Sensing, Computing, Actuating
Lecture 11 - Inductive Sensors and Demodulation

Exercise 1: Measuring inclination

An LVDT sensor is used to measure the angle Θ of a crane. A load of 10 kg is connected to the core of the LVDT sensor. The outer casing of the LVDT sensor is connected to the arm of the crane. The mass is connected to the frame of the sensor using a spring. The mass can move in the longitudinal direction of the axis. This is graphically depicted in the figure below. The primary winding of the LVDT is connected to a supply voltage that generates a sinusoidal voltage with an amplitude of 5V. The LVDT has a sensitivity of 100 mV/(mm/V). The spring constant k is equal to 200 N/cm.

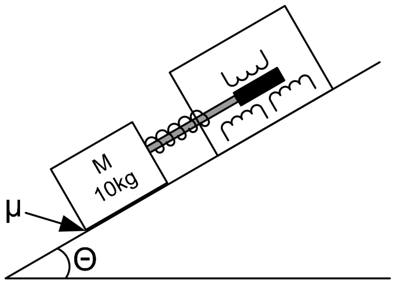

Figure 1: Meausing inclination using an LVDT.

(a) What is the output voltage of the sensor in terms of the angle Θ? (You may ignore the friction between the mass and the arm of the crane.)

(b) In the previous question you have ignored the friction between the mass and the arm of the crane. Assume now that the (static) friction is equal to μ. What is the relation between the displacement x of the mass, the angle Θ and the friction μ? (Hint: give x as a function of Θ and μ.)

(c) Does the sensor show hysteresis when we consider the friction? (Explain your answer.)

(d) A certain application requires that the output voltage of the LVDT sensor is amplified. For this purpose, the sensor from Figure 1 is connected to an instrumentation amplifier. The electrical equivalent circuit is shown in Figure 2.

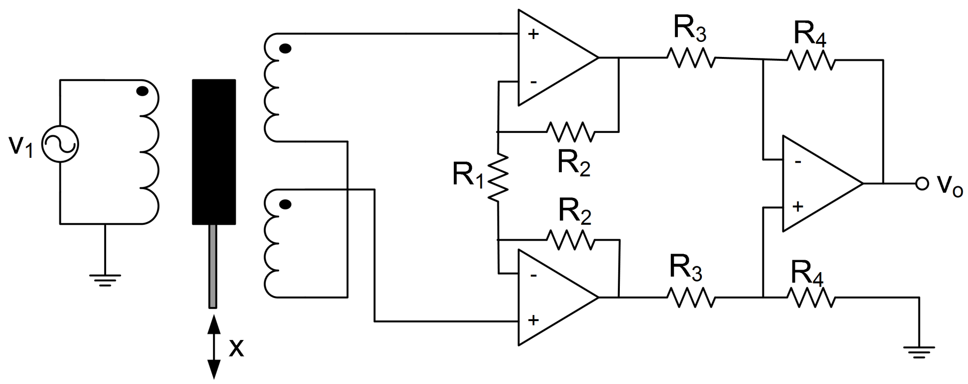

Figure 2: Amplification of the LVDT output signal.

The resistors R_2, R_3 and R_4 have a resistance of 15 kΩ. What value shoudl the resistance R_1 have such that the amplitude of the output voltage v_o is equal to 0 V when $\Theta = 0°$ and 5 V when $\Theta = 90°$? (You may ignore the friction between the mass and the crane.)

(e) The arm of the crane moves in 1 second from an angle $\Theta = -45°$ to an angle $\Theta = +45°$. Assume that this movement happens with a constant speed. A sinusoidal voltage v_1 with a frequency of 10 Hz and an amplitude of 5V has been placed on the primary winding of the LVDT sensor. Draw the excitation voltage on the primary winding ($v_1(t)$), the angle of the crane ($\Theta(t)$), and the output voltage of the instrumentation amplifier ($v_o(t)$). (Clearly show on each axis the dimension and scale. Ignore the friction between the mass and the crane.)

(f) The output of the instrumentation amplifier from Figure 2 is connected to a single-sided rectifier with low-pass filter as shown in Figure 3. Draw the output voltage ($v_o(t)$) of the circuit when the arm is kept still at an angle of 45°.

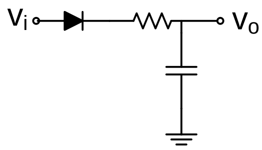

Figure 3: Single-sides rectifier with low-pass filter

(g) Can you reconstruct the direction (positive or negative angle) from the output signal ($v_o(t)$) of the circuit with the single-sided rectifier? (Explain your answer.)

(h) Instead of the instrumentation amplifier from Figure 2 and the single-sided rectifier, you may connect the LVDT sensor from Figure 1 directly to a double-sided rectifier. In addition, the middle connector of the secondary windings is connected to ground. The electrical schematic of the sensor and its signal conditioning circuit is shown in Figure 4. Draw the output voltage ($v_o(t) = v_2(t) - v_1(t)$) of the circuit when the arm is kept still at an angle of 45°.

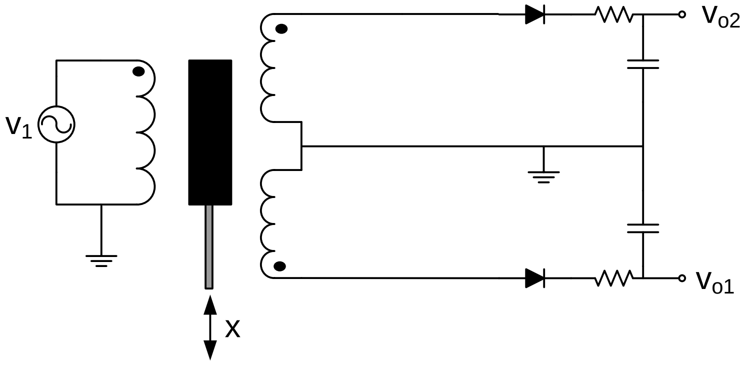

Figure 4: Double-sided rectifier with low-pass filter.

(i) Can you reconstruct the direction (positive or negative angle) from the output signal ($v_o(t)$) of the circuit with the double-sided rectifier? (Explain your answer.)