[OCD150]

UNIVERSITY OF GREATER MANCHESTER

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE, RAS AL KHAIMAH

BENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2025/2026

ADVANCED THERMOFLUIDS & CONTROL SYSTEM

MODULE NO: AME6015

Date: Tuesday, 13th January 2026 **Time: 1:00pm – 3:30pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX (6) questions.

Answer FOUR (4) questions.

All questions carry equal marks.
Attempt 2 questions from PART A and 2 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

PART A

Q1. In an industrial transport system, crude oil with dynamic viscosity μ = 15 poise and relative density 0.9 flows in a vertical circular pipe of 20 mm diameter. Two pressure gauges fitted 20 m apart vertically read 58.86 N/cm² at point A and 19.62 N/cm² at point B as shown in **Figure Q1b.** Determine:

i) Determine the direction and rate of flow through the pipe and state your reasoning clearly.

(8 marks)

ii) Assuming steady, fully developed, laminar flow of a Newtonian liquid, calculate the volumetric flow rate through the pipe.

(8 marks)

iii) Check your assumption in (ii) by evaluating the Reynolds number and commenting on the flow regime.

(4 marks)

iv) Explain briefly how hydrostatics and viscous resistance help engineers predict direction of flow and discharge in vertical pipes.

(5 marks)

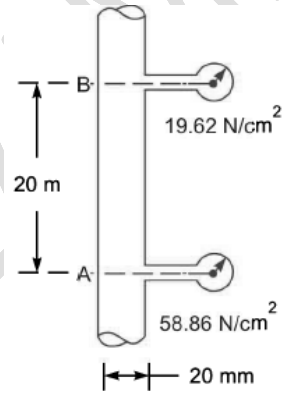

Figure Q1b: Pressure readings

Total 25 marks

Please turn the page

Q2. a) A horizontal crack of width 40 mm, depth 2.5 mm, and length 100 mm allows water to leak through under a pressure difference of 0.02943 N/cm². Given that the viscosity of water is 0.01 poise, use appropriate mathematical relations for laminar flow between parallel plates to:

i) Calculate the volumetric flow rate of leakage, and

(10 marks)

ii) State clearly the assumptions and simplifications made in your analysis.

(3 marks)

b) Water is flowing through a rough horizontal pipe with diameter 500 mm, length 4000 m, and average roughness k = 0.40 mm, at a discharge rate of 0.5 m³/s.
Using appropriate mathematical relations (Darcy–Weisbach equation and empirical correlations for friction factor such as the Moody chart or Colebrook equation):

i) Determine the head loss due to friction and state all assumptions made in the analysis,

(8 marks)

ii) Calculate the power required to overcome this loss.

(4 marks)

Total 25 marks

Q3. (a) Briefly describe the limitations of the First Law of Thermodynamics and outline the Kelvin–Planck and Clausius statements of the Second Law.

(4 marks)

Q3. Continues over the page

Q3. Continued….

(b) A reversible heat pump maintains a refrigerated space at 0 °C, while rejecting heat to the ambient air at 25 °C. The rate of heat extraction is 1440 kJ/min.

i) Determine the C.O.P. of the heat pump and the input work required.

(4 marks)

ii) If the work input is supplied by a reversible heat engine operating between 380 °C and 25 °C, calculate the overall C.O.P. of the system.

(6 marks)

(c) A mass of 1 kg of air at an initial pressure of 8 bar and temperature of 100°C expands reversibly according to the polytropic law $pv^{1.2} = constant$ until the pressure falls to 1.8 bar.

i) Determine the final specific volume, temperature, and change in specific entropy of the air.

(4 marks)

ii) Calculate the work done and the heat transfer during the process.

(5 marks)

iii) Briefly comment on how the energy (work/heat) and entropy interactions illustrate a system-based thermodynamic approach to analysing gas processes.

(2 marks)

Total 25 marks

Please turn the page

PART B

Q4. a) Develop the **state-space model** for the simplified mechanical system shown in **Figure Q4.** The system consists of two masse m_1 and m_2 connected by a spring of stiffness k.Mass m_1 is attached to a wall through a **damper** with damping coefficient b. An **external force** f acts on the second mass m_1 and m_2.The displacements of the masses from their equilibrium positions are denoted by $y1$ and $y2$ respectively.

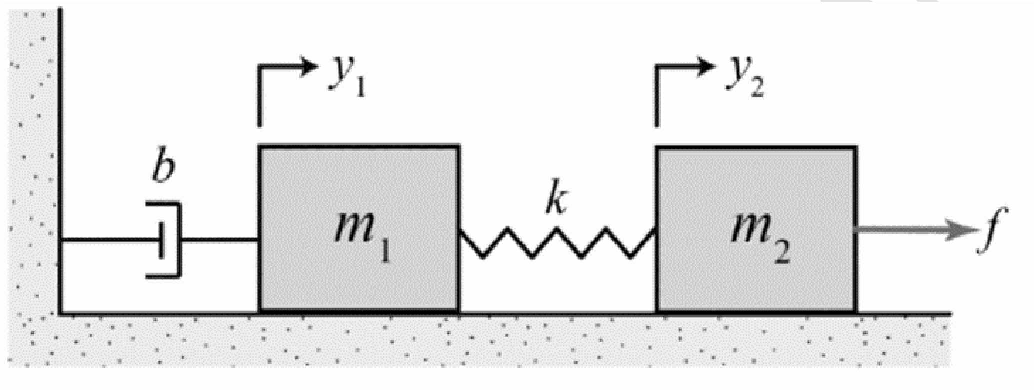

Figure Q4. Simplified mechanical system

(12 marks)

b) Draw the frequency response of the given second-order system

$$G(s) = \frac{1}{s^2+2s+4}$$

Show both the magnitude and phase plots over a suitable range of frequencies, and clearly indicate the resonant frequency, cutoff frequency and bandwidth on the magnitude plot.

(13 marks)

Total 25 marks

Q5. A unity feedback closed-loop control system in **Figure Q5** has

$$G_c(s) = 2 + 2\frac{K_i}{s} + 3\,K_d\,s$$

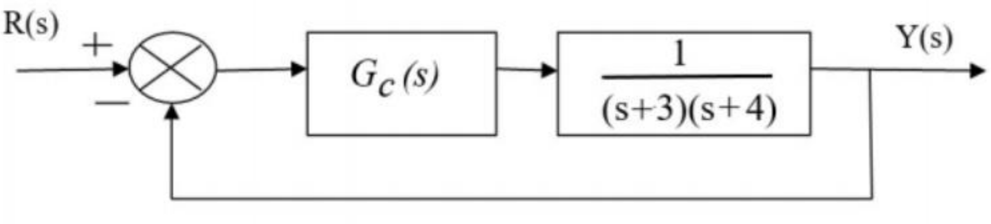

Figure Q5. Closed loop control system

Q5. Continues over the page

Q5. Continued….

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

i) For a PD controller, design the value of Kd for critical damping.
(8 marks)

ii) With Kd as determined in (a), design the limiting value of Ki such that stability is maintained for a PID controller.
(9 marks)

iii) For a PI controller, design the Ki for a ramp input and the steady state error is less than 3%.
(8 marks)

Total 25 marks

Q6. An industrial manufacturing system using a sampled data controller is shown in **Figure Q6.**

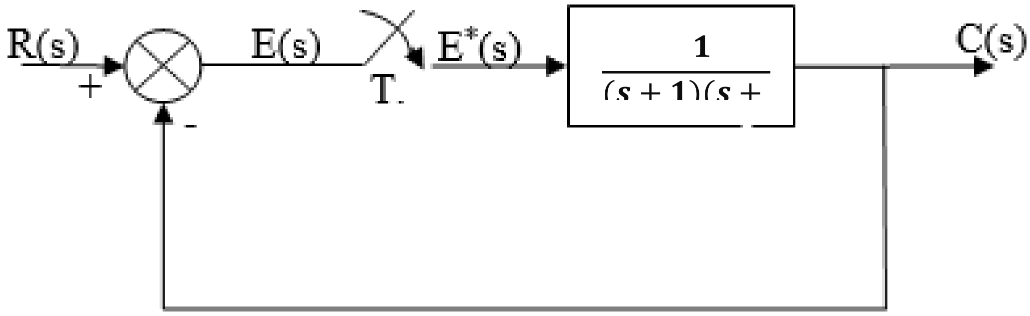

Figure Q6. Sampled data controller

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

ii) Explain the concept of digital (discrete-time) control systems, highlighting their structure, advantages over continuous-time systems, and typical applications in modern industrial automation.
(5 marks)

Total 25 marks

END OF QUESTIONS

Please turn the page for formula sheet

University of Greater Manchester
Off Campus Division, Western International College - Ras Al Khaimah
BEng (Hons) Mechanical Engineering
Semester 1 Examination 2025/2026
Advanced Thermofluids & Control Systems
Module No. AME 6015

FORMULA SHEET

Thermofluids

$P = F/A$

$\rho = m/v$

$\dot{m} = \rho AV$

$P = P_g + P_{atm}$

$P = \rho gh$

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

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

$W = \int PdV$

$P V^n = C$

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

$W = P (v_2 - v_1)$

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

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

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

$F = \rho QV$

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

$Re = V D \rho/\mu$

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

$dQ = du + dw$

$du = Cv\, dT$

$dw = pdv$

$pv = mRT$

$h = h_f + xh_{fg}$

$s = s_f + xs_{fg}$

$v = x\, Vg$

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

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

$$\Delta s = c_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{v_2}{v_1}\right)$$

Total Entropy = m Δs **Please turn the page**

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	$n = 1$	$p_1v_1 \log_e \frac{v_2}{v_1}$	$p_1v_1 \log_e \frac{v_2}{v_1}$	$p_1v_1 = p_2v_2$	∞
Reversible adiabatic	$n = \gamma$	0	$\frac{p_1v_1 - p_2v_2}{\gamma - 1}$	$p_1v_1^{\gamma} = p_2v_2^{\gamma}$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$	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)	$\frac{p_1v_1 - p_2v_2}{n - 1}$	$p_1v_1^{n} = p_2v_2^{n}$ $\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n-1}$ $= \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$	$c_n = c_v\left(\frac{\gamma - n}{1 - n}\right)$

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

Please turn the page

$$\frac{p}{\rho g} + \frac{v^2}{2g} + Z = \text{constant}$$

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

$$h_f = \frac{32\mu \bar{u} L}{\rho g D^2}$$

$$p_1 - p_2 = \frac{12\mu \bar{u} L}{t^2}$$

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

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

$$h_m = \frac{K\mathrm{v}^2}{2g}$$

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

$$Q = \bar{u}\, A$$

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

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

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

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

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

Please turn the page

$I = ToS_{gen}$

Thermal Efficiency of a Heat Engine

$$\eta_{\mathrm{th}} = \frac{Q_1 - Q_2}{Q_1}$$

Coefficient of Performance of a Refrigerator

$$(\mathrm{C.O.P.})_{\mathrm{ref}} = \frac{Q_2}{Q_1 - Q_2}$$

Coefficient of Performance of a Heat Pump

$$(\mathrm{C.O.P.})_{\mathrm{hp}} = \frac{Q_1}{Q_1 - Q_2}$$

Control system

Blocks with feedback loop

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

G(s) = $\dfrac{Go(s)}{1 - Go(s)H(s)}$ (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)

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

Second order Transfer Function

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

University of Greater Manchester
Off Campus Division, Western International College - Ras Al Khaimah
BEng (Hons) Mechanical Engineering
Semester 1 Examination 2025/2026
Advanced Thermofluids & Control Systems
Module No. AME 6015

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

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

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

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

$t_p = \pi/\omega_d$

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

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

End of paper