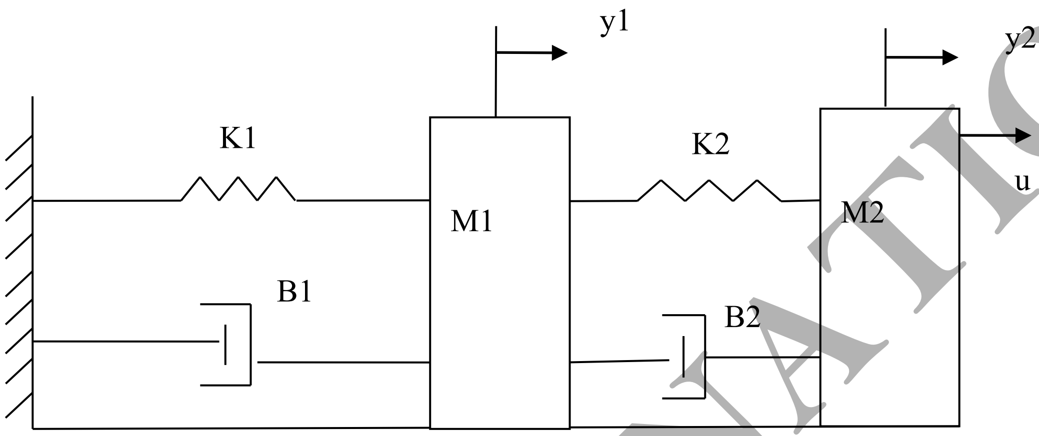
Question 5 continued…



FigureQ5a Simplified industrial robotic system

(15 marks)

(b) The state equations of a mechanical system are given below.

$$\dot{x}_1 = 6x_1 - 11x_2 - 6x_3 + u$$
$$\dot{x}_2 = x_1$$
$$\dot{x}_3 = x_2$$
$$y = x_2 + 3x_3$$

Analyse controllability and observability of the system.

(10 marks)

Total 25 marks

Question 6

An industrial manufacturing system using a sampled data controller is shown in **Figure Q6.**R(s) – Input; C(s)= output l; E(s) = error; $E^*(s)$ =sampled error.

T= sampling time

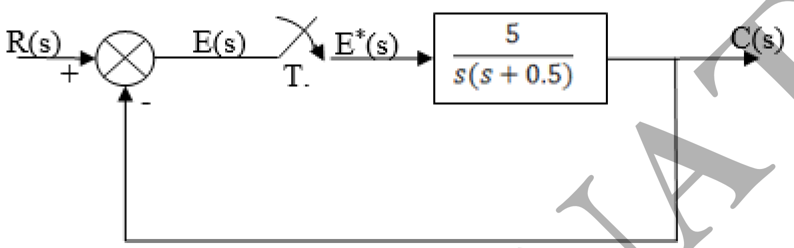


Figure Q6. Sampled data controller

(a) Determine the sampled data transfer function for the given system.

(8 marks)

(b) Analyse the stability of the sampled control system shown for sampling. time T=0.5 sec.

(17 marks)

Total 25 marks

END OF QUESTIONS
Please turn the page for formulas

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FORMULA SHEET

Thermofluids

$$P = F/A$$

$$\rho = m/v$$

$$\dot{m} = \rho AV$$

$$P = P_g + P_{atm}$$

$$P = \rho gh$$

$$\tau = \mu\, du/dy$$

$$Q - W = \Delta U + \Delta PE + \Delta KE$$

$$W = \int PdV$$

$$P V^n = C$$

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

$$W = P\,(v_2 - v_1)$$

$$W = PV \ln\left(\frac{V_2}{V_1}\right)$$

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

$$V_1 = C\sqrt{2g\, h_2\left(\frac{\rho g_m}{\rho g} - 1\right)}$$

$$\sum F = \frac{\Delta M}{\Delta t} = \Delta \dot{M}$$

$F = \rho QV$

$\tau = -(\partial p/\partial x)\, r/2$

$Re = V D \rho/\mu$

$\Delta p = (32\mu VL)/D^2$

$U = 1/(4\mu)\ \ -(\partial p/\partial x)\,(R^2 - r^2)$

$dQ = du + dw$

$du = Cv\, dT$

$dw = pdv$

$pv = mRT$

$h = h_f + xhf_g$

$s = s_f + xsf_g$

$v = x\, Vg$

$$\dot{Q} - \dot{w} = \sum \dot{m} h$$

Please turn the page

$$F = \frac{2\pi L\mu}{L_n\left(\frac{R_2}{R_3}\right)}$$

$$ds = \frac{dQ}{T}$$

$$S_2 - S_1 = C_{pL}\ \mathrm{L_n}\frac{T_2}{T_1}$$

$$S_2 - S_1 = mR\ \mathrm{L_n}\frac{P1}{P2}$$

$$S_g = C_{pL}\ \mathrm{L_n}\frac{T}{273} + \frac{h_{fg}}{T_f}$$

$$S = C_{pL}\ \mathrm{L_n}\frac{T_f}{273} + \frac{hf_g}{T_f} + C_{pu}\ \mathrm{L_n}\frac{T}{T_f}$$

$$\mathrm{S_2 - S_1 = MC_p\ L_n\frac{T_2}{T_1} - MRL_n\frac{P_2}{P_1}}$$

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Process	*Index* n	*Heat added*	$\int_1^2 p\,dv$	*p, v, T relations*	*Specific heat, c*
Constant pressure	$n = 0$	$c_p(T_2 - T_1)$	$p(v_2 - v_1)$	$\frac{T_2}{T_1} = \frac{v_2}{v_1}$	c_p
Constant volume	$n = \infty$	$c_v(T_2 - T_1)$	0	$\frac{T_1}{T_2} = \frac{p_1}{p_2}$	c_v
Constant temperature	$n = 1$	$p_1 v_1 \log_e \frac{v_2}{v_1}$	$p_1 v_1 \log_e \frac{v_2}{v_1}$	$p_1 v_1 = p_2 v_2$	∞
Reversible adiabatic	$n = \gamma$	0	$\frac{p_1 v_1 - p_2 v_2}{\gamma - 1}$	$p_1 v_1^{\gamma} = p_2 v_2^{\gamma}$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$	0
Polytropic	$n = n$	$c_n(T_2 - T_1)$ $= c_v\left(\frac{\gamma - n}{1 - n}\right) \times (T_2 - T_1)$ $= \frac{\gamma - n}{\gamma - 1} \times$ work done (non-flow)	$\frac{p_1 v_1 - p_2 v_2}{n - 1}$	$p_1 v_1^{n} = p_2 v_2^{n}$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n - 1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{n - 1}{n}}$	$c_n = c_v\left(\frac{\gamma - n}{1 - n}\right)$

S. No.	*Process*	*Change of entropy (per kg)*
1.	General case	(*i*) $c_v \log_e \frac{T_2}{T_1} + R \log_e \frac{v_2}{v_1}$ (in terms of T and v) (*ii*) $c_v \log_e \frac{p_2}{p_1} + c_p \log_e \frac{v_2}{v_1}$ (in terms of p and v) (*iii*) $c_p \log_e \frac{T_2}{T_1} - R \log_e \frac{p_2}{p_1}$ (in terms of T and p)
2.	Constant volume	$c_v \log_e \frac{T_2}{T_1}$
3.	Constant pressure	$c_p \log_e \frac{T_2}{T_1}$
4.	Isothermal	$R \log_e \frac{v_2}{v_1}$
5.	Adiabatic	Zero
6.	Polytropic	$c_v \left(\frac{n - \gamma}{n - 1}\right) \log_e \frac{T_2}{T_1}$

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$$F_D = \frac{1}{2} CD \ \rho u^2 s$$

$$F_L = \frac{1}{2} C_L \rho u^2 s$$

$$S_p = \frac{d}{ds}(P + \rho g Z)$$

$$Q = \frac{\pi D^4 \Delta p}{128 \mu L}$$

$$h_f = \frac{64}{R}\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

$$h_f = \frac{4fLv^2}{d2g}$$

$$f = \frac{16}{Re}$$

$$h_m = \frac{Kv^2}{2g}$$

$$h_m = \frac{k(V_1 - V_2)^2}{2g}$$

$$\eta = \left(1 - \frac{T_L}{T_H}\right)$$

Please turn the page

η= $(h_1 – h_2)/(h_1- h_{f\,2})$

$$S_{gen} = \left(S_2 - S_1\right)\big) + \frac{Q}{T}$$

$$W = \left(U_1 - U_2\right) - T_o(S_1 - S_2) - T_0 S_{gen}$$

$$W_u = W - P_o(V_2 - V_1)$$

$$W_{rev} = (U_1 - U_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2)$$

$$\Phi = (U - U_0) - T(S - S_0) + Po(V - V_o)$$

$$I = ToS_{gen}$$

F = τ πDL

$$V = r\omega$$

$$\tau = \mu \frac{V}{t}$$

$$F = \frac{2\pi L \mu u}{L_n\left(\dfrac{R_2}{R_1}\right)}$$

$$T = \frac{\pi^2 \mu N}{60t}\left(R_1^4 - R_2^4\right)$$

$$p = \frac{\rho g Q H}{1000}$$

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Control system

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)

Second order Transfer Function

TF= $\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$

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	Laplace Transforms	**Z Transforms**
A unit impulse function	1	
A unit step function	$\frac{1}{s}$	$\frac{z}{z-1}$
Exponential Function	$\frac{1}{s+a}$	$\frac{z}{z-e^{aT}}$
A unit ramp function	$\frac{1}{s^2}$	
	$1-e^{-st}$	$1-z^{-1}$

First order Systems

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

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

Performance measures for second-order systems

Time Response for second-order systems

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

$\phi = \tan^{-1}(\frac{\sqrt{(1-\zeta^2)}}{\zeta})$

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$t_r = (\pi - \phi)/\omega_d$

$t_p = \pi/\omega_d$

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

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

$$M_r = \frac{1}{2\zeta\sqrt{1-\zeta^2}}$$

$$\omega_r = \omega_n\sqrt{1-2\zeta^2}$$

$$BW = \omega_n[(1-2\zeta^2) + \sqrt{4\zeta^4 - 4\zeta^2 + 2}]^{1/2}$$

controllability matrix

$$\mathcal{C}\left(\hat{\mathbf{A}}, \hat{\mathbf{B}}\right) = \left[\hat{\mathbf{B}} \vdots \hat{\mathbf{A}}\hat{\mathbf{B}} \vdots \cdots \vdots \hat{\mathbf{A}}^{n-1}\hat{\mathbf{B}}\right]$$

observability

$$\mathcal{O}\left(\hat{\mathbf{A}}, \hat{\mathbf{C}}\right) = \begin{bmatrix} \hat{\mathbf{C}} \\ \hat{\mathbf{C}}\hat{\mathbf{A}} \\ \hat{\mathbf{C}}\hat{\mathbf{A}}^2 \\ \vdots \\ \hat{\mathbf{C}}\hat{\mathbf{A}}^{n-1} \end{bmatrix}$$

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