Linear variable differential transformer and strain gauge transducer

There are many types of transducers displacement measurements, Linear variable differential transformer (LVDT), capacitive transducer, potentiometer transducer, resistive transducer, optical transducer, etc. For our experiments purpose we use the LVDT, since it's able to produce high output for relatively small displacement and for strain measurement we use the strain gauge transducer.

Linear Variable Differential Transformer(LVDT):

The linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement. The transformer has three solenoid coils placed end-to-end around a tube. The centre coil is the primary, and the two outer coils are the secondary's. A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube, the figure below shows the construction of the LVDT. When an alternative current is applied into the primary coil, a voltage is induced in each secondary core; those voltages are directly proportional to the mutual inductance induced with the primary.

As the core moves, these mutual inductances change, causing the voltages induced in the secondary's to change. The coils are connected in reverse series, so that the output voltage is the difference between the two secondary voltages. When the core is in its central position, the distance between the two secondary's is equal , hence equal but opposite voltages are induced in these two coils, so the output voltage is zero.

When the core is displaced in one direction, the voltage in one coil increases as the other decreases, causing the output voltage0 to increase from zero to a maximum. This voltage is in phase with the primary voltage. When the core moves in the other direction, the output voltage also increases from zero to a maximum, but its phase is opposite to that of the primary. The magnitude of the output voltage is proportional to the distance moved by the core (up to its limit of travel), which is why the device is described as " linear". The phase of the voltage indicates the direction of the displacement. Because the sliding core does not touch the inside of the tube, it can move with little friction, making the LVDT a highly reliable device. LVDTs are commonly used for position feedback in servo-mechanisms, and for automated measurement in machine tools, control systems, robots, and many other industrial and mechanical systems.

Strain Gauge:

Strain gauge transducers are kind of sensors that transduce(convert) strain applied into an electrical signal (usually voltage) for the purpose of pressure sensors applications, force and torque measurements. It was invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. A strain gauge is simply a resistor, whose value varies with strain in the material to which it is bonded. They can be used in various fields when a readable value needed to be modeled from a force or strain applications. The construction of the strain gauge sensor is as shown in the following figure. As seen in the figure it has a fine resistance wire, sensitive for load weights.

Objectives:

- To obtain a characteristics of the LVDT and Strain gauge sensor.
- To obtain a mathematical equation for the sensors response.
- To obtain distance measurement using LVDT and Strain Gauge sensor and convert it to a Human readable form.

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Significance of the problem:

By doing this experiments, the functions of LVDT can be learnt. The LVDT advantages might be useful for lots of project such as measurement process, silent process, and any process that needs fast output generation. The disadvantages of LVDT also can be observed by doing this experiment, which are important to be learnt. By knowing the disadvantage, students can take these matters into consideration during system designing process.

The importance of Strain gauge also can be learnt in this lab topic. In robotic system, force measurement is very important. The voltage used must be relevant depending to the load given. Energy wasting will happen if relation between load and voltage is ignored. Nowadays many companies want to produce something that saves energy and environmental friendly, so strain gauge can help to achieve that objectives.

1. 3 Background and Literature Review

LVDT

Linear variable differential transformer is popularly known as LVDT. The LVDT contains one primary winding, and two secondary windings connected to each other in series opposing manner as shown in the figure below. The body whose displacement is to be measured is connected to the iron core.

According to Haresh Khemani in Jan 28, 2010, graduate of Mechanical Engineering from University of Pune, India, “ LVDT comprises of the differential transformer that provides the AC voltage output proportional to the displacement of the core passing through the windings.”. According to him too, LVDT is basically a differential transformer, whose voltage output is linear to the displacement of the object hence it is given the name linear variable differential transformer.

Meanwhile, according to Measurement Specialties Incorporation., a leading global designer and manufacturer of sensors and sensor-based systems, “ An LVDT, or Linear Variable Differential Transformer, is a transducer that converts a linear displacement or position from a mechanical reference (or zero) into a proportional electrical signal containing phase (for direction) and amplitude information (for distance).”. According to this company, the operation does not require electrical contact between the moving part (probe or core rod assembly) and the transformer, but rather relies on electromagnetic coupling; this and the fact that they operate without any built-in electronic circuitry are the primary reasons why LVDTs have been widely used in applications where long life and high reliability under severe environments are a required, such Military/Aerospace applications.

LVDT have been used widely in many applications. Companies such as Trans-Tek Inc. had done so many applications on LVDT such as LVDT use in ATM to Sense Dollar Bills by using miniature transducers, such as the Series 230 AC-AC LVDT. The low mass core is ideal for systems with low driving forces or high acceleration and, therefore, will not adversely influence the delicate nature of these applications. One application requiring a miniature LVDT is the multiple bill detector of an automated teller machine, or ATM. This mechanism is capable of detecting single, double and triple bills, as well as folded, taped, overlapping and soiled bills.

Combining an AC-AC LVDT with the necessary electrical components will result in a relatively low-cost system with high-end performance. AimRite Holdings Corporation is a pioneer in the field of computer controlled suspension technology for the automotive industry. Targeting mainly sports utility vehicles (SUV) trucks, buses and RV. s, AimRite. s trademark product – the COAST system – uses the Model 0283-0000 AC-AC LVDT for continuous position feedback. This advanced suspension design offers numerous benefits including: luxury car ride with sports car performance, on-road and off-road application, replacement of sway bars and shock absorbers, simultaneous control of all vehicle dynamics, compatibility with conventional or air springs, reliability and flexibility at a minimal cost, and robust construction.

Strain Gauge

According to National Instrument, “ Strain is the amount of deformation of a body due to an applied force. More specifically, it is defined as the fractional change in length,” As shown below it can be seen that strain can be positive (tensile) or negative(compressive) depending on the direction of force given.

The strain gauge is one of the commonly used strain measurement sensors. It is a resistive elastic unit that changes in resistance is a function of applied strain.

Where R is the resistance, ï¥ is the strain, and S is the strain sensitivity factor of the gage material (gage factor in some books).

The majority of strain gauges are foil types, available in a wide choice of shapes and sizes to suit a variety of applications. They consist of a pattern of resistive foil which is mounted on a backing material. They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.

According to University of Massachusetts Lowell, strain gauge is a sensor used to transfer a mechanical strain to a quantifiable output. The strain gauge has a resistance which changes as a function of mechanical strain. Although the change in resistance can be quantified using an ohm meter, signal conditioning is used to convert the change in resistance to a voltage. The voltage may then be amplified, thus reducing quantization errors. The relationship between the input strain and the output voltage may be determined using the system sensitivity.

In practice, strain measurement involves quantities larger than few milistrain, Therefore, to measure the strain; it requires accurate measurement of very small changes in resistance. To measure such small change, strain gauges are always used in a bridge configuration with voltage excitation source just like the Wheatstone bridge shown below

From the equation, when R1/R2= R3/R4, output will be zero. Under this condition, bridge is in balance state. Any change of resistance will give value to output voltage. So if R4 is to be change into active strain gauge, any changes in the gauge resistance will unbalance the bridge and produce nonzero output voltage.

In 1992, a patent on Strain gauge for medical applications by Bowman, Bruce R. (Eden Prairie, MN) is published. It is a strain gauge for use in certain medical applications, such as sensing the occurrence of an apnea event. " The device is also applicable to monitoring mechanical motion associated with other medical conditions. The strain gauge actually measures the change in DC resistance produced by stretching and compression of a number of carbon deposits coupled in series on a longitudinally extendible substrate. This extendibility is produced by suitably die cutting a flexible but inherently inelastic insulative substrate. The easily produced device may be used externally or encapsulated for implantation."

Meanwhile in 1987, Strain gauge scale for weighing fish patented by Reder, Lawrence H. It is a portable scale particularly for weighing fish and normally hand held and which includes a strain gauge for sensing the weight of a fish and the strain gauge providing a leg of a Wheatstone Bridge to provide the measuring of the strain placed upon a member to which the fish is attached. The unit includes battery sources for the required power and includes an LED display unit for reading of the weight of the fish. A zero set may be incorporated in the circuitry or a reset to zero reading may be provided. The unit provides a portable, accurate scale for weighing of fish and the unit may also include selective sensing circuitry for reading of other inputs such as temperature of water.

2. 0 Methodology:

In this experiment we are using the DIGIAC 1750, Digital-multimeter and oscilloscope.

LDVT:

It's intended to measure the rectified output voltage using a digital multimeter set on the range of 20V DC. The analog multimeter also used to compare the results when using it against a digital multimeter. The procedure for conducting this experiment are as follows:

The circuit is connected as in Figure 6 with the digital multi-meter on the 2V DC range to monitor the output of the Full-Wave Rectifier.

The power supply is switched ON.

AC Amplifier gain is set to 1000.

Gain Coarse and Gain Fine control of Amplifier #1 is set to 100 and 0. 2 respectively for and adjusted to produce zero output with zero input.

The core position is adjusted by rotating the operating screw to the neutral position to give minimum output voltage (voltage from the digital multi-meter).

The result is recorded as in Table 1 below

Table 1

- The core control screw is rotated in steps of 1 turn for 4 turns in the clockwise direction and the result is recorded.
- Then the control screw is turned in the counter clockwise direction and the result is recorded.
- The graph of output voltage from the analog meter readings against core position is plotted.

Strain Gauge:

The circuit is connected as in Figure 7 below.

Amplifier#1 coarse gain is set to 100

The power supply is switched on and the offset control of Amplifier#1 is set to produce zero voltage output under no load condition.

Figure 10 : electrical connection of strain gauge

Ten coins with similar weights(10 cent coins) are placed on the gauge and the gain fine control is adjusted to produce 7. 0 voltage output

One coin is placed on the load platform and the value is recorded in table 2

Table2

Step #5 is repeated and all values are noted in the table

The graph of output voltage against number of coins is plotted.

Another set of ten coins (20 cents) are placed on the load platform and the steps from 4 to 7 are repeated.

Results and Analysis:

Linear Variable Differential Transformer (LVDT) :

The data shown in the following table shows the reading of both the analog and digital multi-meter for 4 turns in the clockwise and anti-clockwise directions after calibrating the core position into the initial neutral position.

The results recorded in the table above then plotted on the graph in figure 11, showing the relationship between the output voltage for every respected trun of the core position.

The result transformed from the table into the graph resembles the theoretical graph. The maximum negative and positive turn generate maximum voltage. When the turn is at neutral position, the voltage is almost zero indicate that both secondary coils have slightly same value. The graph is not perfectly a straight line due to external disturbance such as electromagnetic field source came from hand phone and other devices

Strain Gauge:

For this experiment we used two different types of loads with different weights, one with 10 cent coins and the other using 20 cent coins. The purpose of using those two different loads is to ensure accuracy and precision since the output should be the same as long the threshold values are set to be the same for both types.

The plot graph in figure 12 shows number of loads (10 cent) vs. output voltage is a transformation of the readable data into realistic form, which show linearity between the output voltage and the weight of a load.

When no load is applied on the strain gauge, the voltage measured is 0V indicated that there is no resistance on the device. Using 10 cent coin, the graph generated is as expected, a linear graph

To test the consistency, we used 20 cent coin and the graph generated is almost same as 10 cent coin experiment.

4. 0 Discussion:

4. 1 LVDT:

The outputs produced are actually small, like can be seen in the data record for Digital multi-meter. So amplifiers are used to amplify the output so that the pattern of the output can be observed more clearly. Then, mathematical expression can be obtained. Let say, 9V is the highest output voltage that can be obtained.

By using linear equation y = mx + c

y is the output voltage

x is the number of turns

m is the sensitivity

c is the displacement/offset

For Expected Output:

c = 0 because the values touches y axis at 0V.

m= (9-0) / (4-0) = 2.. 25 V/turn

So the mathematical expression is:

y = 2. 25| x|, since for -ve turn, the output is same for +ve turn.

For Experimental Output:

c = 0. 5

For +ve turn, averagely, m = (9-0. 5) / (4-0) = 2. 125 V/turn

So the mathematical expression is: y = 2. 125x + 0. 5; for positive turn

For -ve turn, averagely, m = -(8-0. 5) / (4-0) = -1. 875 V/turn

So the mathematical expression is: y = -1. 875x + 0. 5; for negative turn

Even though the output generated is increasing as the number of turns increases, but the pattern of output readings are not smooth just like the expected output. It can be seen in figure below that the experimental values are not totally linear because the increasing rate is not consistent. This might happen because of LVDT disadvantage which is sensitive to stray magnet field. So, during the experiment, any electronic devices that produces magnetic field such as cell phone and notebook must be avoided to be close to the LVDT

In term of waveform generated, it can be seen as in figure 15 that during the zero turn, the output voltage is in same phase as input, except the amplitude is lower. Meanwhile during positive turns, the output is lagging the input and the voltage amplitude is higher. As for the negative turn, the output is leading the output and the amplitude is higher.

Strain Gauge

Same like the LVDT experiments, the output produced by strain gauge is small, so it is amplified by the amplifier to make the observation more clearly. As illustrated in figure 16, it can be seen that the value of output increase as the number of load increases. By doing this experiment using two types of load, the consistency of the system can be tested.

By using 10 cent and 20 cent coins as load, two data sets obtained. There are some differences in the values of the output of these two data. It suppose to give the same value no matter what type of load is used since the value of offset and maximum output have already been set at the beginning of the experiment. This might happen because of the external force as example, from the hand when putting the load on the platform and also from the pressure of the room that are not consistent. Even a small change in pressure of environment can affect the output because output from the strain gauge is amplified by 100.

For the mathematical expression for this experiment can be obtain by using the same method as LVDT.

By using linear equation $y = mx + c$

y is the output voltage

x is the number of load

m is the sensitivity

c is the displacement/offset

For Expected Output:

c = 0 because the values touches y axis at 0V.

m= (7-0) / (10-0) = 0. 7 V/turn

So the mathematical expression is:

y = 0. 7x

For Experimental Output:

c = 0 because the values touches y axis at 0V.

For 10 cent, averagely, m = (7. 25-0) / (10-0) = 0. 725 V/turn

So the mathematical expression is: y = 0. 725x; for 10 cent

For -ve turn, averagely, m = (7. 13-0.) / (10-0) = 0. 713 V/turn

So the mathematical expression is: y = 0. 713x; for 20 cent