MECH 420 SENSORS AND ACTUATORS
Assignment 5

Problems 5.5, 5.11, 5.23, 5.36, 5.39, 5.47, 5.56, and 5.66 from the textbook

Problem 1 (Problem 5.5 from Textbook)

Giving examples, discuss situations in which the measurement of more than one type of kinematic variables using the same measuring device is: (a) An advantage, (b) A disadvantage.

Problem 2 (Problem 5.11 from Textbook)

Derive an expression for the sensitivity (normalized) of a rotatory potentiometer as a function of displacement (normalized). Plot the corresponding curve in the nondimensional form for the three load values given by R_L/R_c = 0.1, 1.0, and 10.0. Where does the maximum sensitivity occur? Verify your observation using the analytical expression.

Problem 3 (Problem 5.23 from Textbook)

For directional sensing using an LVDT it is necessary to determine the phase angle of the induced signal. In other words, *phase-sensitive demodulation* would be needed.

(a) First consider a linear core displacement starting from a positive value, moving to zero, and then returning to the same position in an equal time period. Sketch the output of the LVDT for this triangular core displacement.

(b) Next sketch the output if the core continued to move to the negative side at the same speed.

By comparing the two outputs show that phase-sensitive demodulation would be needed to distinguish between the two cases of displacement.

Problem 4 (Problem 5.36 from Textbook)

Propose a design for a humidity sensor using the principle of capacitance. Will this device be linear or nonlinear (*Note*: Static nonlinearity can be accounted for by proper calibration)? Indicate advantages and disadvantages of this sensor.

Problem 5 (Problem 5.39 from Textbook)

A design objective in many control system applications is to achieve small time constants. An exception is the time constant requirements for a piezoelectric sensor. Explain why a large time constant, in the order of 1.0 s, is desirable for a piezoelectric sensor in combination with its signal-conditioning system.

An equivalent circuit for a piezoelectric accelerometer, which uses a quartz crystal as the sensing element, is shown in Figure P5.39. The generated charge is denoted by q, and the output voltage at the end of the accelerometer cable is v_o. The piezoelectric sensor capacitance is modeled by C_p, and the overall capacitance experienced at the sensor output, whose primary contribution is due to cable capacitance, is denoted by 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 the 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 $C_p = 300$ pF, and a circuit with $C_c = 700$ pF compute the time constant.

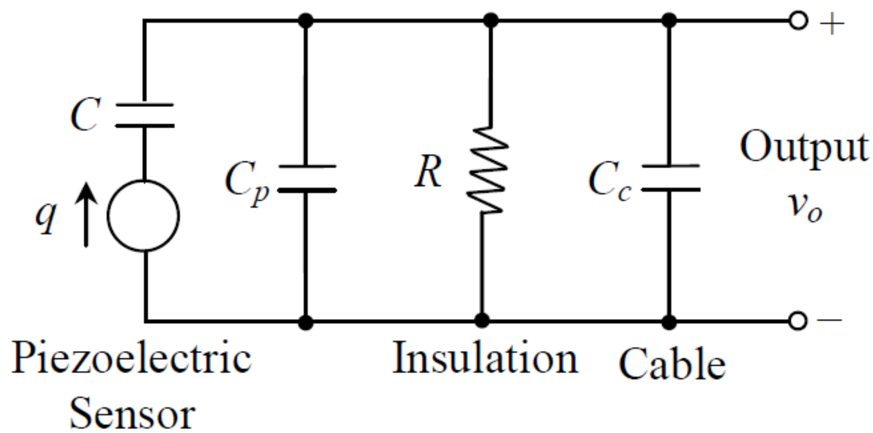

Figure P5.39: Equivalent circuit for a quartz crystal (piezoelectric) accelerometer.

Problem 6 (Problem 5.47 from Textbook)

Consider the joint of a robotic manipulator, shown schematically in Figure P5.47. Torque sensors are mounted at locations 1, 2, and 3. Denoting the magnetic torque generated at the motor rotor by T_m write equations for the torque transmitted to link 2, the frictional torque at bearing A, the frictional torque at bearing B, and the reaction torque on link 1, in terms of the measured torques, the inertia torque of the rotor, and T_m.

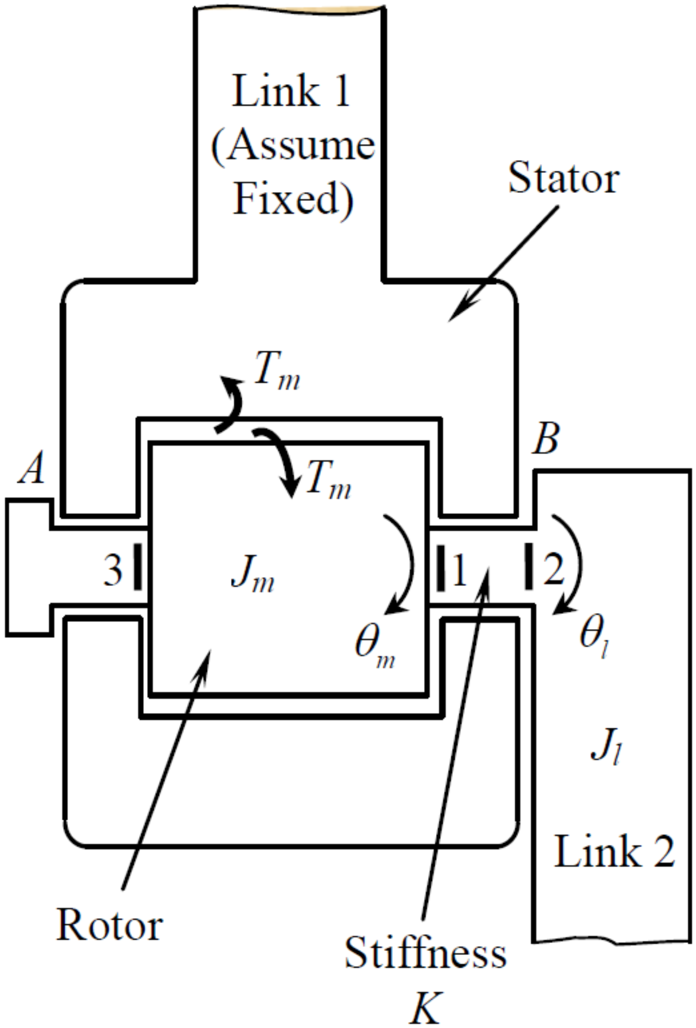

Figure P5.47: Torque sensing locations for a manipulator joint.

Problem 7 (Problem 5.56 from Textbook)

Figure P5.56 shows a schematic diagram of a measuring device.

(a) Identify the various components in this device.

(b) Describe the operation of the device, explaining the function of each component and identifying the nature of the measurand and the output of the device.

(c) List the advantages and disadvantages of the device.

(d) Describe a possible application of this device.

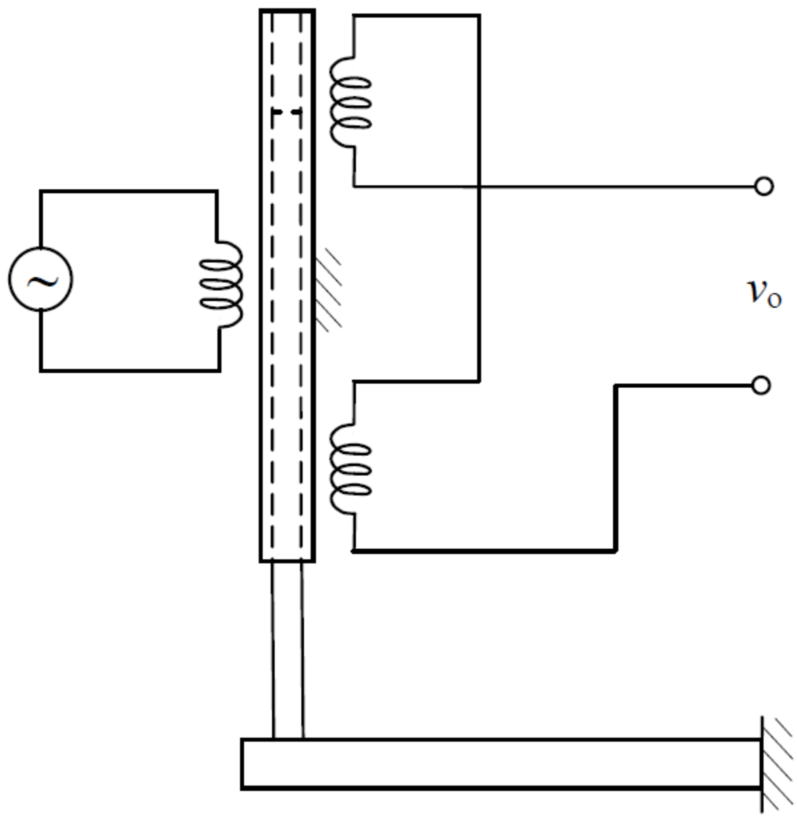

Figure P5.56: An analog sensor.

Problem 8 (Problem 5.66 from Textbook)

A simple rate gyro, which may be used to measure angular speeds, is shown in Figure P5.66. The angular speed of spin is ω and is kept constant at a known value. The angle of rotation of the gyro about the gimbal axis (or the angle of twist of the torsional spring) is θ, and is measured using a displacement sensor. The angular speed of the gyro about the axis that is orthogonal to both gimbal axis and spin axis is Ω. This is the angular speed of the supporting structure (vehicle), which needs to be measured. Obtain a relationship between Ω and θ in terms of such parameters as the following: J = moment of inertia of the spinning wheel; k = torsional stiffness of the spring restraint at the gimbal bearings; and b = damping constant of rotational motion about the gimbal axis; and the spinning speed. How would you improve the sensitivity of this device?

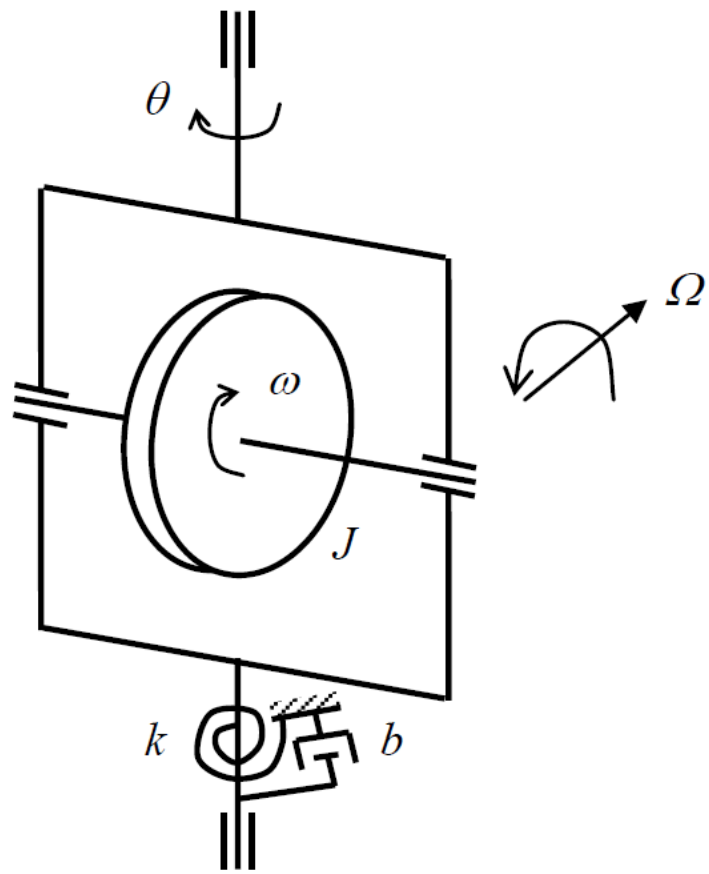

Figure P5.66: A rate gyro speed sensor.