[OCD006]

# UNIVERSITY OF BOLTON

# OFF CAMPUS DIVISION

# WESTERN INTERNATIONAL COLLEGE

# BENG(HONS) MECHANICAL ENGINEERING

# TRIMESTER ONE EXAMINATION 2021/2022

# ADVANCED THERMOFLUIDS & CONTROL SYSTEMS

# MODULE NO: AME6015

**Date: Thursday 13th January 2022** **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 – ATTEMPT ANY TWO QUESTIONS FROM PART A**

**Q1.**

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

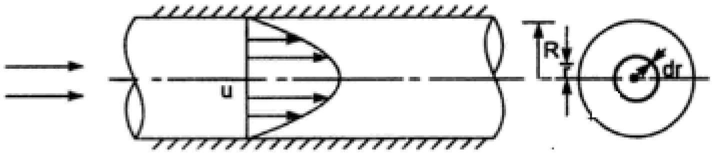


**Figure Q1a.** Circular pipe

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

**(10 marks)**

ii) The velocity variation is parabolic

**(10 marks)**

b) 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.

Determine the following:

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

**(3 marks)**

ii) Power lost in overcoming the viscous resistance of oil

**(2 marks)**

**Total 25 marks**

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**Q2**

a) Water at 30°C 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°C = 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

**(4 marks)**

iv. Minor head loss

**(5 marks)**

v. Total head loss

**(3 marks)**

b) An oil of viscosity 0.1Ns/$m^2$ 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)**

c) Explain the following terms

i) surface roughness fraction

ii) Friction factor

**(2 marks)**

**Total 25 marks**

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**Q3**

a) Steam enters an engine at an absolute pressure of 10bar and at a temperature of 400ºC.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)**

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**

**END OF PART A. PLEASE TURN THE PAGE FOR PART B…**

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**PART B – ATTEMPT ANY TWO QUESTIONS FROM PART B**

**Q4**

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

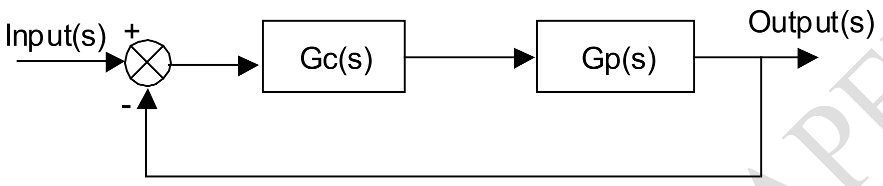


**Figure Q4.** closed-loop control system



Given

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

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.

**(6 marks)**

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

**(8 marks)**

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

**(6 marks)**

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

**(5 marks)**

**Total 25 marks**
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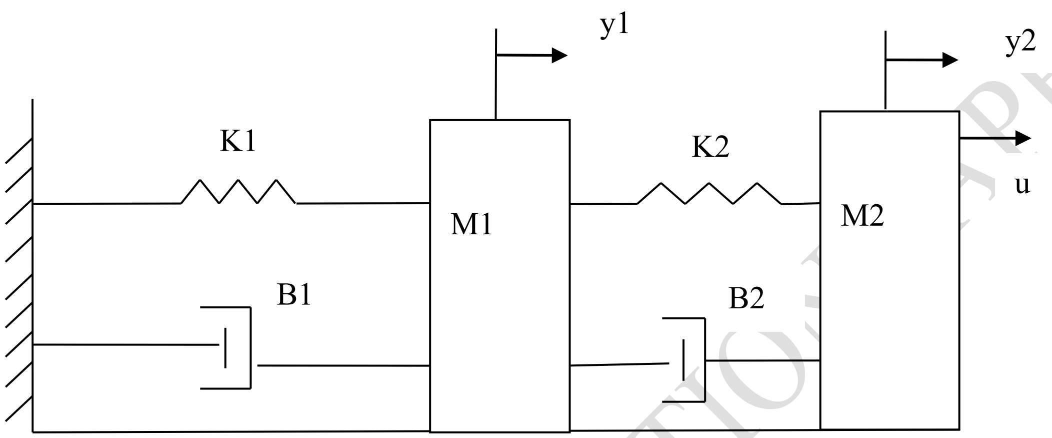
**Q5**

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

**(15 marks)**

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

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -2x_1 - 3x_2 + u$$
$$y = x_1 + x_2$$

**(10 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 I;E(s) = error ;$E^*(s)$ =sampled error; T= sampling time

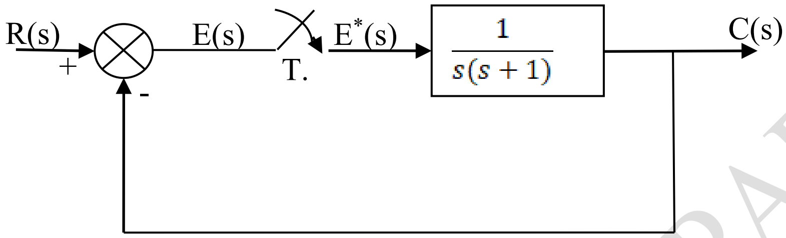


**Figure Q6.** sampled data controller

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

**(13 marks)**

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

**(12 marks)**

**Total 25 marks**



**END OF QUESTIONS**

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## FORMULA SHEET

**Thermofluids**

$P = \rho gh$

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

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

$W = \int PdV$

$PV^n = C$

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

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

$Re = V D \rho/\mu$

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

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

$dQ = du + dw$

$du = Cv \, dT$

$dw = pdv$

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$$pv = mRT$$

$$h = h_f + xhf_g$$

$$s = s_f + xsf_g$$

$$v = x\,Vg$$

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

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

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

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

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

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

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

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

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| *Process* | *Index* $n$ | *Heat added* | $\int_1^2 pdv$ | *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*) $c_v \log_e \frac{p_2}{p_1} + c_p \log_e \frac{v_2}{v_1}$ (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) = $\frac{Go(s)}{1 + Go(s)H(s)}$ (for a negative feedback)

**Steady-State Errors**

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

**Second order Transfer Function**

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

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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**

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

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

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

$t_p = \pi/\omega_d$

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

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

**END OF FORMULA SHEETS**

**END OF PAPER**