[ESS24]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BSC(HONS) MECHATRONICS TOP-UP

SEMESTER ONE EXAMINATION 2019/2020

ADVANCED MECHATRONIC SYSTEMS

MODULE NO: MEC6002

Date: Wednesday 15th January 2020 **Time: 10:00am – 12:00pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY 4 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.

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Question 1

(a) A vehicle system has a time constant of 0.15 seconds. If it's speed is suddenly increased from being at 30 KM/Hour into 100 KM/Hour,

(i) What will be the speed indicated by the speedometer after 0.3 seconds?

(4 marks)

(ii) If the maximum speed of the vehicle is 150 KM/Hour and a unit step inputs into the system, determine the time t taken for the speed output of the system from 0 KM/Hour to reach 80% of its maximum speed value.

(6 marks)

(b) Figure Q1(b) shows a block diagram for a hydraulic control system.

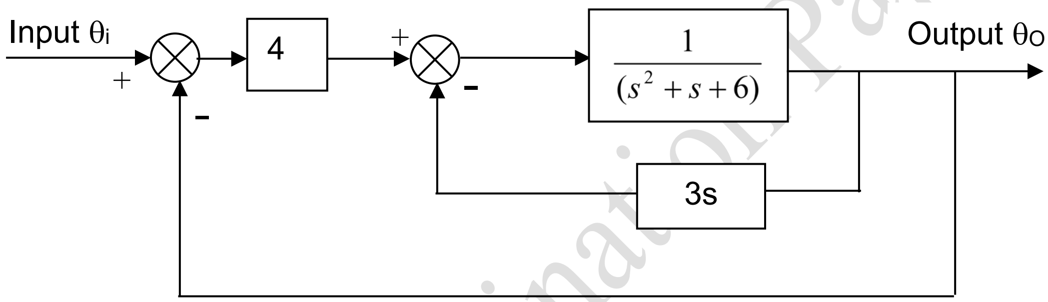

Figure Q1(b) A Hydraulic Control System

(i) What is the hydraulic system's transfer function $G(s) = \theta_o/\theta_i$?

(5 marks)

(ii) 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)

Total 25 Marks

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Question 2

If a position control system has experienced a disturbance D(s), and a gain K has been inserted into the system as shown in Figure Q2, determine

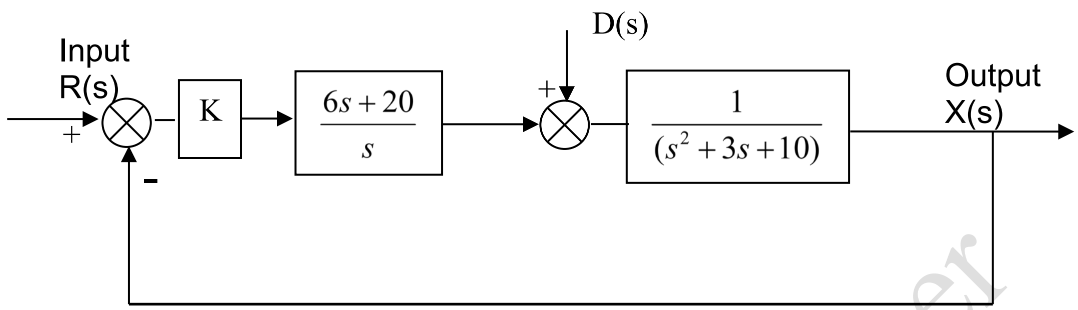

Figure Q2 A Position Control System

(a) the whole system's output $\theta_o(s)$ function **(8 marks)**

(b) the range of values of K for the system which will result in stability, using Routh-Hurwitz stability criterion.

(10 marks)

(c) the steady-state error if the disturbance D(s) = 0, R(s) is a unit ramp input, and K = 2.

(7 marks)

Total 25 Marks

Question 3

Figure Q3 shows a simplified CNC machine system, where K1 and K2 are the spring stiffness, C is the viscous damping coefficient, and M1 and M2 are the masses for Mass 1 and Mass 2. The input to the system is the Force F 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. **(8 marks)**

QUESTION 3 CONTINUES OVERLEAF, PLEASE TURN THE PAGE…

Question 3 continued…

(b) Determine the Laplace transforms of the differential equations obtained from Q3(a) above. Assume the initial conditions of the system are zeros (i.e. at time = 0, y, y', y'' are all zeros). **(4 marks)**

(c) Determine the transfer function $G(s) = y_2(s)/F(s)$ **(8 marks)**

(d) Using the transfer function G(s) obtained from Q3(c) above, draw an open loop block diagram and a closed loop block diagram (with a feedback H = H(s)) for this system. **(5 marks)**

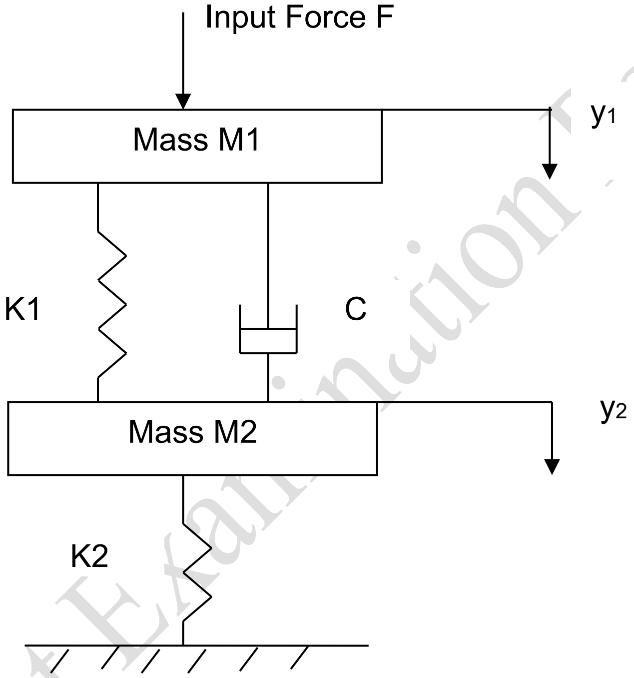

Figure Q3 A Simplified CNC Machine System

Total 25 Marks

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Question 4

Figure Q4 shows a mechatronic control system, which requires high accuracy for position and velocity response. If the mechatronic system has a transfer function of:

$$G_p(s) = \frac{1}{(2s+6)(s+5)}$$

and a PID controller is used in the system.

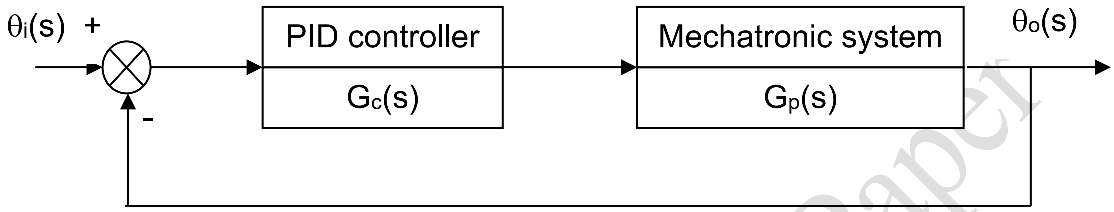

Figure Q4 A Mechatronic Control System

The design criteria for this system are:
Settling time < 0.8 sec
Overshoot < 5%
Steady state error = 0.5 (for a unit parabolic input = $1/s^2$)

(a) Design a PID controller to determine the parameters K_p, K_i, and K_d and clearly identify the design procedure. **(19 Marks)**

(b) Explain the effects on a control system of including Proportional controller (P), Proportional + Integral (PI) controller, Proportional + Derivative (PD) controller, and PID controller. **(6 Marks)**

Total 25 Marks

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Question 5

(a) Suppose that an automatic milk filling system involves the processes of: plastic bottle arriving, milk filling, metal lid covering, and paper logo fixing.

(i) You are asked to select sensors to detect the following:

- the arrival of a plastic bottle
- the right level of milk filled
- the correct position of the metal lid covering
- the correct presence, orientation and position of the paper logo

(4 marks)

(ii) Use your answer at part (i) above to justify your recommendation for each sensor selected. **(8 marks)**

(b) Explain and identify following three actuation systems and their features. Specify three applications in mechatronic systems from each of them:

(i) Mechanical actuation system

(ii) Hydraulic actuation system

(iii) Pneumatic actuation system

(13 marks)

Total 25 Marks

Question 6

(a) Give one example of an analogue feedback control system and one example of a digital feedback control system and explain, helped by sketches, how the signal is carried both in the analogue and the digital system. Suppose that Inputs, Plants and Sensors are all analogue signals. **(8 marks)**

QUESTION 6 CONTINUES OVERLEAF, PLEASE TURN THE PAGE…

(b) An assembly model is shown in Figure Q6(b), in which the computer performs the function of controller to control the assembly process.

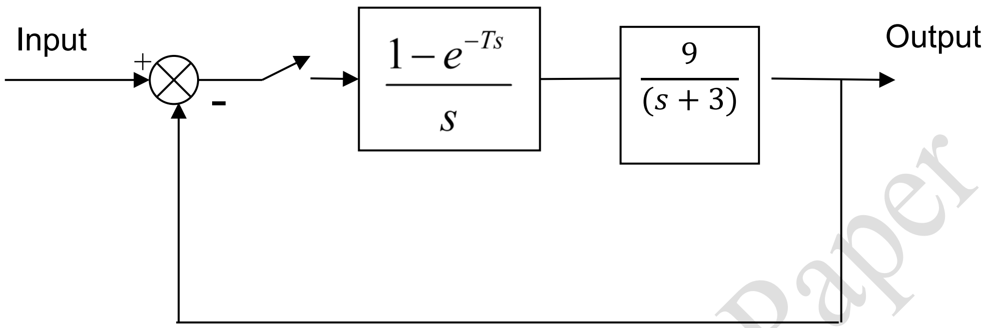

Figure Q6(b) An automation assembly control system

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

(9 marks)

(ii) If the controller has a 10 bit Analogue to Digital Converter with the signal range between -16 Volt to +16 Volt:

- What is the resolution of the AD converter? **(2 marks)**
- What integer number represented a value of 7.5 Volts? **(2 marks)**
- What voltage does the integer 350 represent? **(2 marks)**
- What voltage does 1011001110 represent? **(2 marks)**

END OF QUESTIONS

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FORMULA SHEETS

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

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

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

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

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

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

Second-order systems

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

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

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

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

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

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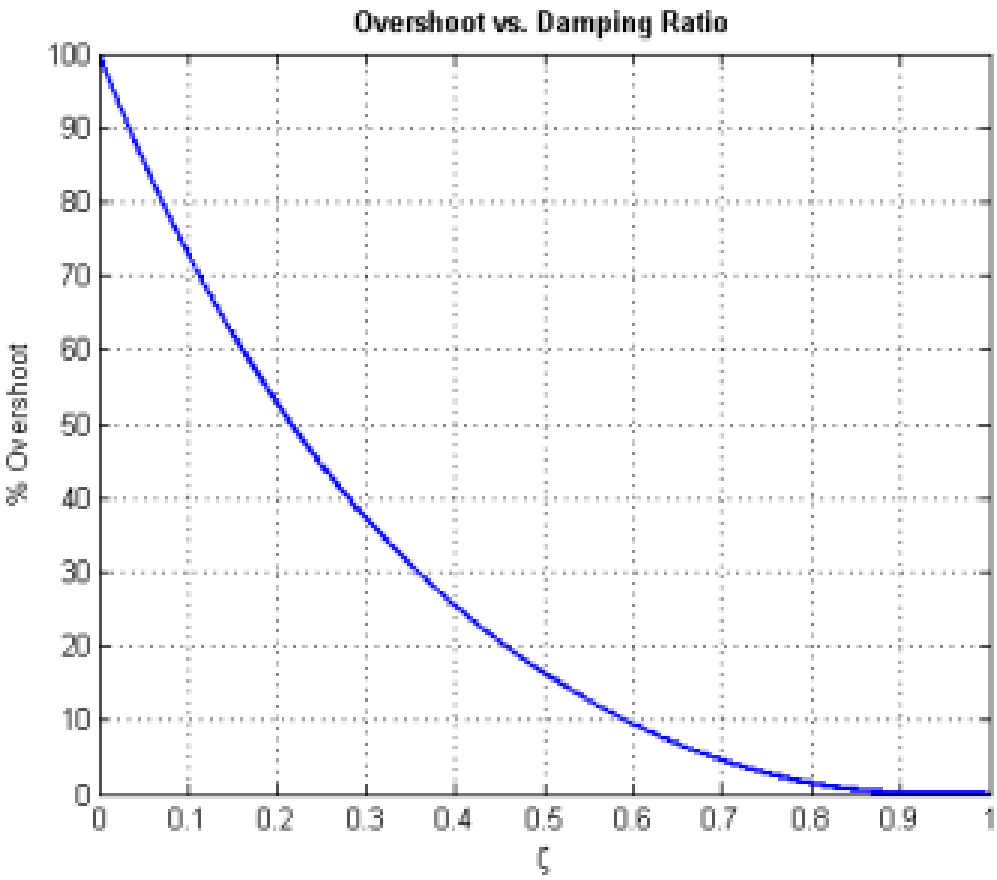

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Table 4.1 Laplace transforms

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, $u(t)$	$\frac{z}{z-1}$
Unit step delayed by kT	$\frac{z}{z^k(z-1)}$
Unit ramp, t	$\frac{Tz}{(z-1)^2}$
t^2	$\frac{T^2 z(z+1)}{(z-1)^3}$
e^{-at}	$\frac{z}{z-e^{-aT}}$
$1-e^{-at}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
$t\,e^{-at}$	$\frac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
$e^{-at}-e^{-bt}$	$\frac{(e^{-aT}-e^{-bT})z}{(z-e^{-aT})(z-e^{-bT})}$
$\sin \omega t$	$\frac{z \sin \omega T}{z^2 - 2z\cos \omega T + 1}$
$\cos \omega t$	$\frac{z(z-\cos \omega T)}{z^2 - 2z\cos \omega T + 1}$
$e^{-at}\sin \omega t$	$\frac{z\,e^{-aT}\sin \omega T}{z^2 - 2z\,e^{-aT}\cos \omega T + e^{-2}}$
$e^{-at}\cos \omega t$	$\frac{z(z-e^{-aT}\cos \omega T)}{z^2 - 2z\,e^{-aT}\cos \omega T + e^{-2}}$

Table 15.2 *z*-transforms

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

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