OCD015

# UNIVERSITY OF BOLTON

# OFF CAMPUS DIVISION

# WESTERN INTERNATIONAL COLLEGE

# BENG(HONS) MECHANICAL ENGINEERING

# SEMESTER ONE EXAMINATION 2022/2023

# ADVANCED THERMOFLUIDS & CONTROL SYSTEM

# MODULE NO: AME6015

**Date: Wednesday, 11 January 2023** **Time: 10:00 – 12:30**

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**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 that the shear stress variation across the section of the pipe is linear.

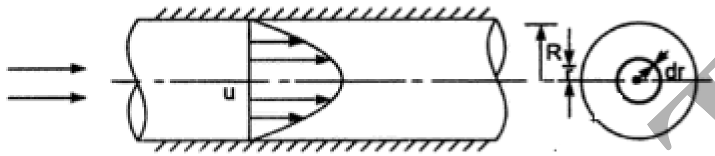


**Figure Q1a.** Circular pipe

(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 loss due to friction, and (ii) Power required to pump the oil.

(7 marks)

c) The velocity distribution for flow over a plate is gives by $u = 2y - y^2$ where u is the velocity in m/s at a distance y metres above the plate. Determine the velocity gradient and shear stress at the boundary and 1.5 m from it. Take dynamic viscosity of fluid as 0.9 N-s/$m^2$.

(6 marks)

**Total 25 marks**



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**Q2.**

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.

(15 marks)

b) A Collar bearing having external and internal diameters 240 mm and 180 mm respectively is used to take the thrust of a shaft. An oil film of thickness 0.25 mm and of viscosity 0.8 poise is maintained between the collar surface and the bearing. Find the power lost in overcoming the viscous resistance of oil when the shaft is running at 300 rpm.

(10 marks)

**Total 25 marks**

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**Q3.**

(a) Steam enters an engine at an absolute pressure of 10 bar 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

(2marks)

(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 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**

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## PART B

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

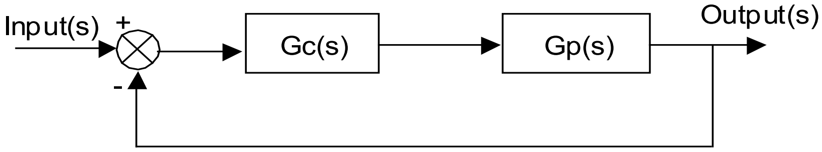


**Figure Q4.** closed-loop control system

Given

$$G_cG_c(s)=10+10\frac{K_i}{s}+10sK_D\frac{K_i}{s}+10sK_D$$

$$G_p(s)=\frac{4}{s^2+6s}$$

Where $G_C(s)$ = controller gain

$G_p(s)$ = plant transfer function

$K_p$ = Proportional gain

$K_i$ = Integral gain

$K_d$ = Differential gain

(a) If $K_i$=0, determine the value of $K_d$ for critical damping.

(4 marks)

(b) With $K_D$ as determined in (a) determine the limiting value of $K_i$ such that stability is maintained.

(7 marks)

(c) Find the Ki for a unit parabolic input ($\Theta_i = \frac{1}{s^3}\frac{1}{s^3}\frac{1}{s^2}$) if $G_C(s)$ is a PI controller and the steady state error is less than 5%.

(3 marks)

(d) Design a PID controller by determining $K_p$ and $K_d$ (using the $K_i$ obtained from (c) above) to achieve less than 20 % overshoot and settling time (ts) less than 4 seconds.

(8 marks)

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

(3 marks)

**Total 25 marks**

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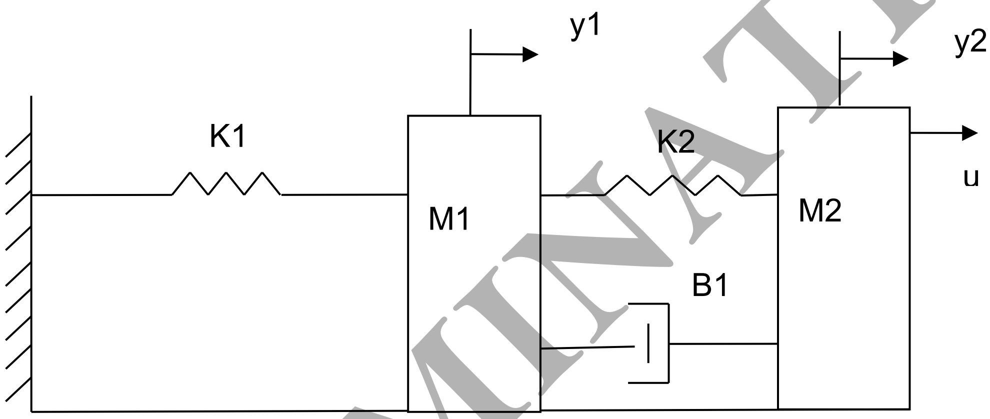
**Q5.**

(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

(17 marks)

(b) The state equations of a mechanical system are given below. Analyse controllability and observability of the linear time invariant system.

$$\dot{x}_1 = -x_1$$
$$\dot{x}_2 = -2x_2 + u$$
$$y = x_1 + x_2 x_1 + x_2$$

(8 marks)

**Total 25 marks**

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**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

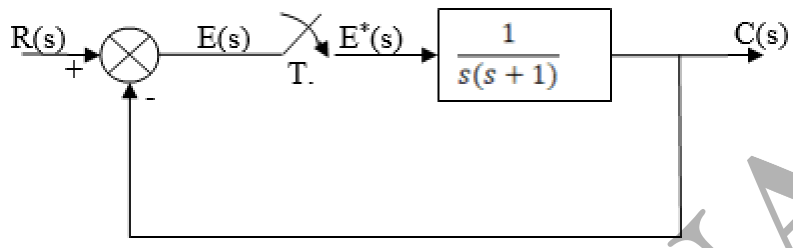


**Figure Q6.** sampled data controller

a) Analyse the stability of the sampled control system shown for sampling time T=1 sec.

(20 marks)

b) Explain how ADC and DCAs operates in a digital control system using a block diagram.

(5 marks)

**Total 25 marks**

**END OF QUESTIONS**

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**FORMULA SHEET**

**Thermofluids**

$P = \rho g h$

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

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

$W = \int P dV$

$P V^n = C$

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

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

$Re = V D \rho/\mu$

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

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

$dQ = du + dw$

$du = Cv \, dT$

$dw = pdv$

$pv = mRT$

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$h = h_f + xhf_g$

$s = s_f + xsf_g$

$v = x\ Vg$

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

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

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

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

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

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

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

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



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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 | $n = 1$ | $p_1 v_1 \log_e \frac{v_2}{v_1}$ | $p_1 v_1 \log_e \frac{v_2}{v_1}$ | $p_1 v_1 = p_2 v_2$ | $\infty$ |
| Reversible adiabatic | $n = \gamma$ | 0 | $\frac{p_1 v_1 - p_2 v_2}{\gamma - 1}$ | $p_1 v_1^{\gamma} = p_2 v_2^{\gamma}$<br>$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1}$<br>$= \left(\frac{p_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$ | 0 |
| Polytropic | $n = n$ | $c_n(T_2 - T_1)$<br>$= c_v\left(\frac{\gamma - n}{1 - n}\right) \times (T_2 - T_1)$<br>$= \frac{\gamma - n}{\gamma - 1} \times$ work done (non-flow) | $\frac{p_1 v_1 - p_2 v_2}{n - 1}$ | $p_1 v_1^{n} = p_2 v_2^{n}$<br>$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n - 1}$<br>$= \left(\frac{p_2}{p_1}\right)^{\frac{n - 1}{n}}$ | $c_n = c_v\left(\frac{\gamma - n}{1 - n}\right)$ |

| *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*)<br>(*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*)<br>(*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 | $c_v \left(\frac{n - \gamma}{n - 1}\right) \log_e \frac{T_2}{T_1}$ |

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

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

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

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

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

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

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

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

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

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

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$V = r\omega$

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

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

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

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

**Control system**

**Blocks with feedback loop**

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

**Steady-State Errors**

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

**Second order Transfer Function**

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



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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 | $\frac{1}{s^2}$ | |
| | $1-e^{-st}$ | $1-z^{-1}$ |

**Time Response for second-order systems**

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

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

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

$t_p = \pi/\omega_d$

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

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

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