UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

ADVANCED THERMOFLUIDS AND CONTROL SYSTEMS

MODULE NO: AME6015

Date: Thursday 17th January 2019 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY 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:

Thermodynamics properties of fluids (provided)

Formula sheet (provided)

Density of water = 1000kg/m^3

Q1

a) Show that the force for the Journal oiled bearing shown in figure Q1a is

$$F = \frac{2\Pi \text{ L } \mu U}{\text{Ln } (\frac{R2}{R1})}$$

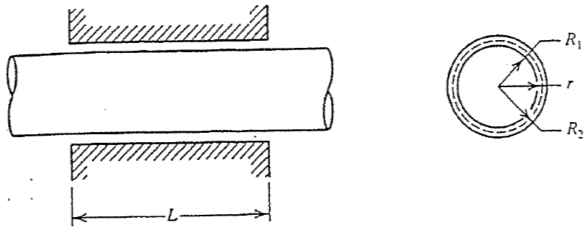

Figure Q1a

Use: ƛ $= \mu \frac{du}{dy}$

(10 marks)

b) A crank shaft journal oiled bearing in an automobile engine is lubricated by an oil at 99°C with dynamic viscosity μ = 9.6 X10^{-3} Ns/m^2

The bearing diameter is 76mm, the diametral clearance is 0.0635mm and the shaft rotates at 360rpm. It is 31.8mm long. The bearing is under no load so the clearance is symmetric.

Determine

i) The torque required to turn the journal

(8 marks)

ii) The power dissipated

(7 marks)

Total 25 marks

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Q2

a) Air flows through a long duct of constant area at 0.15 kg/s. A short section of the duct is cooled by liquid nitrogen that surrounds the duct. The rate of heat loss in this section is 15 KJ/s from the air. The absolute pressure, temperature and velocity entering the cooled section are 188 kPa, 440 K and 210 m/s respectively. At the outlet the absolute pressure and temperature are 213 kPa and 351 K.

Calculate the change in enthalpy, internal energy and entropy for this flow.

Take C_V = 0.717 kJ/kg K

C_P = 1 KJ/kg K

R = 0.287 kJ/kg K **(15 marks)**

b) A Rankine cycle works between 40 bar and 400℃ at the boiler exit and 0.035 bar at the condenser. Sketch the cycle and calculate the cycle efficiency.

Assume isentropic expansion and ignore the energy term at the feed pump.

(10 marks)

Total 25 marks

Q3

a) Calculate the loss of heat due to friction and the power required to maintain flow in a horizontal circular pipe of 40mm diameter and 750m long when water with coefficient of dynamic viscosity 1.14 x 10^{-3} Ns/m^2 flow at a rate of 4 litres per minute

(7 marks)

b) The tip deflection δ of a cantilever beam is a function of tip load *W*, beam length *l*, second moment of area *I* and Young's modulus *E*. Determine a suitable set of dimensionless parameters using Buckingham Pi theorem.

(8 marks)

c) Steam at 7 bar, dryness fraction 0.9, expands reversibly at constant pressure until the temperature is 200ºC. Calculate the work input and heat supplied per unit mass of steam during the process.

(10 marks)

Total 25 marks

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Q4. A simplified model of a manufacturing automation control system is shown in Figure Q4. The manufacturing system is given by the transfer function as:

$$G_P(s) = \frac{3}{3s^2 + 8s}$$

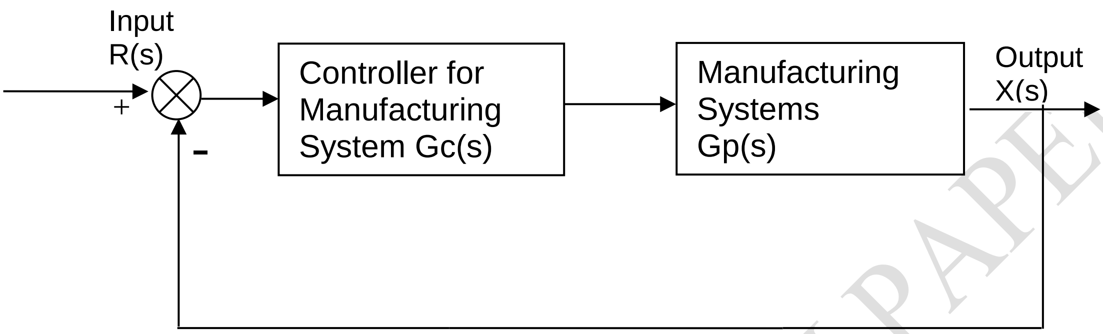

Figure Q4 A manufacturing automation control system

The design criteria for this system are:

Rise time < 0.5 sec
Overshoot < 10%
Steady state error <= 0.2 (for a unit parabolic input = $1/s^3$)

a) Design a PID controller to determine the parameters K_p, K_i, and K_d and clearly identify the design procedure.

(18 marks)

b) If a velocity feedback is introduced into Figure Q4 and suppose Gc(s) = 10, draw a block diagram with the velocity feedback and determine the velocity gain Kv for the damping ratio to be increased to 0.85. **(7 marks)**

(Total 25 marks)

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Q5. A translational mechanical system is shown in Figure Q5.

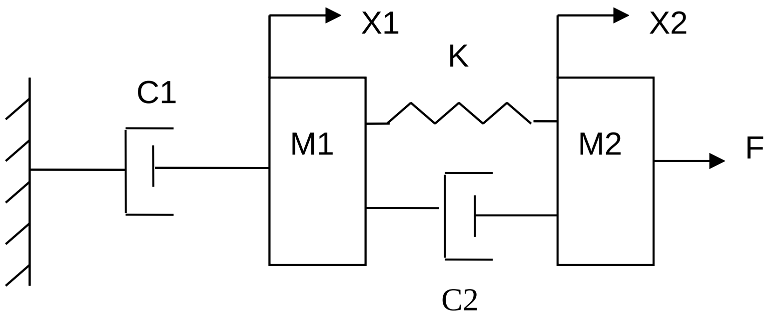

Figure Q5 A Translational Mechanical System

a) Derive the differential equations describing the behaviour of the system.

(6 marks)

b) Select the state variables and transfer the differential equations obtained from Q5(a) above to the relevant first-order differential equations.

(6 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.

(8 marks)

d) Analyse the following system's controllability and observability:

$$A = \begin{bmatrix} 1 & 0 \\ -3 & 5 \end{bmatrix} \qquad B = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad C = \begin{bmatrix} -2 & 4 \end{bmatrix}$$

(5 marks)

Total 25 marks

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Q6.

a) If a machining centre control system consists of a Digital to Analogue Converter with a zero-order hold element in series with the machining centre which has a transfer function

$$G(s) = \frac{6}{2.5s+1}$$

Figure Q6 (a) shows the system

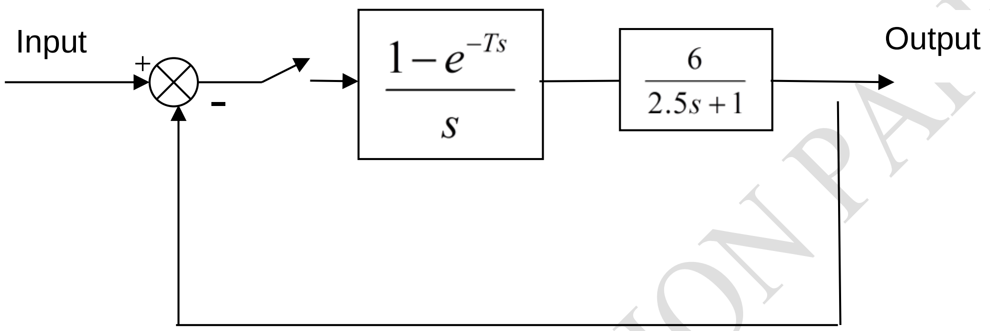

Figure Q6 (a) A machining centre control system

i) Find the sampled-data transfer function, $G_{sys}(z) = \frac{Output}{Input}$ for the digital control system . The sampling time, T, is 0.2 seconds. **(8 marks)**

ii) Check the stability of the digital system. **(4 marks)**

iii) Find the steady-state error for the digital control system, if the system subjects a unit step input. **(3 marks)**

b) If the controller has a 8 bit Analogue to Digital Converter with the signal range between -12 Volt to +12 Volt:

i) What is the resolution of the AD converter? **(2 marks)**

ii) What integer number represented a value of -8 Volts? **(2 marks)**

iii) What voltage does the integer 150 represent? **(3 marks)**

iv) What voltage does 10101101 represent? **(3 marks)**

Total 25 marks

END OF QUESTIONS

Formula Sheet over the page….

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)

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_0(s)}{1+G_0(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \dfrac{1}{1+\lim_{z\to 1} G_O(z)}$ (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

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

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

$\theta_O = G_{ss}(1-e^{-t/\tau})$ (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)

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Second-order systems

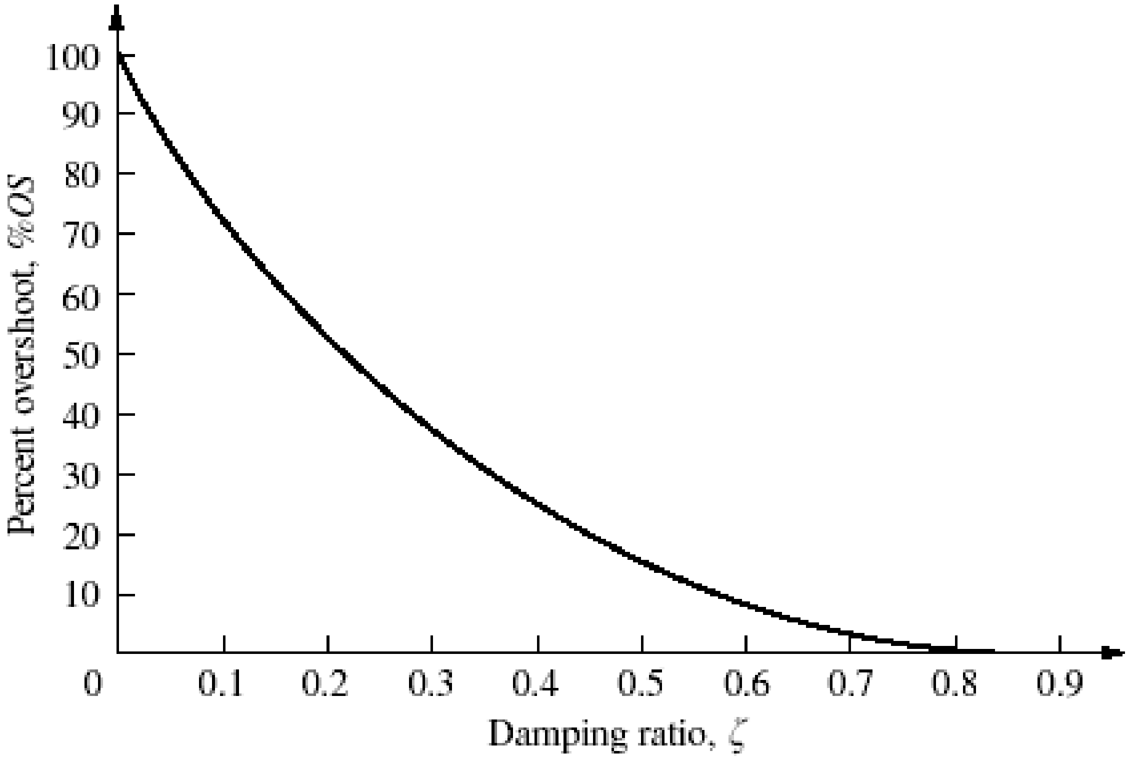
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n \frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

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

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

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

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



Controllability: R = [B AB A^2B…..$A^{(n-1)}$ B]

Observability:

$$\mathcal{O} = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix}$$

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Table 4.1 Laplace transforms

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-st}}{s}$		A delayed unit step function
$\frac{1-e^{-st}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	$t\,e^{-at}$	
$\frac{2}{(s+a)^3}$	$t^2 e^{-at}$	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)\,e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin \omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos \omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta<1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta=\cos\phi$	

Table 15.1 z-transforms

Sampled $f(t)$, sampling period T	$F(z)$
Unit impulse, $\delta(t)$	1
Unit impulse delayed by kT	z^{-k}
Unit step, $u(t)$	$\dfrac{z}{z-1}$
Unit step delayed by kT	$\dfrac{z}{z^k(z-1)}$
Unit ramp, t	$\dfrac{Tz}{(z-1)^2}$
t^2	$\dfrac{T^2z(z+1)}{(z-1)^3}$
e^{-at}	$\dfrac{z}{z-e^{-aT}}$
$1-e^{-at}$	$\dfrac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
$t\,e^{-at}$	$\dfrac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
$e^{-at}-e^{-bt}$	$\dfrac{(e^{-aT}-e^{-bT})z}{(z-e^{-aT})(z-e^{-bT})}$
$\sin \omega t$	$\dfrac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
$\cos \omega t$	$\dfrac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
$e^{-at}\sin\omega t$	$\dfrac{z\,e^{-aT}\sin\omega T}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$
$e^{-at}\cos\omega t$	$\dfrac{z(z-e^{-aT}\cos\omega T)}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$

Table 15.2 z-transforms

$f[k]$	$f[0], f[1], f[2], f[3], \ldots$	$F(z)$
$1u[k]$	$1, 1, 1, 1, \ldots$	$\dfrac{z}{z-1}$
a^k	$a^0, a^1, a^2, a^3, \ldots$	$\dfrac{z}{z-a}$
k	$0, 1, 2, 3, \ldots$	$\dfrac{z}{(z-1)^2}$
ka^k	$0, a^1, 2a^2, 3a^3, \ldots$	$\dfrac{az}{(z-a)^2}$
ka^{k-1}	$0, a^0, 2a^1, 3a^2, \ldots$	$\dfrac{z^2}{(z-a)^2}$
e^{-ak}	$e^0, e^{-a}, e^{-2a}, e^{-3a}, \ldots$	$\dfrac{z}{z-e^{-a}}$

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

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

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

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

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

$$F = \rho\, QV$$

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

$$dQ = du + dw$$

$$du = cu\ dT$$

$$dw = pdv$$

$$pv = mRT$$

$$h = h_f + xhf_g$$

$$s = s_f + xsf_g$$

$$v = x\ Vg$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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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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