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The Open University of Sri Lanka
Faculty of Engineering Technology

Study Programme	: Bachelor of Technology honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	: **MEX3273 - MODELLING OF MECHATRONICS SYSTEMS**
Academic Year	: 2016/2017
Date	: 26th November 2017
Time	: 1.30pm – 4.30pm
Duration	: 3 hours

General instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of 8 questions. All questions carry equal marks.
3. Answer any 5 questions only.
4. Laplace transformation table is attached at the end of this question paper.

(Q1)

a) Explain the procedure of model development for a particular system.

b) "The applicability of the concept of the transfer function is limited to linear, time-invariant, differential equation systems". Comment on this statement.

c) State the steps taken to linearize a nonlinear system.

d) "Accurate design of the system should consider the entire system as a whole rather than designing the electrical, electronic, and mechanical aspects separately and sequentially". Explain.

(Q2)

a) Why are analogies important in modeling of dynamic systems? Explain.

b) Draw the *force-voltage* and *force-current* analogies for the mechanical system is shown in Figure 1.

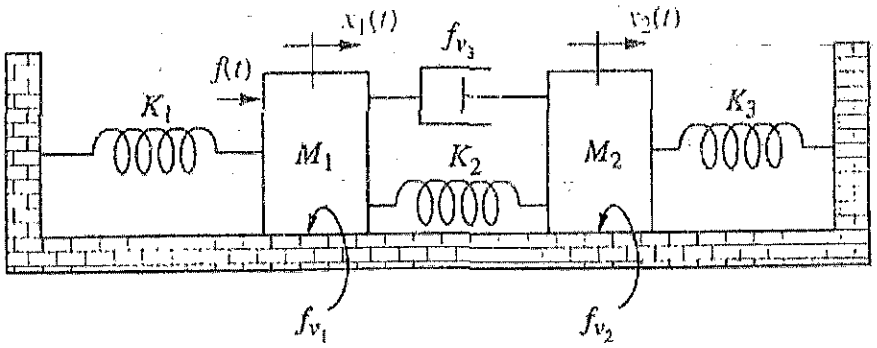


Figure 1

(Q3)

a) The transfer function of a human leg relates the output angular rotation about the hip joint to the input torque supplied by the leg muscle. A simplified model for the leg is shown in Figure 2. The model assumes an applied muscular torque, $T_m(t)$, viscous damping, D, at the hip joint, and inertia, J, around the hip joint. Also, a component of the weight of the leg, Mg, where M is the mass of the leg and g is the acceleration due to gravity, creates a nonlinear torque. If we assume that the leg is of uniform density, the weight can be applied at $L/2$, where L is the length of the leg.

i. Evaluate the nonlinear torque.

ii. Find the transfer function, $\theta(s)/T_m(t)$, for small angles of rotation, where $\theta(s)$ is the angular rotation of the leg about the hip joint.

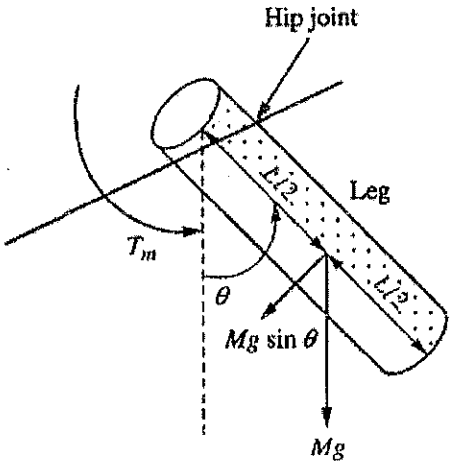


Figure 2

b) For the electrical system of Figure 3, find the transfer function of $\frac{I_2(s)}{V(s)}$.

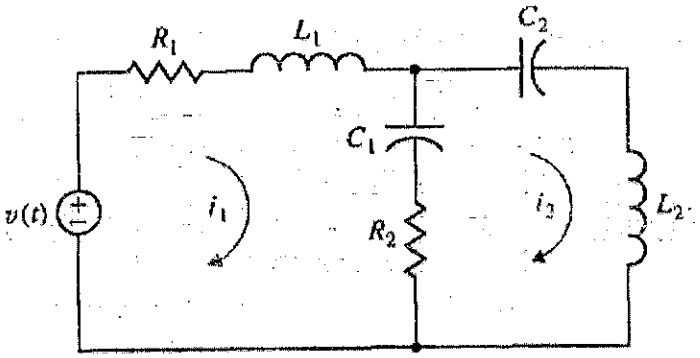


Figure 3

(Q4)

a) Consider op-amp circuit shown in Figure 4. Obtain the governing equations for the system and find the transfer function for $\frac{V_o(s)}{V_i(s)}$.

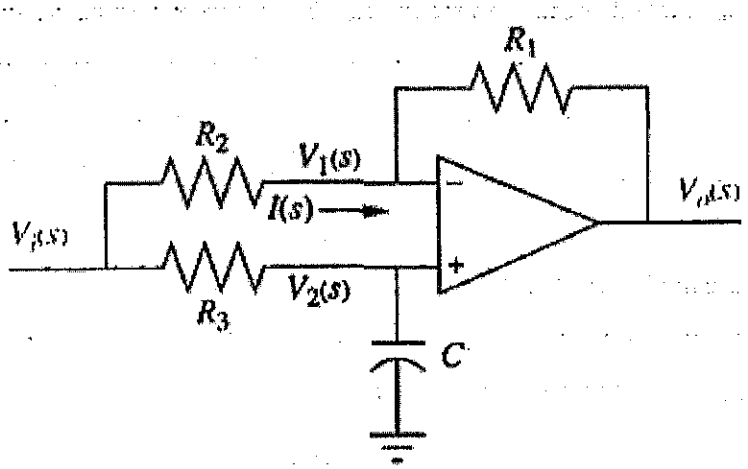


Figure 4

b) If $R_1 = R_2$, this circuit is known as an all-pass filter, since it passes sine waves of a wide range of frequencies without attenuating or amplifying their magnitude. Find the step response of the filter and plot the graph when $R_1 = R_2$, $R_3C = 1/10$.

(Q5)

The DC motor is a power actuator device that delivers energy to a load. It converts direct current electrical energy into rotational mechanical energy. A schematic of a DC motor is shown in Figure 5. A major fraction of the torque generated in the armature of the motor is available to drive an external load. The transfer function of the DC motor for a linear approximation to an actual motor, and second-order effects, such as hysteresis and the voltage drop across the brushes, will be neglected. The input voltage may be applied to the field terminals. The air-gap flux $\emptyset$ of the motor is proportional to the field current, provided the field is unsaturated.

a) Derive the governing equations for the field current control DC motor.

b) Determine the transfer function of $^{\theta(s)}/_{V_f(s)}$.

c) Draw the block diagram for the field current control DC motor.

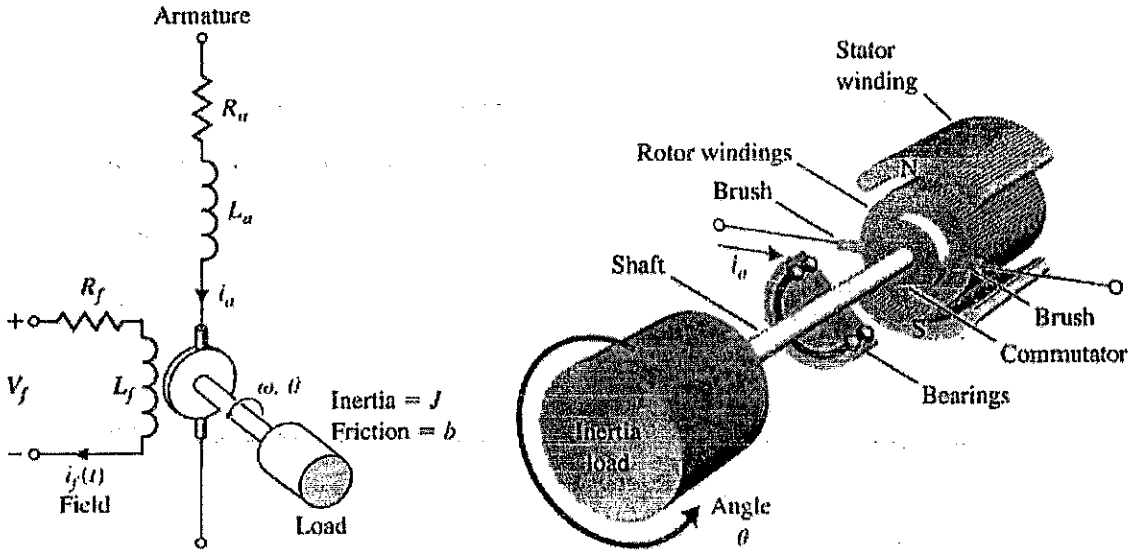


Figure 5

(Q6)

a) Obtain expressions for the impedances of basic mechanical and electrical elements.

b) Consider two-cart system illustrated in Figure 6. Using impedance method to derive governing equations of the motion of the system.

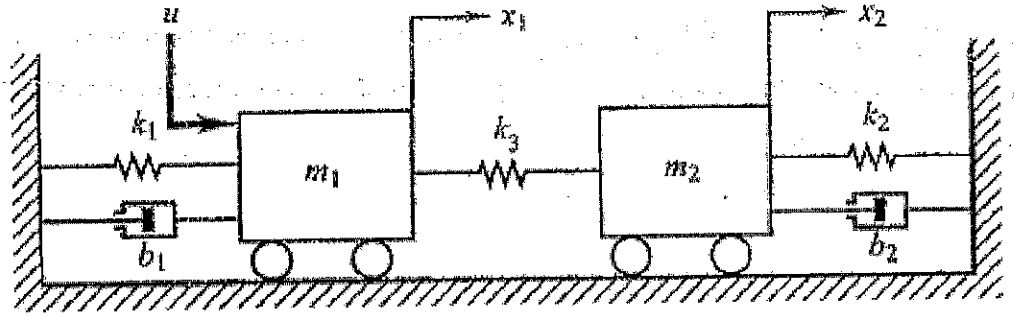


Figure 6

(Q7)

a) Define the following terms with regard to state-space representation of dynamic systems.

i. State of a system

ii. State variables

iii. State vector

iv. State-space

b) A closed-loop control system is shown in Figure 7. Determine the state-variable model.

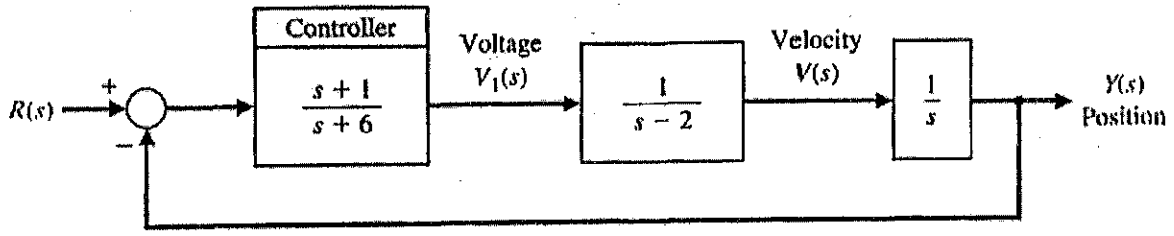


Figure 7

(Q8)

a) For the block diagram shown in Figure 8, determine the transfer function $\frac{C(s)}{R(s)}$ by using block diagram simplification techniques.

b) Develop a signal flow graph for the block diagram in Figure 8 and verify answer in part (a) by using the mason's rule.

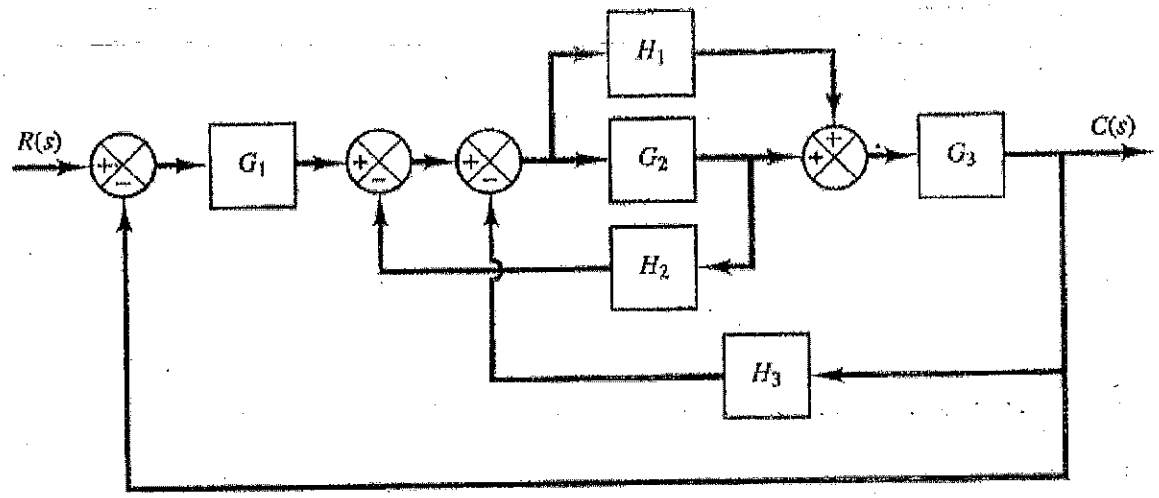


Figure 8

Mason's Gain formula:

$$G(s) = \frac{C(s)}{R(s)} = \frac{1}{\Delta}\sum_{k} T_k \Delta_k$$

Where,

T_k	Path gain or transmittance of k^{th} forward path
Δ	Determinant of graph 1 - (sum of all individual loop gains) + (sum of gain products of all possible combinations of two non-touching loops) - (sum of gain products of all possible combinations of three non-touching loops) + . . . $1 - \sum_{a} L_a + \sum_{b,c} L_b L_c - \sum_{d,e,f} L_d L_e L_f + \cdots\cdots$
$\sum_{a} L_a$	Sum of all individual loop gains
$\sum_{b,c} L_b L_c$	Sum of gain products of all possible combinations of two non-touching loops
$\sum_{d,e,f} L_d L_e L_f$	Sum of gain products of all possible combinations of three non-touching loops
Δ_k	Cofactor of the k^{th} forward path determinant of the graph with the loops touching the k^{th} forward path removed, that is, the cofactor Δ_k, is obtained from Δ by removing the loops that touch path P_k

Laplace transforms:

TIME FUNCTION $f(t)$	LAPLACE TRANSFORM $F(s)$
Unit Impulse $\delta(t)$	1
Unit step	$\frac{1}{s}$
t	$\frac{1}{s^2}$
t^n	$\frac{n!}{s^{n+1}}$
$\frac{df(t)}{dt}$	$sF(s)-f(0)$
$\frac{d^n f(t)}{dt^n}$	$s^n F(s) - s^{n-1} f(0) - s^{n-2} \frac{df(0)}{dt} \ldots - \frac{d^{n-1} f(0)}{dt^{n-1}}$
e^{-at}	$\frac{1}{s+a}$
te^{-at}	$\frac{1}{(s+a)^2}$
$\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$
$\cos \omega t$	$\frac{s}{s^2+\omega^2}$
$e^{-at} \sin \omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$
$e^{-at} \cos \omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$

END