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Design and Implementation of An LVDT for Displacement Measurement

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Abstract

This paper presents the design and implementation of an LVDT (Linear Variable Differential Transformer) interfaced with an Arduino microcontroller for displacement measurement applications. The study covers theoretical background, working principles, hardware implementation, signal conditioning, and practical testing of the system. Experimental results confirm that the Arduino-based LVDT interface provides a cost-effective, accurate, and reliable solution for displacement sensing applications.

Keywords: LVDT, Arduino, Displacement Measurement, Signal Conditioning, Sensor Interfacing.

1. Introduction

Linear displacement measurement plays a crucial role in automation, robotics, and industrial applications. Among various displacement sensors, Linear Variable Differential Transformers (LVDTs)[1] stand out due to their robustness, infinite resolution, and non-contact sensing capability[2]. This paper focuses on the construction, working principle, and interfacing of an LVDT with an Arduino microcontroller for real-time displacement measurement. Linear displacement is movement in one direction along a single axis. A position or linear displacement sensor is a device whose output signal represents the distance an object has travelled from a reference point. A displacement measurement also indicates the direction of motion as shown in figure1. A linear displacement typically has units of millimeters (mm) or inches (in.) and a negative or positive direction associated with it. The main advantage of the LVDT transducer over other types of displacement transducer is the high degree of robustness[3] as there is no physical contact across the sensing element.

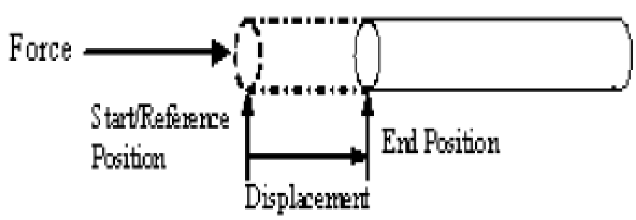

Fig.1 Linear Displacement Measurement

A linear displacement typically has units of millimeters (mm) or inches (in.) and a negative or positive direction associated with it. The main advantage of the LVDT transducer over other types of displacement transducer is the high degree of robustness[3] as there is no physical contact across the sensing element.

2. System Design and Methodology

The system comprises an LVDT sensor, Arduino UNO microcontroller, signal conditioning circuit, and display unit. The Arduino provides excitation signals, processes the sensor output, and displays displacement values on an LCD. The signal conditioning is performed. The physical construction of a typical LVDT consists of a movable core of magnetic material and three coils comprising the static transformer[4-6]. One of the three coils is the primary coil and the other two are secondary coils. As shown in Figure 2, an LVDT consists of a coil assembly and a core. The coil assembly is typically mounted to a stationary form, while the core is secured to the object whose position is being measured. The coil assembly consists of three coils of wire wound on the hollow form. A core of permeable material can slide freely through the centre of the form[7-9]. The inner coil is the primary, which is excited by an AC source as shown. Magnetic flux produced by the primary is coupled to the two secondary coils, inducing an AC voltage in each coil.

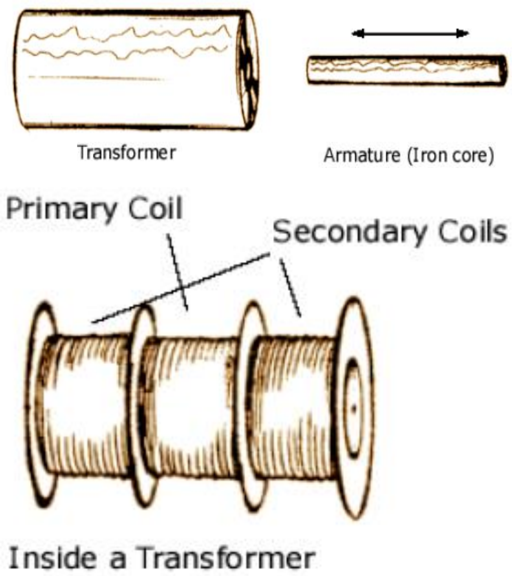

Fig.2 Typical Linear Variable Differential Transformer construction(LVDT)

The basic transformer formula which states that the voltage is proportional to the number of coil winding, is the backbone of the LVDT.

$$\frac{V_{out}}{V_{in}} = \frac{N_{out}}{N_{in}} \qquad (1)$$

Where N is the number of coil winding and V is the voltage.

When the iron core slides through the transformer, a certain number of coil winding are affected by the proximity of the sliding core and thus generate a unique voltage output[10]. An LVDT measures displacement by associating a specific signal value for any given position of the core. This association of a signal value to a position occurs through electromagnetic coupling of an AC excitation signal on the primary winding to the core and back to the secondary windings. The position of the core determines how tightly the signal of the primary coil is coupled to each of the secondary coils. The two secondary coils are series opposed, which means wound in series but in opposite directions. This results in the two signals on each secondary being 180^0 out of phase[11]. Therefore, phase of the output signal determines direction and its amplitude, distance. Figure 3 depicts a cross-sectional view of an LVDT. The core causes the magnetic field generated by the primary winding to be coupled to the secondaries. When the core is centered perfectly between both secondaries and the primary[12], as shown, the voltage induced in each secondary is equal in amplitude and 1800 out of phase. Thus, the LVDT output (for the series-opposed connection shown in this case) is zero because the voltages cancel each other.

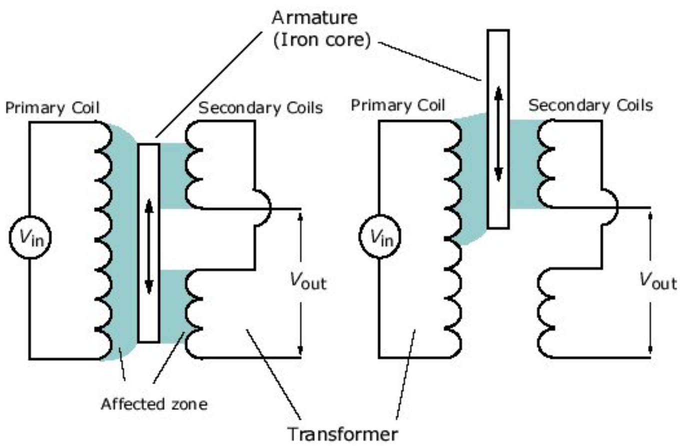

Fig.3 Cross-Sectional View of LVDT Core and Windings.

Displacing the core to the top causes the first secondary to be more strongly coupled to the primary than the second secondary. The resulting higher voltage of the first secondary in relation to the second secondary causes an output voltage that is in phase with the primary voltage. Figure 4 shows the linearity of the device within a range of core displacement. Note that the output is not linear as the core travels near the boundaries of its range. This is because less magnetic flux is coupled to the core from the primary. However, because LVDTs have excellent repeatability, nonlinearity near the boundaries, the range of the device can be predicted by a table or polynomial curve-fitting function, thus extending the range of the device.

Since the output of an LVDT is an AC waveform, it has no polarity. The magnitude of the output of an LVDT increases regardless of the direction of movement from the electrical zero position. In order to know in which half of the device the centre of the core is located, one must consider the phase of the output as well as the magnitude as compared to the AC excitation source on the primary winding. The output phase is compared with the excitation phase, and it can be either in or out of phase with the excitation source, depending upon which half of the coil the centre of the core is in.

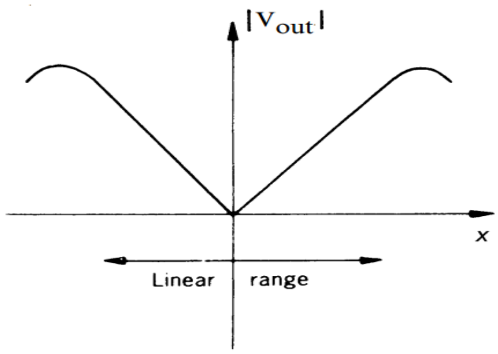

Fig.4 Proportionally Linear LVDT Response to Core Displacement.

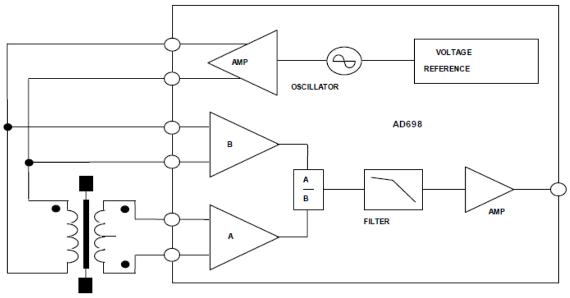

Fig.5 Functional Block Diagram for AD 698.

The signal conditioning electronics must combine information on the phase of the output with information on the magnitude of the output, so the user can know the direction the core has moved as well as how far from the electrical zero position it has moved. LVDT signal conditioners generate a sinusoidal signal as an excitation source for the primary coil. This signal is typically between 50 Hz and 25 kHz. The carrier frequency is generally selected to be at least 10 times greater than the highest expected frequency of the core motion. The signal conditioning circuitry synchronously demodulates the secondary output signal with the same primary excitation source. The resulting DC voltage is proportional to core displacement. The polarity of the DC voltage indicates whether the displacement is toward or away from the first secondary. The AD698 is a complete, monolithic Linear Variable Differential Transformer (LVDT) signal conditioning subsystem. Figure5 represents the functional block diagram of AD698. It is used in conjunction with LVDTs to convert transducer mechanical position to a unipolar or bipolar dc voltage with a high degree of accuracy and repeatability. All circuit functions are included on the chip. With the addition of a few external passive components to set frequency and gain, the AD698 converts the raw LVDT output to a scaled dc signal. The AD698 contains a low distortion sine wave oscillator to drive the LVDT primary. Two synchronous demodulation channels of the AD698 are used to detect primary and secondary amplitude. The part divides the output of the secondary by the amplitude of the primary and multiplies by a scale factor. This eliminates scale factor errors due to drift in the amplitude of the primary drive, improving temperature performance and stability. The AD698 uses a unique ratio metric architecture to eliminate several of the disadvantages associated with traditional approaches to LVDT interfacing. The benefits of this new circuit are no adjustments are necessary; temperature stability is improved; and transducer interchangeability is improved.

3. Hardware Implementation

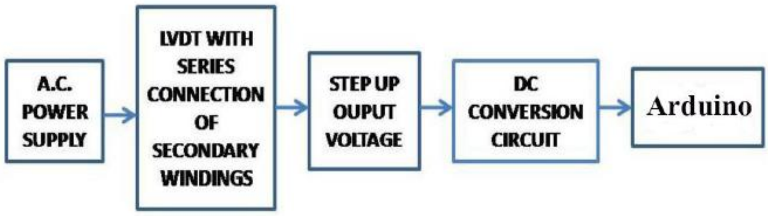

Fig.6 Block diagram for hardware implementation of LVDT.

Figure 6 represents the block diagram for the design of LVDT interfacing with the Arduino. A single phase , 230V, 50Hz, AC supply was given to the primary winding of the LVDT. Initially movable iron or core was placed at the centre position. The upper secondary winding terminals and lower secondary winding terminals were in series opposition short circuited, and the output was taken at the other two terminals. The output terminals of secondary winding are connected to diode bridge rectifier to convert AC to DC and this positive voltage can be measured by using Arduino which determines the total voltage corresponds to the displacement of the movable iron. The direction is indicated by polarity of DC voltage, how the positive and negative voltages are increasing and decreasing. The direction of the core is determined in three cases

I. **Case 'A'**:
If the iron is placed in the forward direction, then, the voltage in the Vs1 is high and voltage in the Vs2 is very low with negative sign. The Difference is positive voltage.

II. **Case 'B'**:
If the iron is placed in the backward direction, then, the voltage in the Vs1 is low and voltage in the Vs2 reading is high and results negative voltage.

III. **Case 'C'**:
If the iron is placed at the centre position across the primary winding, then the reading of Vs1 and Vs2 voltages gets cancelled each other and resultant voltage is zero. This point is known as null position.
The step-by-step implementation of the LVDT is given below.

1. Design a normal LVDT with 100 turns in primary and a total 200 turns in each secondary winding with double layer.
2. Give AC supply with 6Volts ,0.6Amp current to primary winding.
3. Place the iron core across the primary coil in such a way that the voltage induced in the both the secondary's gets cancelled each other and this position is known as Null Position which gives an error of 0.003v.
4. Now move the iron in forward direction and note the readings .
5. Similarly repeat the Step 4 in reverse direction.
6. Plot the graph by taking forward displacement along positive X-axis and reverse displacement along negative X-axis and total voltage along Y-axis.
7. Determine the linearity i.e. lower bound point and upper bound point.

8. Now calculate the slope (m) of the linearity and determine the line equation passing through origin having the slope (m) [i.e. y=mx].
9. Now move the iron to any arbitrary position and note the readings of both the voltmeters and the total voltage. If the sign of the total voltage is positive ,it indicates forward direction, and the value indicates the position (x) of the iron. [i.e. x=y/m].
10. The results were validated using graph and with the known values.

4. Results & Discussion

The Specifications for the design of LVDT and the results are discussed in this section. Table 1 represents the specifications of the hardware. Table 2 represents the maximum induced secondary voltages at the null position. Figure 7 determines the practical implementation of the LVDT.

Table 1: Parameter Specifications

S.No	Parameters	Range
1	LVDT Excitation (i/p)	1-phase, A.C, 50Hz, 6V, 0.6A
2	Output Voltage Range	+0.501 to – 0.523V
3	Zero Adjustment Range	+ 0.003 V
4	Linearity	+ 0.05% of full scale
5	Operating Temperature	- 20 to 140 deg F
6	Power Consumption	0.2212 watts

Table 2: Maximum Induced secondary voltages at Null position

S.No	Secondary Voltages	Values
1	**Vs1**	**0.478 V**
2	**Vs2**	**0.475V**
3	**Vs1-Vs2**	**0.003V**

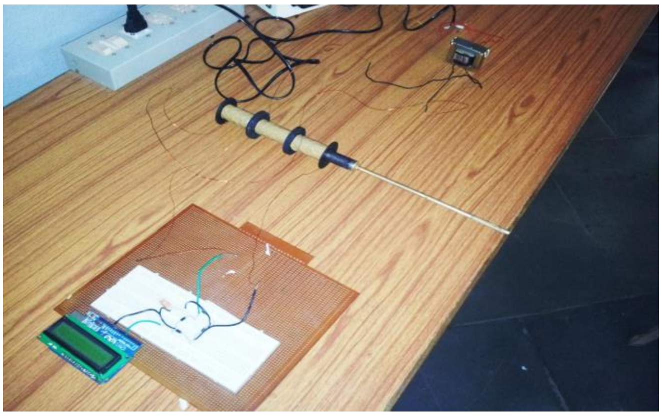

Fig.7 Hardware setup

Table 3 represents the Voltages in forward/backward directions in LVDT. From the table ,it can be observed that 0.003V is the null position which indicates that core is at the exact centre position. It can be observed from the table that the distance from 37 mm to 0.22 mm the core is moving in the forward direction and from 0.22mm to 40mm in the backward direction. The graphical representation of the above values shown in Figure.8, there is a linear relationship between the displacement and the voltage induced in the secondary windings.

Table 3 Voltages in forward/backward directions in LVDT

S.No	Core moving1cm Downwards from Max.voltage(Volts)	Core Displacement in downward direction (1mm=0.0134volts)
1	0.501	37.388
2	0.445	33.432
3	0.315	23.731
4	0.139	10.596
5	0.067	5.223
6	0.003(Null Position)	0.2238
7	0.22	17.146
8	0.384	29.761
9	0.495	38.299
10	0.523	40.454

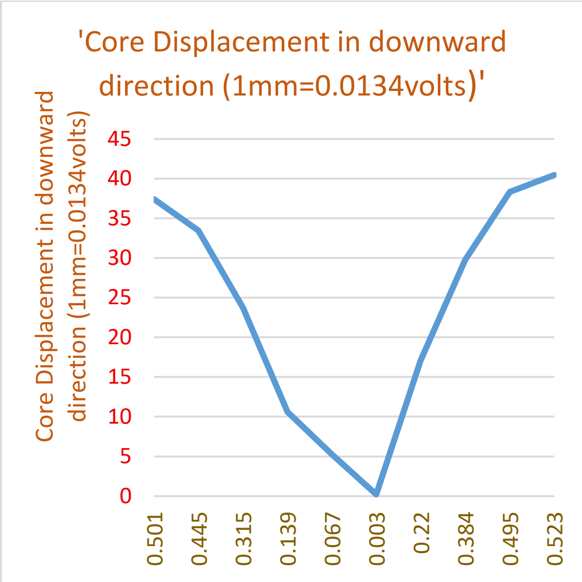

Fig.8 Experimental values of LVDT

Conclusion

This paper demonstrates a cost-effective displacement measurement system using an Arduino and an LVDT sensor. The results indicate that the system provides high accuracy, robustness, and real-time monitoring capability. In this project the design and operation of the LVDT which gives a linear analog position detecting signal is investigated. Arduino energises the LVDT and the output signal of LVDT is then processed by a phase-sensitive demodulate. The output of Arduino is proportional to the core movement. It is used in conjunction with LVDTs to convert transducer mechanical position to a unipolar or bipolar dc voltage with a high degree of accuracy and repeatability. Hence, output result confirms that the measurement of position as well as direction of the movable iron of LVDT was possible if the connections of the secondary windings were in series opposition. The results confirm that the magnetic field distribution from primary coil to secondary coil is uniform, so that the voltage induced in the secondary windings was according to the movement of the iron. The output results of LVDT displacements were valid and these results were verified using Arduino-program.

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