[ENG 19]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) IN MECHANICAL ENGINEERING

SEMESTER 2 EXAMINATION 2021/2022

THERMOFLUIDS & CONTROL SYSTEMS

MODULE NO: AME5013

Date: Tuesday 17th May 2022 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions on this paper.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

CANDIDATES REQUIRE :

Property Tables provided.
Formula sheet (attached)
Take density of water as 1000 kg/m^3

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Q1. Solve either part A and B or A and C

a) Describe with the aid of a diagram the principles of operation of the Venturi meter. (10 marks)

b) Water is flowing in a fire hose with a velocity of 1.0 m/s and a pressure of 200 kPa. At the nozzle the pressure decreases to atmospheric pressure of 101.3 kPa. There is no change in height . calculate the velocity of the water exiting the nozzle. (15 marks)

c) In **Figure Q1c** fluid P is water and fluid Q is mercury. If the specific gravity of mercury is 13.6 times that of water and the atmospheric pressure is 101.3 kPa what is the absolute pressure at A when h_1 = 20 cm and h_2 = 35 cm.

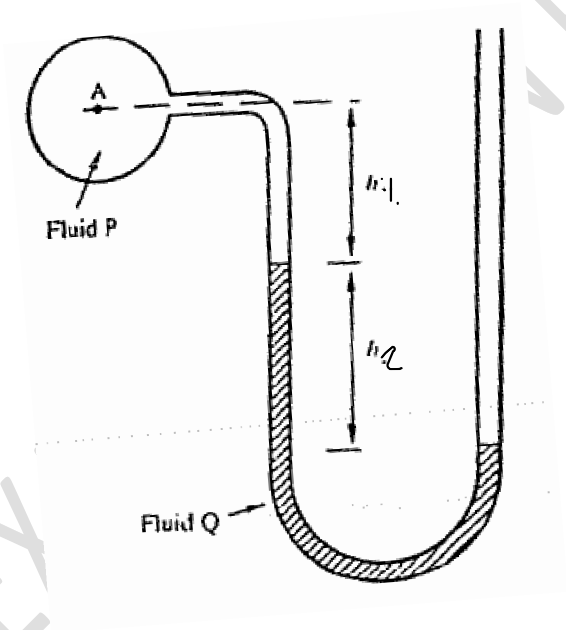

Figure Q1c

(15 marks)

Total 25 marks

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Q2. a) The actual velocity of a liquid issuing through a 7 cm diameter orifice fitted in an open tank is 6 m/s under a head of 3 m. If the discharge measured in a collecting tank is 0.020 m^3/s. Calculate the coefficient of velocity, contraction and the theoretical discharge through the orifice.

(15 marks)

b) A pitot static tube is used to measure the velocity of air flowing through a duct. The manometer shows a difference in head of 5 cm of water. If the density of air and water are, 1.13 kg/m^3 and 1000 kg/m^3 determine the velocity of air. Assume the coefficient of the Pitot tube as 0.98.

(10 marks)

Total 25 marks

Q3. a) A gas in a piston –cylinder equipment undergoes a Polytropic process such that PV^n = constant. The initial pressure is 10 bar, the initial volume is 0.01 m^3 and final volume is o.03 m^3. Calculate the work done for the process if

i) n= 2

ii) n= 0

iii) n=1.0 (10 marks)

b) A jet of fluid has a relative density of 0.85 and 75 mm diameter.it moves with a velocity of 21 m/s. The jet enters the stationary vanes tangentially, and is deflected through 120° when the vanes are stationary. Assume that the Friction between the fluid and the surface is neglected Calculate the magnitude and direction of the resultant force acting on the blade.

(15 marks)

Total 25 marks

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Q4.

You were just hired as an engineer in Keating Supercars. You are asked to model the suspension of the new car model. Your line manager suggested that the vehicle body can be simulated as a solid wall, the wishbone as a spring with stiffness K1, the suspension spring as a spring with stiffness K2, the suspension damper as a damper with damping coefficient C and the wheel as a mass with mass M. **Figure Q4** shows the model of your suspension. The input to the system is the Force F acting from the road to the wheel and the outputs are displacements y_1 *and* y_2.

a) Develop the differential equations for the displacements y_1 *and* y_2 of the machine system. (10 marks)

b) Determine the Laplace transforms of the differential equations obtained from Q4(a) above. Assume the initial conditions of the system are zeros (i.e. at time = 0, y, y', y'' are all zeros). (5 marks

c) Determine the transfer function G(s) = y_2(s)/F(s) (10 marks)

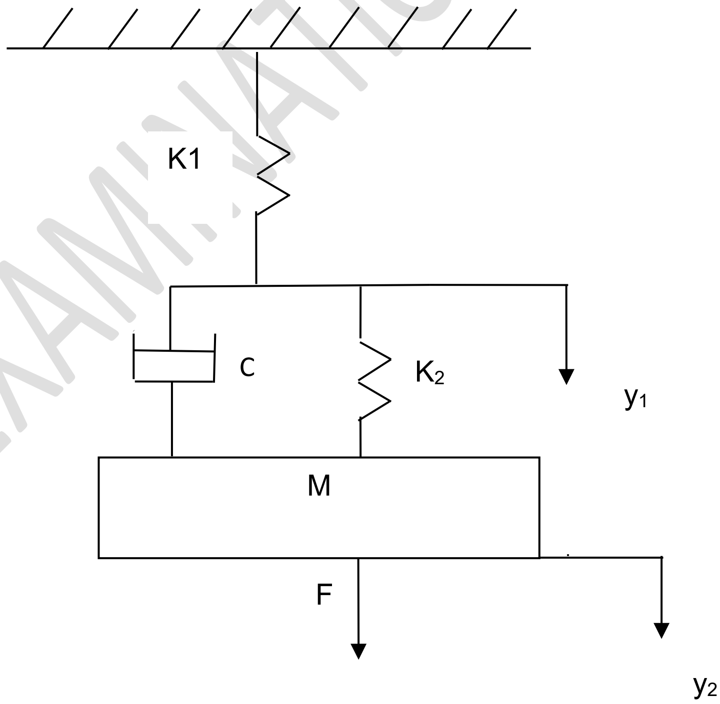

Figure Q4 **Total 25 marks**

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Q5.

A robotic arm is used at your company's assembly line. The robotic arm is designed to turn towards the point you command it to turn. The transfer function of the robotic arm is:

$$G(s) = \frac{200}{4s + 1}$$

You give a unit step input to the robotic arm.

a) Calculate the time required for the robotic arm to reach 75% of its final value.
(5 marks)

b) After 10 seconds, at what percentage of its final value has the robotic arm reached?
(10 marks)

c) In a different part of your company, the manufacturing control system is described by **Figure Q5**. Simplify the block diagram to a single open-loop process. If a unit step input is applied into the system, determine the system's percentage overshoot, rise time, settling time, peak time, natural frequency, damped frequency, and damping ratio.
(10 marks)

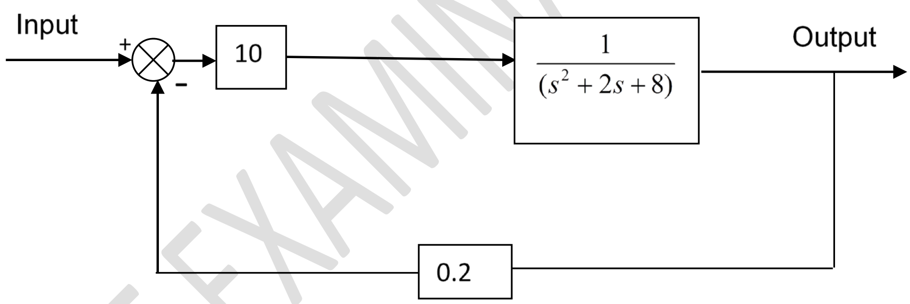

Figure Q5 Manufacturing Control System

Total 25 marks

Q6.

You are designing the controller of an aircraft. The system experiences a disturbance D(s) due to aerodynamic forces. A gain K was inserted into the system as shown in **Figure Q6**, determine

a) the whole system's output *X*(s) function (8 marks)

b) the range of values of K for the system which will result in stability. You may use Routh-Array method. (10 marks)

c) the steady-state error if the disturbance D(s) = 0, R(s) is a unit ramp input, and K = 3. (7 marks)

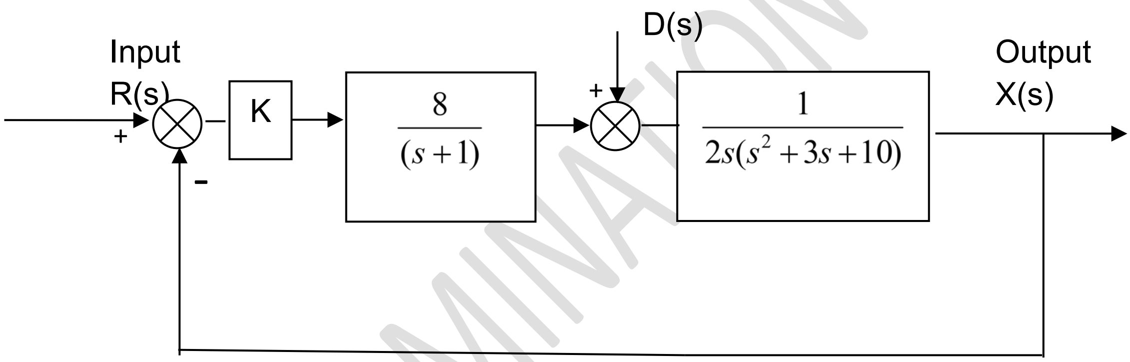

Figure Q6 Aircraft Controller

Total 25 marks

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Formula Sheet

$P = F/A$

$\rho = m/v$

$\dot{m} = \rho A V$

$P = P_g + P_{atm}$

$P = \rho g h$

$$\textit{Bulk Modulus } \beta = -\frac{dP}{dv/v}$$

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

$$h = \frac{4\sigma}{\rho g s d}$$

$$Z_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$

$$V_1 = \sqrt{\frac{2g\,h\left(\frac{\rho_L}{\rho} - 1\right)}{\left(\frac{a_1}{a_2}\right)^2 - 1}}$$

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

$W = \int P dV$

$P V^n = C$

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

$W = P(v_2 - v_1)$

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

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

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

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

$F = \rho QV$

$Re = V L \rho/\mu$

$dQ = du + dw$

$du = cu\, dT$

$dw = pdv$

$pv = mRT$

$h = h_f + xh_{fg}$

$s = s_f + xs_{fg}$

$v = x V_g$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$I = ToS_{gen}$$

$$V = r\omega$$

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

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

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

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

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)

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_1(s)}{1+G_1(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \lim_{s\to 0}[-s\cdot\dfrac{G_2(s)}{1+G_2(G_1(s)+1)}\cdot\theta_d]$ (if the system subjects to a disturbance 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

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

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

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Performance measures for second-order systems

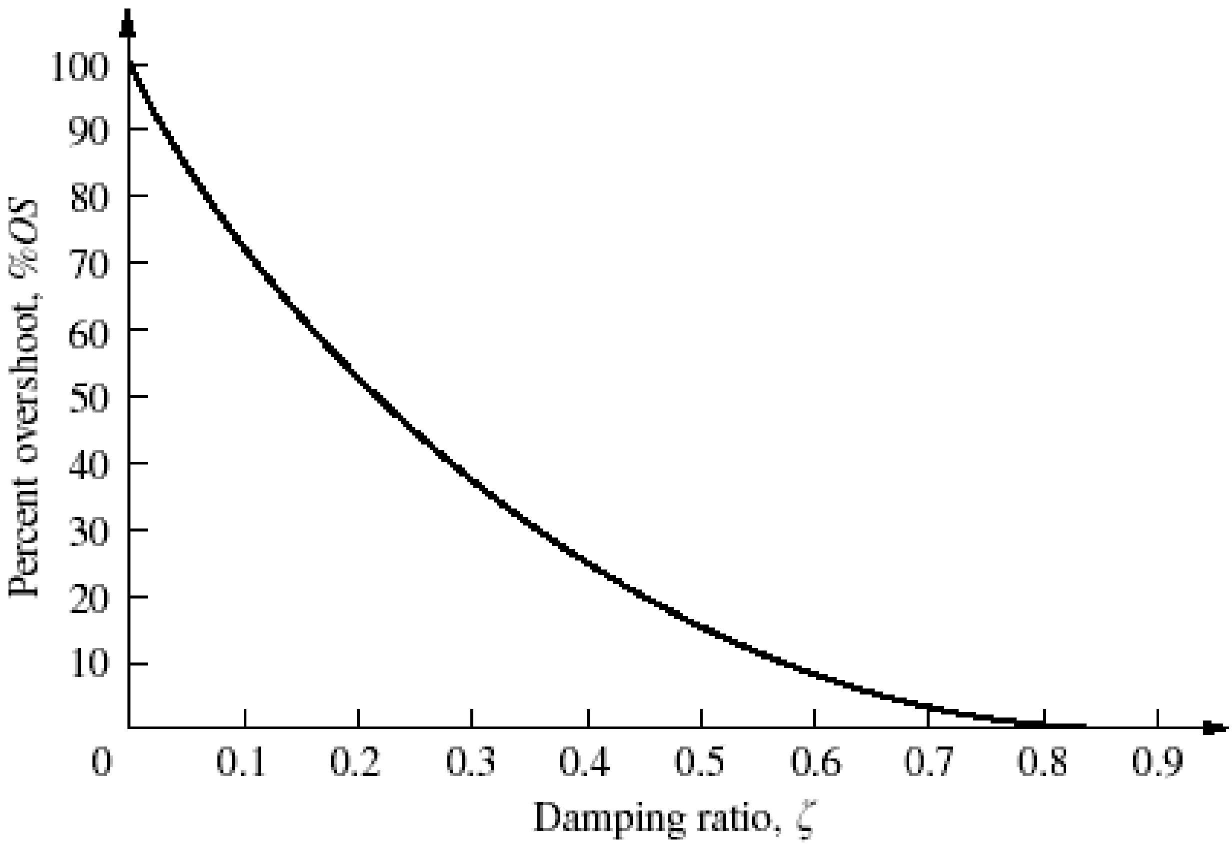
$\omega_d t_r = 1/2\pi$

$\omega_d t_p = \pi$

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

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

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



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