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The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**:DMX3573/MEX3273 Modelling of Mechatronics Systems**
Academic Year	: 2017/18
Date	: 5th February 2019
Time	: 1330-1630hrs

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Eight (8)** questions in Nine **(9)** pages.
3. Answer any **Five (5)** questions only. All questions carry equal marks.
4. Answer for each question should commence from a new page.
5. This is a Closed Book Test (CBT).
6. Answers should be in clear hand writing.
7. Do not use Red colour pen.

Question 01 *[20 marks]*

a) A Segway Personal Transporter (PT) is a two-wheeled vehicle in which the human operator stands vertically on a platform. As the driver leans left, right, forward, or backward, a set of sensitive gyroscopic sensors sense the desired input. These signals are fed to a computer that amplifies them and commands motors to propel the vehicle in the desired direction. One very important feature of the PT is its safety. The system will maintain its vertical position within a specified angle despite road disturbances, such as up hills and down hills or even if the operator over-leans in any direction. Draw a functional block diagram of the PT system that keeps the vehicle (Figure Q1(a)) in a vertical position. Indicate the input and output signals, intermediate signals, and main sub systems.

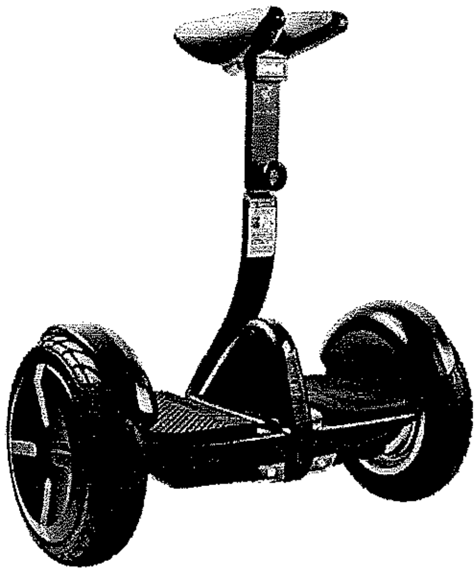

Figure Q1(a)

b) One of the most beneficial applications of an automotive control system is the active control of the suspension system. One feedback control system uses a shock absorber consisting of a cylinder filled with a compressible fluid that provides both spring and damping forces. The cylinder has a plunger activated by a gear motor, a displacement-measuring sensor, and a piston. Spring force is generated by piston displacement, which compresses the fluid. During piston displacement, the pressure unbalance across the piston is used to control damping. The plunger varies the internal volume of the cylinder. This feedback system is shown in Figure Q1(b). Develop a linear model for this device using a block diagram model.

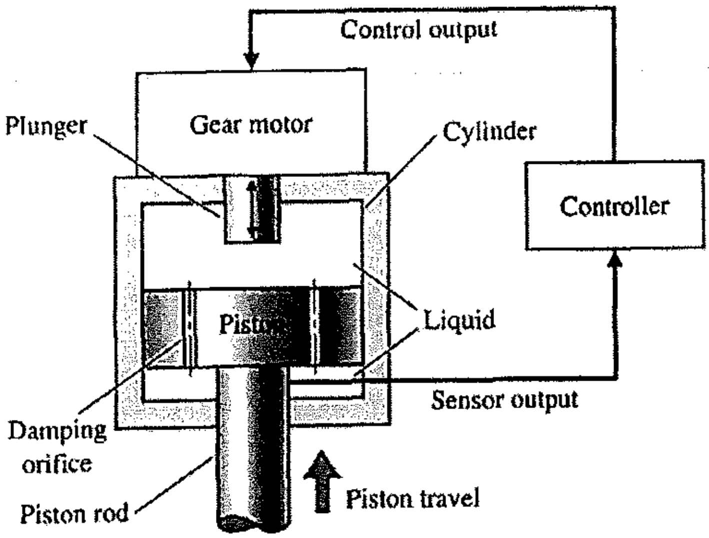

Figure Q1(b)

Question 02 *[20 marks]*

Find the transfer function for $Y(s)/R(s)$ for the idle-speed control system for a fuel-injected engine by using block diagram simplification techniques as shown in Figure Q2.

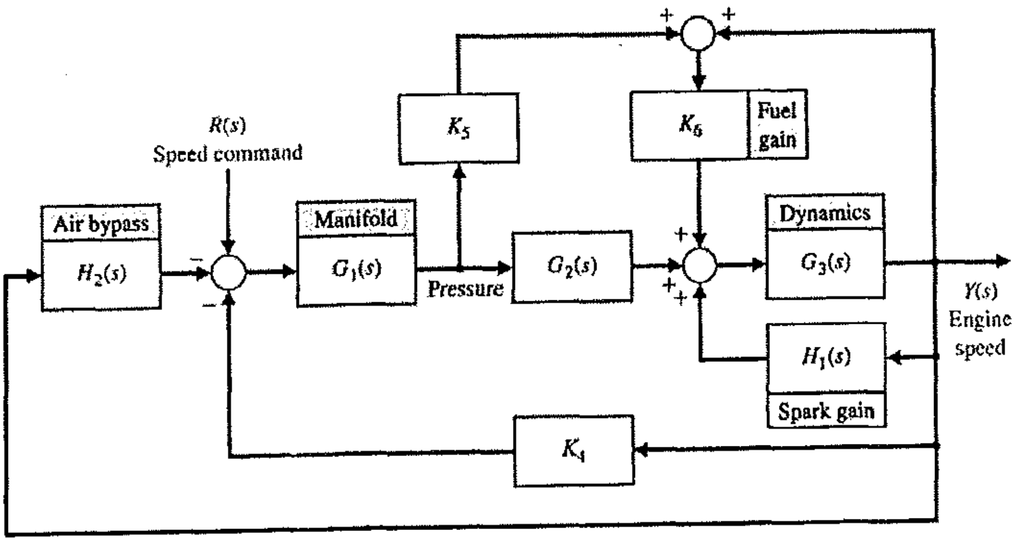

Figure Q2

Question 03 [*20 marks*]

The basic control problem is to regulate the belt speed and tension by varying the motor torques. A practical system similar to that shown occurs in textile fiber manufacturing processes when yarn is wound from one spool to another at high speed. Between the two spools, the yarn is processed in a way that may require the yarn speed and tension to be controlled within defined limits. A model of the system is shown in Figure Q3.

a) Find $Y_2(S)/R_1(S)$.

b) Determine a relationship for the system that will make Y_2 independent of R_1.

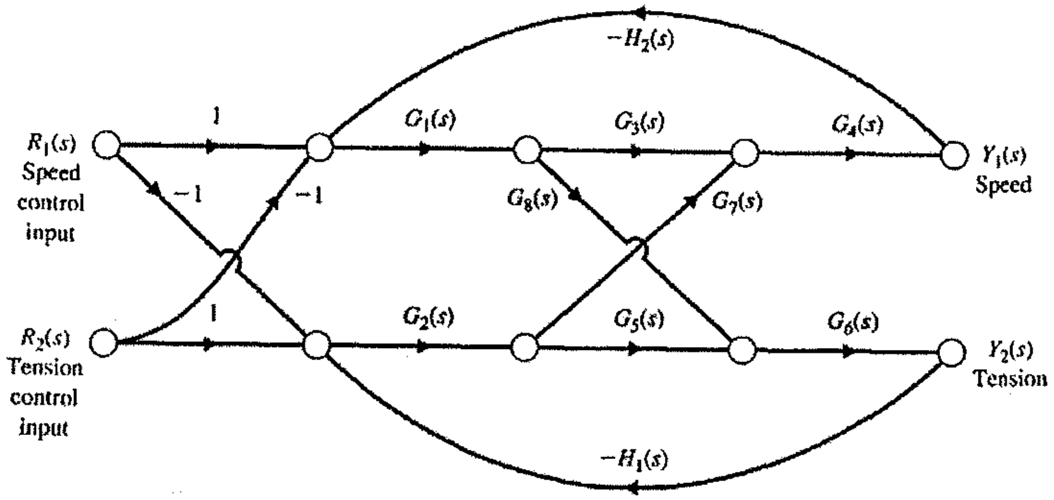

Figure Q3

Question 04 [*20 marks*]

a) Determine a state variable differential matrix equation for the circuit shown in Figure Q4.

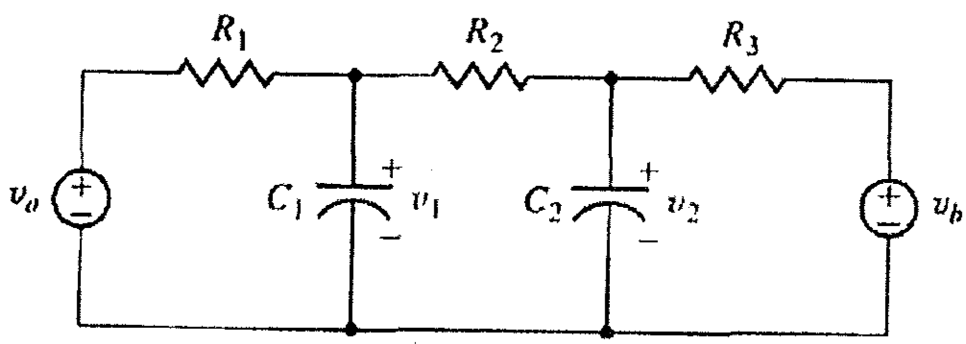

Figure Q4

b) Obtain a block diagram and a state variable representation of this system.

$$\frac{Y(S)}{R(S)} = T(S) = \frac{14(S+4)}{S^3 + 10S^2 + 31S + 16}$$

Question 05 [*20 marks*]

a) Distinguish between a signal and a noise in the context of mathematical representation of signals and systems.

b) Discuss the potential benefits that modeling offer in the context of design. What are some of its major limitations?

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

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

Question 06 [*20 marks*]

a) A Bridged-T network is often used in AC control systems as a filter network. The circuit of one Bridged-T network is shown in Figure Q6. Determine the transfer function of the filter network.

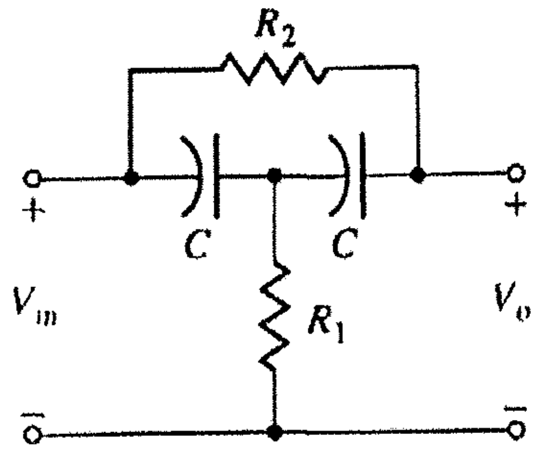

Figure Q6

b) The transfer function of a system is given below. Determine $y(t)$, when $r(t)$ is an unit step input.

$$\frac{Y(s)}{R(s)} = \frac{15(s+1)}{s^2+9s+14}$$

Question 07 *[20 marks]*

For electromechanical systems that require large power amplification, rotary amplifiers are often used. An amplidyne is a power amplifying rotary amplifier. An amplidyne and a servomotor are shown in Figure Q7.

a) Obtain the transfer function $\theta(s)/V_c(s)$.

b) Draw the block diagram of the system. Assume $v_d = k_2 i_q$ and $v_q = k_1 i_c$.

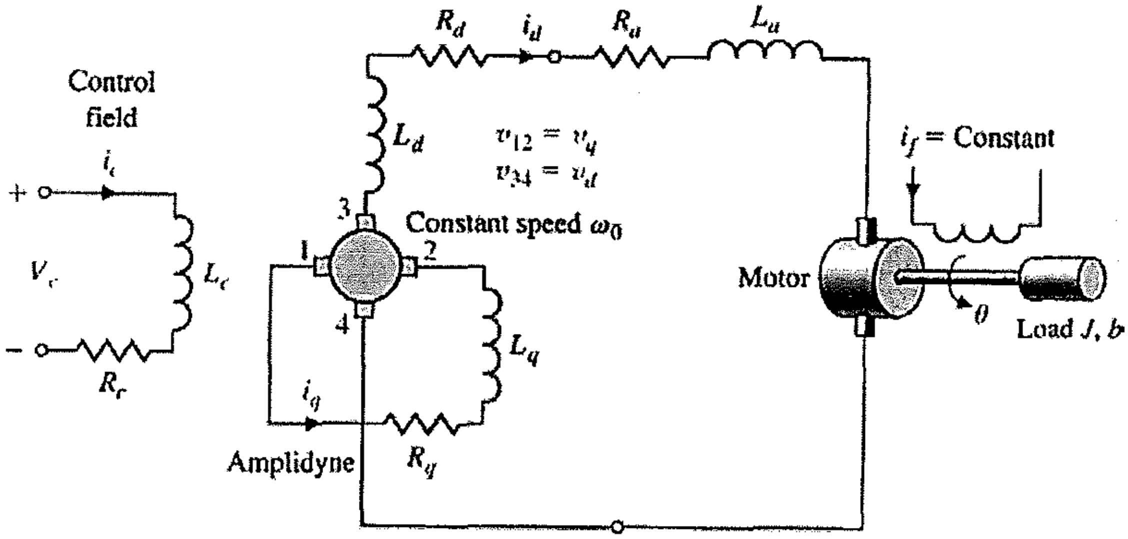

Figure Q7

Question 08 *[20 marks]*

A hydraulic servomechanism with mechanical feedback is shown in Figure Q8. The power piston has an area equal to A. When the valve is moved a small amount Δz, the oil will flow through to the cylinder at a rate $p\Delta z$, where p is the port coefficient. The input oil pressure is assumed to be constant. From the geometry, you find that $\Delta z = k\frac{l_1 - l_2}{l_1}(x-y) - \frac{l_2}{l_1}y$.

a) Determine the closed-loop signal flow graph for this mechanical system.

b) Obtain the closed-loop transfer function $Y(s)/X(s)$ using Mason's gain formula.

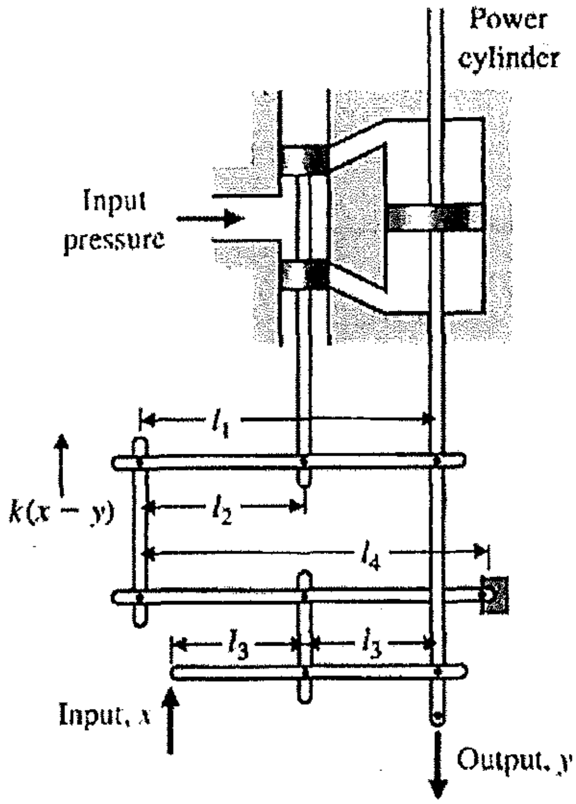
Power
cylinder
Input
pressure
l_1
$k(x-y)$
l_2
l_4
l_3
l_3
Input, x
Output, y

Figure Q8

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