UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2021/2022

ADVANCED THERMOFLUID AND CONTROL SYSTEMS

MODULE NO: AME6015

Date: Tuesday 11th January 2022 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

CANDIDATES REQUIRE: **Formula Sheets (attached following questions).**

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Question 1

a) Steam is at 22 bar and has enthalpy of 2750KJ/Kg. Find the dryness fraction, specific volume and internal energy

(12 Marks)

b) A Reversible engine operates between temperature of 400℃ and 2800℃, the heat being supplied is at the rate of 300KJ/s. Determine its efficiency and power output.

(**8 Marks**)

c) A Steam Power Plant working on the Carnot cycle operates between 1 bar 99.6°C and 10 bar 179.92 °C. Determine the pressure, temperature and entropy of all points and draw the cycle on the P-V and T-S diagram.

(5 Marks)

Total 25 Marks

Question 2

a) The phenomenon of drag is of consideration important to engineers involved in the design of vehicles. The drag F on a fully submerged smooth sphere of diameter D depends on its velocity V, the density of fluid ρ, and the viscosity of the fluid μ. Arrange these variables into independent dimensionless numbers.

(15 Marks)

b) Gasoline at a temperature of 20°C ($v=4.5\times10^{-7}$ m^2/s) flows through a flexible pipe from a gas pump to the gas tank of a car. If 3L/s are flowing and the pipe has an inside diameter of 60mm, what is the Reynolds number? Is the flow laminar or turbulent?

(10 Marks)

Total 25 Marks

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Question 3

a) The Radiator of a steam heating system has a volume of 15L and is filled with superheated water vapour at 200Kpa and 200 degrees Celsius. At this moment both the inlet and the exit valves are closed. After a while the temperature of the steam drops to 80 degrees Celsius as a result of heat transfer to the room air. Determine the entropy change of the steam during this process.

(10 Marks)

b) i) Determine the head loss due to a flow of 100l/s of glycerine at 20℃ through 100m of 20cm diameter pipe. Glycerine has a specific gravity of 1.26 and Viscosity 0.886 Ns/m^2.

ii) Rework the problem for water as fluid, with density = 1000Kg/m^3 at 20℃ and viscosity of 1.005×10^{-3} Ns/m^2. For water use the Moody diagram provided in the Appendix with ε=0.025cm.

(15 Marks)

Total 25 Marks

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Question 4

a) Derive the differential equations describing the behaviour of the spring-mass-damper system shown in **Figure Q4**.

(8 Marks)

b) Select the state variables and transfer the differential equations obtained from 4a into the state-space representation.

(10 Marks)

c) Determine the state space equations and system matrices A, B, C and D, where A, B, C, and D have their usual meaning, and the output variable are y_1 and $\dot{y}_1$.

(4 Marks)

d) Evaluate the system matrices A, B, C and D for $m_1 = 2$, $m_2 = 5$, $k_1 = 10$, $k_2 = 6$ and $c_2 = 0.2$.

(3 Marks)

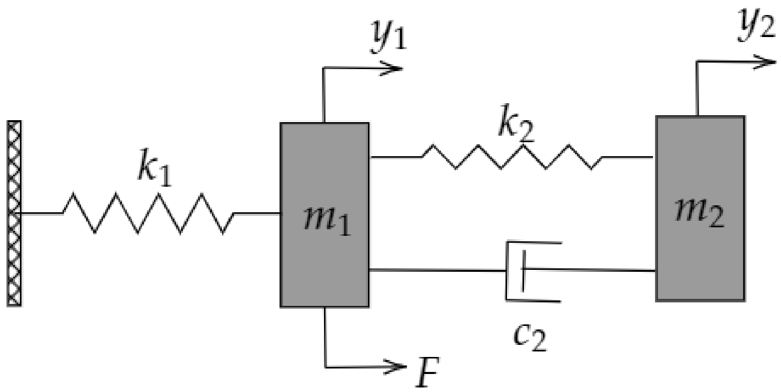

Figure Q4: Spring-mass-damper system with two masses.

Total 25 Marks

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Question 5

A PID controller is used to control an automation processing plant as shown in Figure Q5. The open loop transfer function of the plant is given by

$$G_p(s) = \frac{60}{(s+2)(s+5)}$$

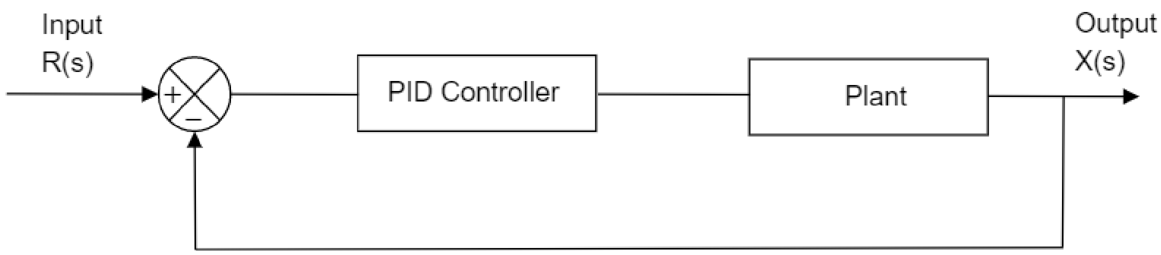

Figure Q5: Control system of the processing plant.

(a) Evaluate the performances of closed loop plant system (natural frequency, damping ratio, Percentage Overshoot, peak time, settling time and steady-state error) to assess its performance without the PID controller.

(10 Marks)

(b) Design a PID controller to determine the parameter K_p, K_i and K_d, and clearly identify the design procedure if the system responses for a unit step input are required as:

- The maximum overshoot is less than 8%.
- The settling time is 40% less than that of without the PID controller.
- The steady-state error is 0.

(15 Marks)

Total 25 Marks

Question 6

The transfer function of a servo control system is given as

$$G(s) = \frac{100}{(s+2)(s+10)}$$

a) Draw the asymptotic Bode plot.

(15 Marks)

b) Draw the Nyquist plot using the ω values at 0, 0.5, 1, 2, 3, 5, 10 and 100.

(10 Marks)

Total 25 Marks

END OF QUESTIONS

Formula Sheets follow over the page….

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Formula sheet

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

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

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_o(s)}{1+G_o(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \dfrac{1}{1+\lim_{z\to 1} G_0(z)}$ (if a digital system subjects to a unit step input)

Laplace Transforms

A unit impulse function 1

A unit step function $\dfrac{1}{s}$

A unit ramp function $\dfrac{1}{s^2}$

First order Systems

$G(s) = \dfrac{\theta_o}{\theta_i} = \dfrac{G_{ss}(s)}{\tau s+1}$

$\tau\left(\dfrac{d\theta_o}{dt}\right)+\theta_o = G_{ss}\theta_i$

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

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

$\theta_o(t) = G_{ss}(\dfrac{1}{\tau})e^{-(t/\tau)}$ (for an impulse input)

Second-order systems

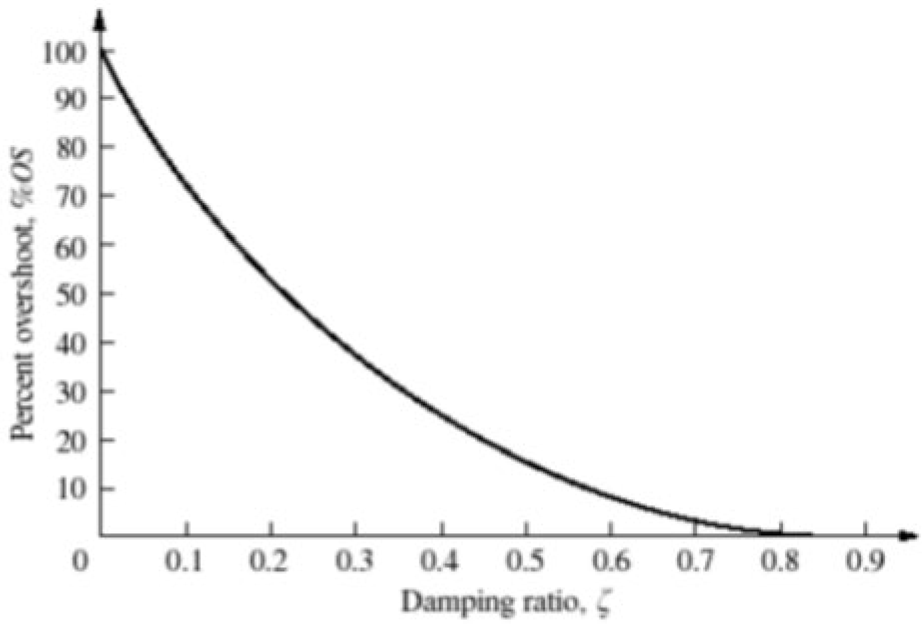
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n \frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\omega_d t_r = 1/2\pi$ $\omega_d t_p = \pi$

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

$t_s = \dfrac{4}{\zeta\omega_n}$ $\omega_d = \omega_n\sqrt{(1-\zeta^2)}$



Controllability: $R = [B \; AB \; A^2B \ldots\ldots A^{(n-1)} B]$

Observability:

Laplace Transforms of common functions

Functions		
Unit pulse (Dirac delta distribution)	$\delta(t)$	$F(s)=1$
Unit step function	$1(t)$	$F(s)=\frac{1}{s}$
Ramp function	$f(t)=at$	$F(s)=\frac{1}{s^2}$
Sine function	$f(t)=\sin at$	$F(s)=\frac{a}{s^2+a^2}$
Cosine function	$f(t)=\cos at$	$F(s)=\frac{s}{s^2+a^2}$
Exponential function	$f(t)=e^{at}$	$F(s)=\frac{1}{s-a}$
Operations		
Differentiation	$L(f'(t))$	$sF(s)-f(0)$
Integration	$L\left(\int f(t)dt\right)$	$\frac{1}{s}F(s)$
Time shift	$Lf(t-a)$	$e^{-as}F(s)$

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$$W = \frac{P_1 V_1 - P_2 V_2}{n - 1} \qquad W = P\,(v_2 - v_1)$$

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

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

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

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

$$F = \rho\, QV$$

$$Re = V\,L\,\rho/\mu$$

$$dQ = du + dw$$

$$du = cu\,dT$$

$$dw = pdv$$

$$pv = mRT$$

$$h = hf + xhf_g$$

$$s = sf + xsf_g$$

$$v = x\,Vg$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I = ToS_{gen}$$

$$V = r\omega$$

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

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

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

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

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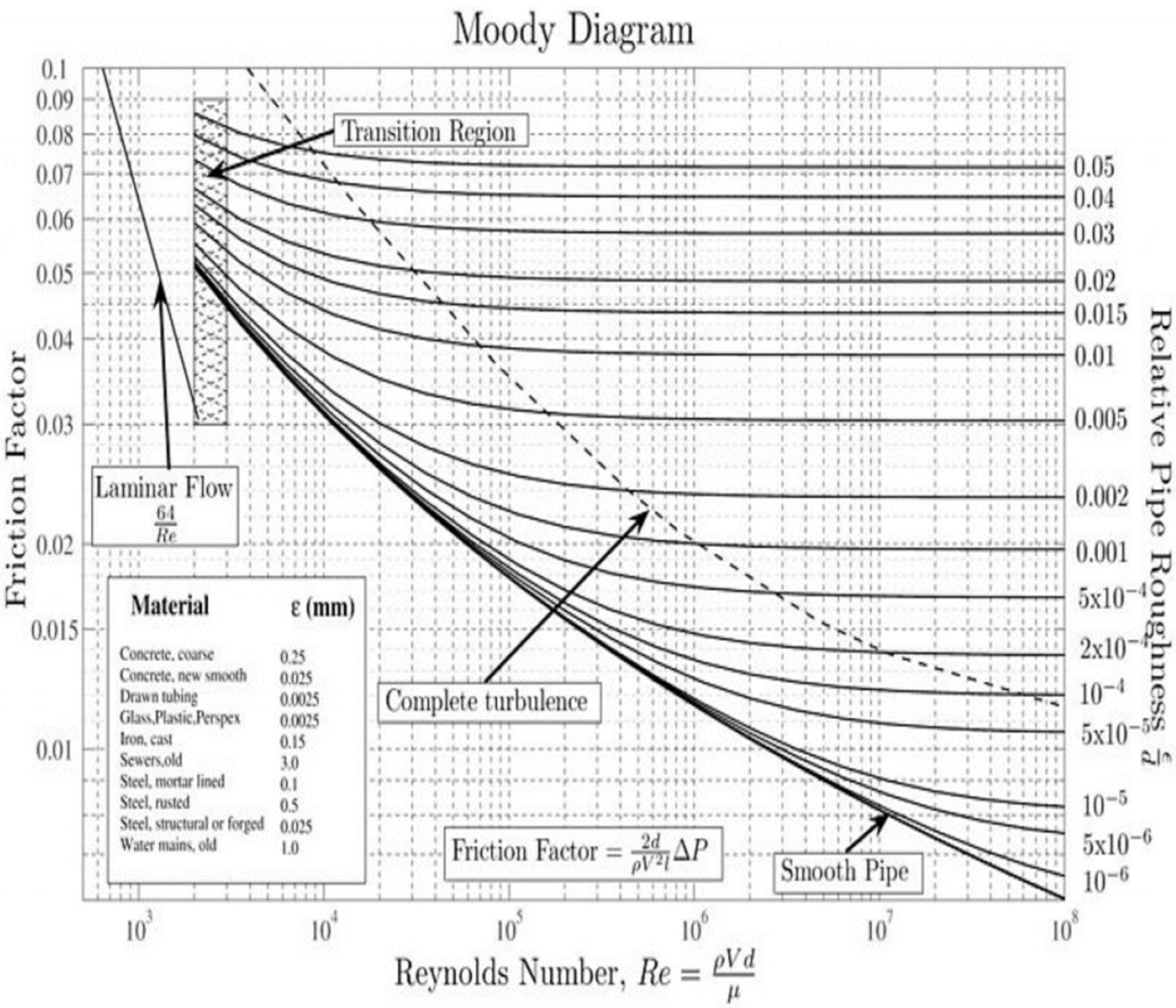

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DIMENSIONS FOR CERTAIN PHYSICAL QUANTITIES

Quantity	Symbol	Dimensions	Quantity	Symbol	Dimensions
Mass	m	M	Mass /Unit Area	m/A^2	ML^{-2}
Length	l	L	Mass moment	ml	ML
Time	t	T	Moment of Inertia	I	ML^2
Temperature	T	θ	-	-	-
Velocity	u	LT^{-1}	Pressure /Stress	p/σ	$ML^{-1}T^{-2}$
Acceleration	a	LT^{-2}	Strain	τ	$M^0L^0T^0$
Momentum/Impulse	mv	MLT^{-1}	Elastic Modulus	E	$ML^{-1}T^{-2}$
Force	F	MLT^{-2}	Flexural Rigidity	EI	ML^3T^{-2}
Energy - Work	W	ML^2T^{-2}	Shear Modulus	G	$ML^{-1}T^{-2}$
Power	P	ML^2T^{-3}	Torsional rigidity	GJ	ML^3T^{-2}
Moment of Force	M	ML^2T^{-2}	Stiffness	k	MT^{-2}
Angular momentum	-	ML^2T^{-1}	Angular stiffness	T/η	ML^2T^{-2}
Angle	η	$M^0L^0T^0$	Flexibility	1/k	$M^{-1}T^2$
Angular Velocity	ω	T^{-1}	Vorticity	-	T^{-1}
Angular acceleration	α	T^{-2}	Circulation	-	L^2T^{-1}
Area	A	L^2	Viscosity	μ	$ML^{-1}T^{-1}$
Volume	V	L^3	Kinematic Viscosity	τ	L^2T^{-1}
First Moment of Area	Ar	L^3	Diffusivity	-	L^2T^{-1}
Second Moment of Area	I	L^4	Friction coefficient	f/μ	$M^0L^0T^0$
Density	ρ	ML^{-3}	Restitution coefficient		$M^0L^0T^0$
Specific heat-Constant Pressure	C_p	$L^2T^{-2}\theta^{-1}$	Specific heat-Constant volume	C_v	$L^2T^{-2}\theta^{-1}$

Note: a is identified as the local sonic velocity, with dimensions $L.T^{-1}$

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