UNIVERSITY OF BOLTON

WESTERN INTERNATIONAL COLLEGE FZE

BEng (Hons) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

ADVANCED THERMOFLUIDS & CONTROL SYSTEM

MODULE NO: AME6015

Date: Wednesday 16th January 2019 **Time: 10:00 AM – 12:30 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

Q1. a) For the laminar flow through a circular pipe of radius R as shown in Figure Q1a., prove the following:

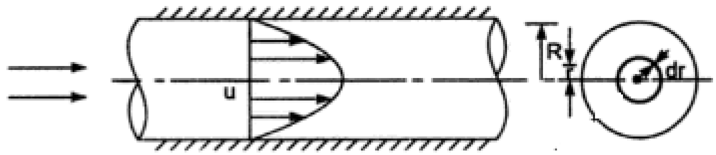

Figure Q1a. Circular pipe

i) The shear stress variation across the section of the pipe is linear

(10 marks)

ii) The velocity variation is parabolic

(10 marks)

b) An oil of viscosity $0.1 Ns/m^2$ and relative density 0.9 is flowing through a circular pipe of diameter 50mm and of length 300m.The rate of flow of fluid through the pipe is 3.5 litres/s. Evaluate the following

i) The pressure drop in a length of 300m

(3 marks)

ii) Shear stress at the pipe wall

(2 marks)

Total 25 marks

Please turn the page

Q2.a) Water at 30^oC flows at a rate of 55 litres/s in a cast iron pipe of 40cm diameter and 80m length. The system includes a sudden entrance (k_e= 0.5), gate valve (k_g=0.15) and a globe valve (k_{gv}=10).

Given the kinematic viscosity of water at 30^oC = 1.008 x 10^{-6} m^2/s.

The surface roughness value for cast iron = 0.086mm.

Evaluate the following:

i. Reynolds Number

(2 marks)

ii. Friction factor from Moody diagram

(4 marks)

iii. Major head loss

(4marks)

iv. Minor head loss

(5 marks)

v. Total head loss

(3 marks)

b) The external and internal diameters of a collar bearing R_1 and R_2 are 200mm and 150mm respectively. Between the collar surface and the bearing, an oil film of thickness 't' 0.25 mm and of viscosity 0.9 poise, is maintained.

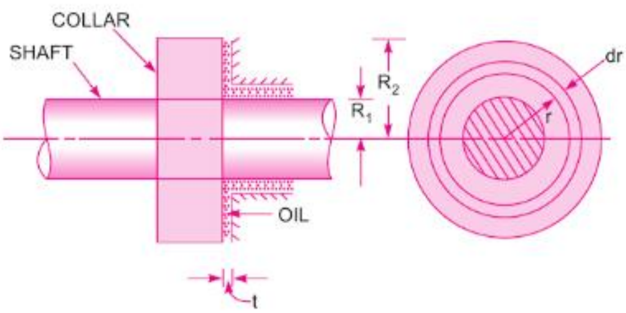

Figure Q2a. Collar Bearing

Q2 continued over the page

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Q2 continued.

Determine the following:

i. Torque required to overcome the viscous resistance of the oil when the shaft is running at 250 r.p.m

(4 marks)

ii. Power lost in overcoming the viscous resistance of oil

(3 marks)

Total 25 marks

Q3. (a) Steam enters an engine at an absolute pressure of 10bar and at a temperature of 400^{o}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:

Process 1-2: Constant volume heat addition till pressure becomes 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)

Q3 continued over the page
Please turn the page

Q3 continued.

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/kgK and gas constant,R= 287 J/kgK

Total 25 marks

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PART B

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

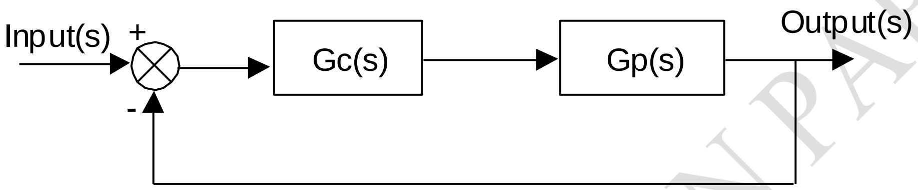


Figure Q4.

Given $Gc(s) = 15 + 10\frac{Ki}{s} + 5sKd$ & $Gp(s) = \frac{2}{s^2 + 2s + 6}$

Where G_c forward path gain of controller, G_p forward path gain of plant, K_p is proportional gain, K_i is integral gain and K_d is derivative gain.

(a) For a PD controller, design the value of K_d for critical damping.

(5 Marks)

(b) With K_d as determined in (a) , design the limiting value of K_i such that stability is maintained for a PID controller.

(5 Marks)

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

(5 Marks)

(d) Design a PID controller by determining K_p and K_d (using the K_i Obtained from (c) above) to achieve maximum overshoot M_p less than 15 % and settling time ts less than 4 seconds. (6 marks)

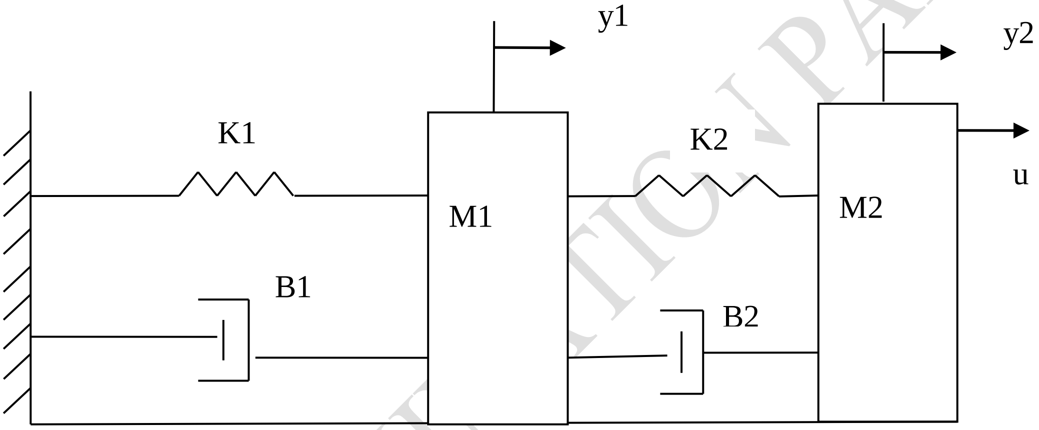
(e) Analyse how system dynamics is affected by PID parameters K_p, K_i, K_d .

(4 marks)

Total 25 marks
Please turn the page

Q5. (a) Develop the state space model of a simplified industrial robotic system shown in **FigureQ5a**

K= spring constant; B= Damping Coefficient; M= mass ;y=displacement; u=Force applied.



FigureQ5a Simplified industrial robotic system (15 marks)

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

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = -2x_1 - 3x_2 + u$$

$$y = x_1 + x_2$$

Analyse controllability and observability of the system.

(10 marks)

Total 25 marks

Please turn the page

Q6.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

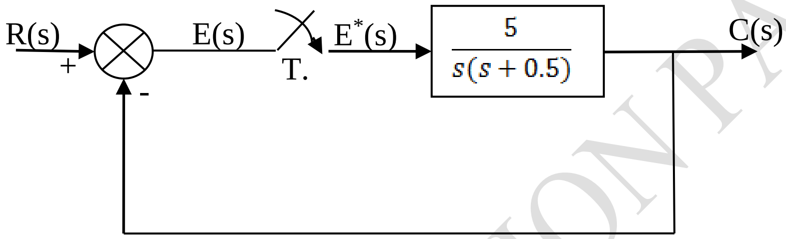


Figure Q6. Sampled data controller

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

(11 marks)

(b) Analyse the stability of the sampled control system shown for sampling time T=0.5 sec and T=1 sec.

(12 marks)

(c) Compare and contrast the stability for the above given sampling times.

(2 marks)

Total 25 marks

END OF QUESTIONS

Please turn the page for the formula sheet

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FORMULA SHEET
Thermofluids

$P = F/A$

$\rho = m/v$

$\dot{m} = \rho A V$

$P = P_g + P_{atm}$

$P = \rho g h$

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

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

$W = \int P dV$

$P V^n = C$

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

$W = P (v_2 - v_1)$

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

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

Please turn the page

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

$$\sum F = \frac{\Delta M}{\Delta t} = \Delta M^{\cdot}$$

$$F = \rho\ QV$$

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

$$Re = V\ D\ \rho/\mu$$

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

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

$$dQ = du + dw$$

$$du = Cv\ dT$$

$$dw = pdv$$

$$pv = mRT$$

$$h = h_f + xhf_g$$

$$s = s_f + xsf_g$$

$$v = x\ Vg$$

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

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

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

$$S_2 - S_1 = C_{pL} \text{ L}_n \frac{T_2}{T_1}$$

$$S_2 - S_1 = mR \text{ L}_n \frac{P1}{P2}$$

$$S_g = C_{pL} \text{ L}_n \frac{T}{273} + \frac{h_{fg}}{T_f}$$

$$S = C_{pL} \text{ L}_n \frac{T_f}{273} + \frac{hf_g}{T_f} + C_{pu} \text{ L}_n \frac{T}{T_f}$$

$$S_2 - S_1 = MC_p \text{ L}_n \frac{T_2}{T_1} - MRL_n \frac{P_2}{P_1}$$

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)	$\frac{p_1 v_1 - p_2 v_2}{n - 1}$	$p_1 v_1^{n} = p_2 v_2^{n}$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n - 1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{n - 1}{n}}$	$c_n = c_v\left(\frac{\gamma - n}{1 - n}\right)$

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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*) $c_v \log_e \frac{p_2}{p_1} + c_v \log_e \frac{v_2}{v_1}$ (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	$c_v \left(\frac{n-\gamma}{n-1}\right) \log_e \frac{T_2}{T_1}$

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

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

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

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

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

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

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

Please turn the page

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

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

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

$\eta = (h_1 - h_2)/(h_1 - h_{f2})$

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

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

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

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

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

$$I = ToS_{gen}$$

$F = \tau \pi DL$

Please turn the page

$$V = r\omega$$

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

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

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

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

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)

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

Second order Transfer Function

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

Please turn the page

	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

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

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

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

$t_p = \pi/\omega_d$

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

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

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