THE OPEN UNIVERSITY OF SRI LANKA
FACULTY OF ENGINEERING TECHNOLOGY
LEVEL 4
FINAL EXAMINATION – 2011/2012
MEX4271 – SENSORS AND ACTUATORS

DATE : 21st FEBRUARY 2012
TIME : 0930 HRS. TO 1230 HRS.
DURATION : THREE HOUR [3 Hours]

READ THE FOLLOWING INSTRUCTIONS CAREFULLY BEFORE ANSWERING THE QUESTION PAPER

Instructions

1. This question paper consists of eight (08) questions.
2. Answer five questions only.

Question 01

Potentiometer is an active device that can be used as a motion sensor. It consists of a uniform coil of wire or a film of high resistive material such as carbon, platinum or conductive plastic and the resistance is proportional to its length.

a) The range of a coil-type potentiometer is 10 cm. If the wire diameter is 0.1 mm, determine the resolution of the device.

(5 marks)

b) A mobile robot used a potentiometer attached to the drive wheel to record its travel during the "teach" mode in a teach-repeat operation. The required resolution for robot motion is 1 mm, and the diameter of the drive wheel of the robot is 20 cm. Examine the design considerations (resolution of the coil; no. of turns in the coil; wire diameter; diameter of the core of the coil) for a standard (single coil) rotatory potentiometer to be used in this application. Assume resistivity of the wire to be 4μΩcm; resistance of the potentiometer to be 5Ω and an average pot diameter to be 10 cm.

(15 marks)

Question 02

Differential transformer is a non-contact displacement passive sensor that does not possess many of the shortcomings of the potentiometer and it is available in both linear and rotatory variable types.

a) List five primary advantages of a LVDT over a potentiometer for position sensing.

(5 marks)

b) A LVDT with a simplified signal conditioning system is shown in Figure Q2. The system variables and parameters are also shown in the Figure Q2. Write expression for voltage signal v_o. If the bandwidth of the measurand is 2 Hz, estimate a suitable value for the filter capacitance C. Justify your answer. Assume the carrier frequency to be 60 Hz and $R = 20$ kΩ.

(15 Marks)

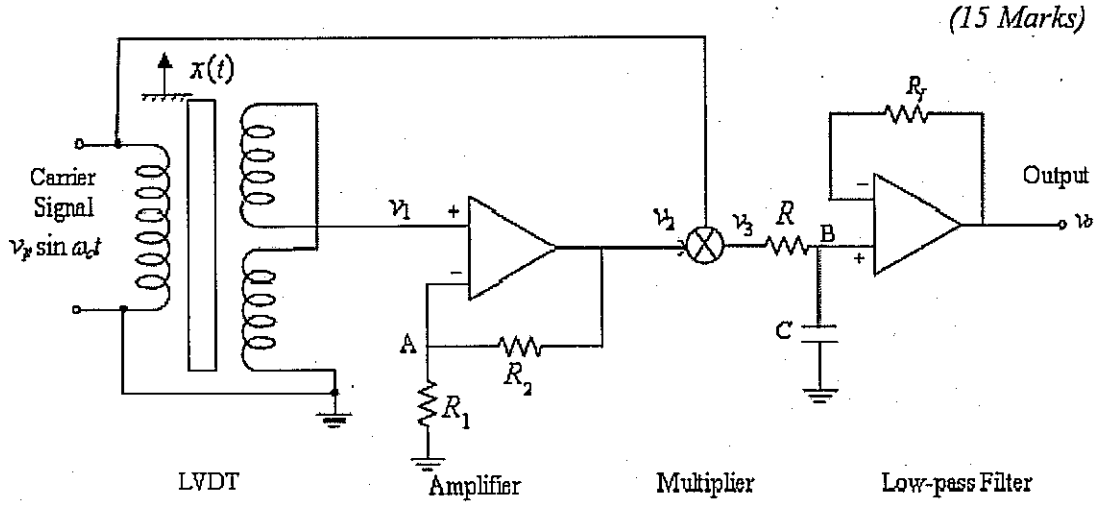


Figure Q2: LVDT with Signal Conditioning System

$x(t)$ – Displacement of the LVDT core (measurand)
r – Transformer parameter for the LVDT

Question 03

The DC tachometer, the AC inductive tachometer and the AC permanent magnet tachometer employ the principle of electromagnetic induction.

a) Compare and contrast the principles of operation of the DC tachometer and the AC tachometer (both permanent magnet and inductive types). What are the advantages and disadvantages of these two types of tachometers?

(5 marks)

b) A DC tachometer is shown in the Figure Q3. The field windings are powered by DC voltage v_f. Angular speed ω and torque T_i are the input variables. The output voltage v_o of the armature circuit and the corresponding current i_o are the output variables. Obtain a transfer-function model for this device. Discuss the significance of the mechanical time constant and the electrical time constant of the tachometer.

(15 marks)

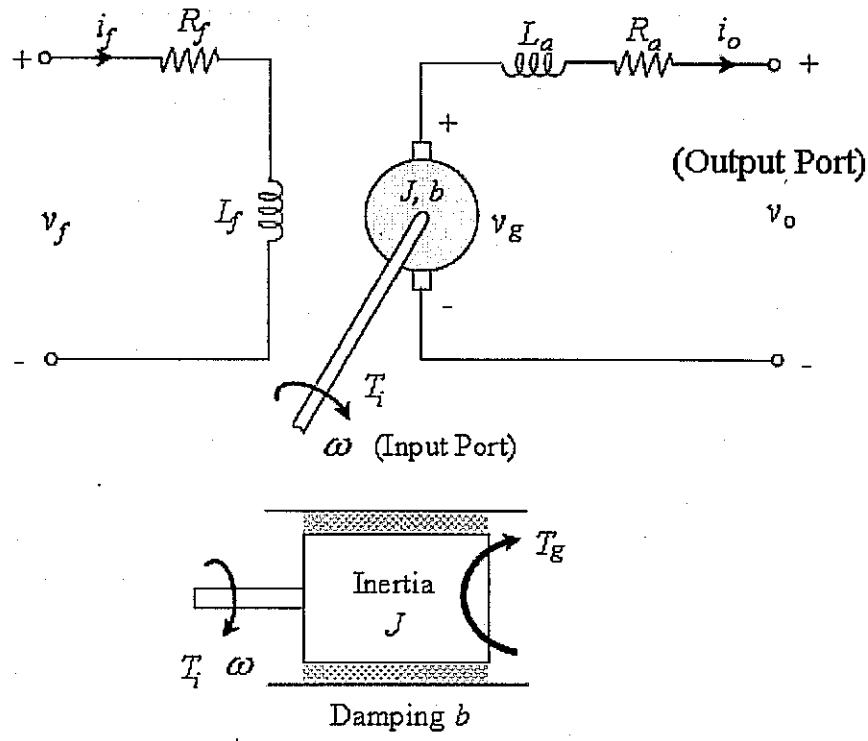


Figure Q3: A DC tachometer

Question 04

Piezoelectric sensors are typically high impedance sensors, particularly at low frequencies. Such type of sensors requires specific signal conditioning hardware.

b) Discuss factors that limit the lower frequency and upper frequency limits of the output from the piezoelectric sensors.

(5 marks)

b) An equivalent circuit for a piezoelectric accelerometer that uses a quartz crystal as the sensing element is shown in Figure Q4. The charge generated is denoted by q and the voltage output at the end of the accelerometer cable is v_o. the sensor capacitance is modeled by C, and the overall capacitance experienced at the sensor output, whose primary contribution C_c. The resistance of the electric insulation in the accelerometer is denoted by R. Write a differential equation relating v_o to q. What is the corresponding transfer function? Using this result, show that the accuracy of accelerometer improves when the sensor time constant is large and when the frequency of the measured acceleration is high. For a quartz crystal sensor with $R = 1 \times 10^{11} \Omega$ and $C_c = 1000$ pF, compute the time constant.

(15 marks)

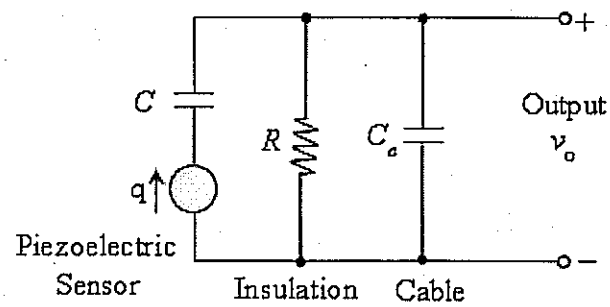


Figure Q4: Equivalent circuit for a piezoelectric accelerometer

Question 05

The DC motor converts direct current (DC) electrical energy into rotational mechanical energy. A major fraction of the torque generated in the rotor (armature) of the motor is available to drive an external load.

a) Explain the principle of operation of the DC permanent magnet motor.

(5 Marks)

b) A DC motor uses 2 hp under no-load conditions to maintain a constant speed of 600 rpm. The motor torque constant k_m = 1 Vs, the rotor moment of inertia J_m = 0.1 kgm^2, and the armature circuit parameters are R_a = 10Ω and L_a = 0.01 H. Determine the electrical damping constant, the mechanical damping constant, the electrical time constant of the armature circuit and the mechanical time constant of the rotor, and the true time constant of the motor.

(15 Marks)

Question 06

Much attention has been given to the development of AC motors, with the widespread availability of alternative current (AC) as an economical form of power supply for operating industrial machinery.

a) List three advantages and two primary disadvantages of AC motors over DC motors.

(5 Marks)

b) A certain 5 hp three-phase induction motor operates from a 440V rms (line to line) three-phase source draws a line current of 6.8 A rms at a power factor of 78% lagging [i.e, cos (θ) = 0.78] under rated full-load conditions. The full-load speed is 1150 rpm. Under no-load conditions, the speed is 1195 rpm, and the line current is 1.2 A rms at a power factor of 30% lagging. Find the power loss and efficiency with full load, the input power with no load, and the speed regulation.

(15 Marks)

Question 07

Stepper motors are incremental-drive actuators. It is reasonable to treat as them as digital actuators and stepper motors are driven in fixed angular steps.

a) Explain the terms residual torque and holding torque in connection with a stepper motor.

(5 Marks)

b) Consider the single-stack, three-phase **V**ariable **R**eluctance Stepper Motor shown in Figure Q7. Number of rotor teeth (n_r) = 8 and Number of stator teeth (n_s) = 12. For this arrangement, compare the following phase-switching sequences:

i) 1-2-3-1
ii) 1-12-2-23-3-31-1
iii) 12-23-31-12

What is the step angle, and how would you reverse the direction of rotation in each case?

(15 Marks)

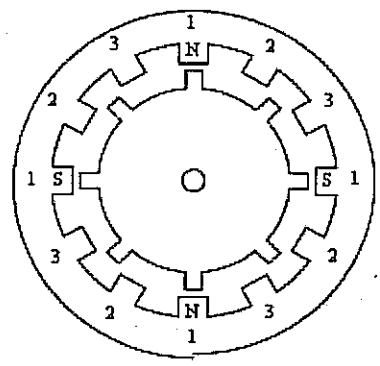


Figure Q7: Variable Reluctance Stepper Motor

Question 08

Gears and gear trains are mechanisms which are very widely used to transfer and transform rotational motion. Normally they are used when a change in speed or torque of a rotating device is needed.

a) List four types of gears meshes found in engineering applications.

(6 Marks)

b) A compound gear train consists of the final driven wheel with 15 teeth, which meshes with a third wheel with 90 teeth. On the same shaft as the second wheel is a wheel with 15 teeth. This meshes with a fourth wheel, the first driver, with 60 teeth. What is the overall gear ratio?

(7Marks)

c) Explain working principle of **Planetary Gear Trains.**

(7Marks)

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