ENG15

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng(Hons) MECHATRONICS ENGINEERING

SEMESTER ONE EXAMINATION 2024/25

ADVANCED MECHATRONIC SYSTEMS

MODULE NO: MEC6002

Date: Monday 13th January 2025 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are FIVE 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.

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QUESTION 1

You have recently been appointed as an engineer at an innovative energy storage start-up, tasked with the development of a product that harnesses potential energy for storage purposes. In instances of surplus electricity within the grid, a motorised winch mechanism engages, drawing a mass towards a spring, subsequently immobilised by a braking system. Upon the grid's requisition for energy, the mass is disengaged, reverting to its original state, thus releasing stored energy. Your immediate superior has proposed the conceptualisation of this product through a model comprising a solid barrier, two springs characterised by stiffness constants K1 and K2, a damper endowed with a damping coefficient C, and a mass denoted as M. **Figure 1** shows the model of your product. The input to the system is the Force F acting from the winch to the mass and the outputs are displacements y_1 and y_2.

a) Drive the governing 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 (a) above. Assume the initial conditions of the system are zeros (i.e. at time = $0, y_1\ \dot{y}_1, \ddot{y}_1$ are all zeros).

[5 marks]

c) Determine the transfer function $G(s) = \frac{y_2(s)}{F(s)}$.

[10 marks]

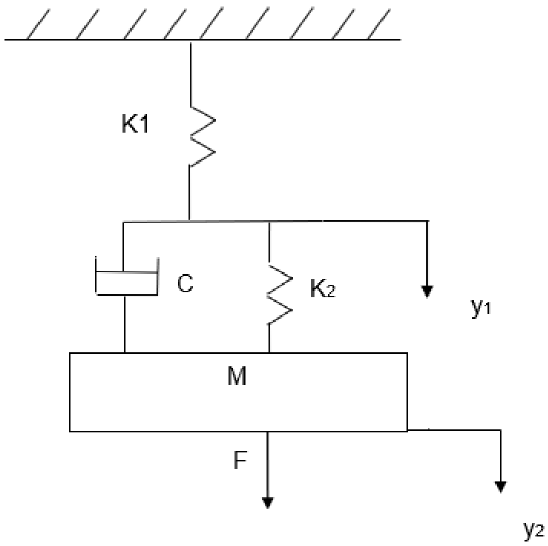

Figure 1 Energy System Mechanism

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QUESTION 2

Consider the vertical motion of the wing-tip fuel tanks system for a **X-59** Lockheed Martin aircraft as shown in **Figure 2**. The differential equation of motion governing this system is given as follows:

$$\ddot{y} + 6\dot{y} + 27y = 27x$$

a) Determine the transfer function, angular frequency, damping ratio and damped angular frequency.

[12 Marks]

b) Determine Peak time (t_p), Maximum overshoot (M_p), Settling time (t_s), and Rise time (t_r).

[13 Marks]

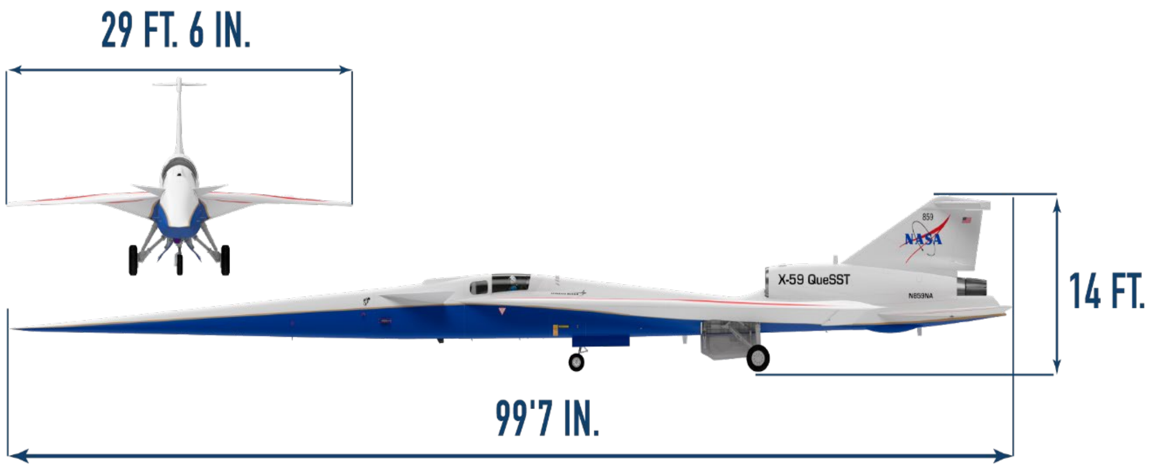

Figure 1 X-59 Lockheed Martin Aircraft

Total 25 marks

QUESTION 3

a) Determine the governing equation that describes the correlation between the input torque T and the angular displacement θ of a driveline with a locked wheel, as shown in **Figure 3(a).**

Using Laplace Transforms find the transfer function of the derived equations, assuming that the system receives a unit step input at an initial condition taken to be zero overall.

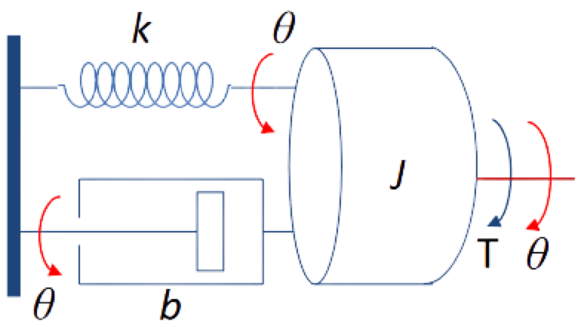

Figure 3(a) Schematical diagram of locked wheel

[18 Marks]

b) The response of a first-order mechatronic system to an impulse is represented by the following equation,

$$C(t) = 3e^{-0.5t}$$

Determine its time constant (τ), DC gain (K), transfer function (G_s), and step response.

[7 Marks]

Total 25 marks

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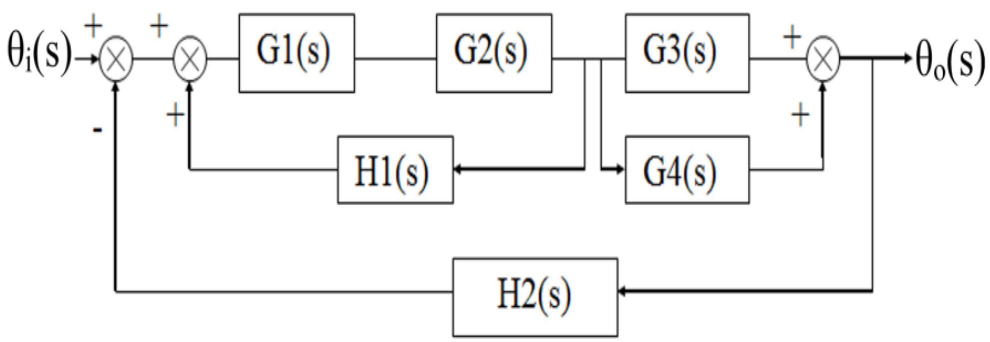
QUESTION 4

a) A robot control system can be represented by the block diagram shown in **Figure 4(a**). Using block diagram reduction techniques, find the θ_o for this control system if a unit step input is applied.



[9 Marks]

b) A mechatronic system has following transfer function:

$$G(s) = \frac{100}{25s+10}$$

Determine and sketch the response of the system when ramp input is applied to the system.

[9 Marks]

c) Consider position control system used with machine has an amplifier in series with valve slider arrangement having transfer functions 27 mA/V and 12 mm/mA respectively. Also feedback displacement measurement arranged with transfer function 7mV/mm. Draw loop diagram and find the overall transfer function.

[7 Marks]

Total 25 marks

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QUESTION 5

a) Using Suitably labelled diagrams and explanations, differentiate between open and closed loop control systems.

[8 Marks]

b) State any four advantages of closed loop over open loop system.

[8 Marks]

c) Consider the system as shown in **Figure 5(c)**, where V(t) is the input voltage, and i(t) is the output current. Determine the response i(t) of the system when V(t) is a unit-step input.

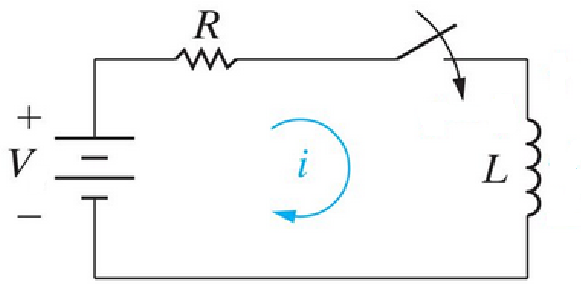

Figure 5(c) Linear system

[9 Marks]

Total 25 marks

END OF QUESTIONS

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Formula Sheet

$f'(t)$	$sF(s) - f(0)$
$f''(t)$	$s^2F(s) - sf(0) - f'(0)$

	$f(t)$	$F(s)$
1.	$\delta(t)$	1
2.	$u(t)$	$\frac{1}{s}$
3.	$t\,u(t)$	$\frac{1}{s^2}$
4.	$t^n\,u(t)$	$\frac{n!}{s^{n+1}}$
5.	$e^{-at}\,u(t)$	$\frac{1}{s+a}$
6.	$\sin \omega t\,u(t)$	$\frac{\omega}{s^2+\omega^2}$
7.	$\cos \omega t\,u(t)$	$\frac{s}{s^2+\omega^2}$

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

$G(s) = \frac{Go(s)}{1-Go(s)H(s)}$ (for a positive feedback)

$\omega_d t_r = 1/2\pi$

$\omega_d t_p = \pi$

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

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

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

$$\delta = \frac{c}{c_c}$$

$$c_c = \sqrt{4Mk}$$

$$f = \frac{\omega}{2\pi}$$

$$\omega = \omega_n\sqrt{1 - \delta^2}$$

$$\tau\dot{y}(t) + y(t) = Ku(t)$$

$$G(s) = \frac{C(s)}{R(s)} = \frac{K}{\tau s + 1}$$

END OF PAPER