LVDT PRINCIPLES OF OPERATION

Technical Paper

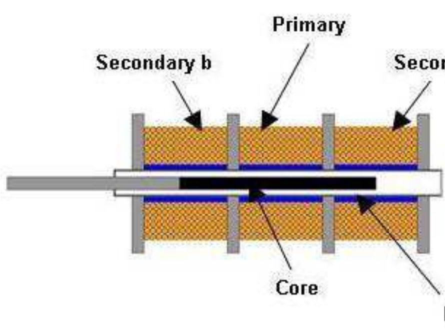
Introduction and purpose

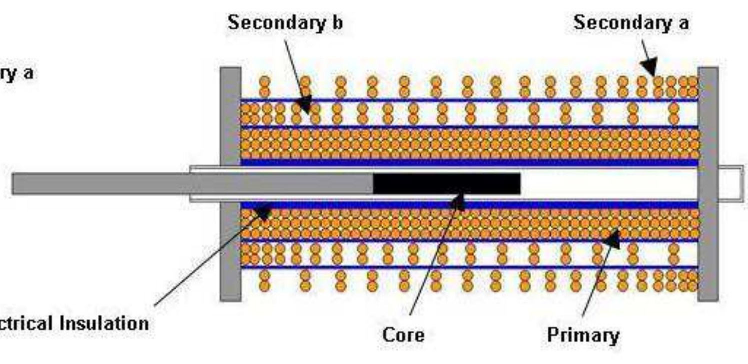
The LVDT (*Linear Variable Differential Transformer)*, is an absolute position/displacement transducer that converts a distance from a mechanical reference (zero, or *null position*) into a proportional electrical signal containing phase (for direction) and amplitude (for distance) information. The LVDT operation does not require an electrical contact between the moving part (probe or *core* assembly) and the coil assembly, but instead relies on electromagnetic coupling; this principle plus the fact that LVDTs can operate without any built-in electronic circuitry are the primary reasons why they have been widely used in applications where long life and high reliability under very severe environments are a required, such as in Military/Aerospace, process controls, automation, robotics, nuclear, chemical plants, hydraulics, power turbines, and many others.

The purpose of this document is to provide additional technical insight to customers who need a better understanding of LVDTs, as well as to engineers who design or specify signal conditioning electronics.

Construction

The LVDT consists of a primary coil (of magnet wire) wound over the whole length of a non-ferromagnetic *boreliner* (or *spool tube*) or a cylindrical, non-conductive material (usually a plastic or ceramic) form. Two secondary coils are wound symmetrically on top of the primary coil for "long stroke" LVDTs (i.e. for actuator rod position) or each side of the primary coil for "Short stroke" LVDTs (i.e. for electro-hydraulic servo-valve or EHSV). The two secondary windings are typically connected in "series opposing" (Differential). A ferromagnetic core, which length is a fraction of the coil assembly length, magnetically couples the primary to the secondary winding turns that are located over the length of the core.





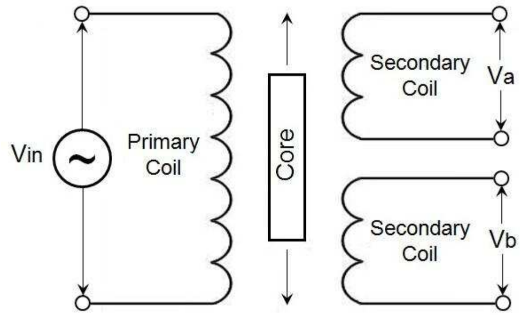
LVDT cross-section, short stroke (<=0.2 inch)

LVDT cross-section, long stroke (>0.2 inch)

Even though the secondary windings of the long stroke LVDT are shown on top of each other in the above illustration, nowadays TE Connectivity winds them both at the same time using custom designed, dual carriage computerized machines. This method reduces manufacturing time and also creates secondary windings with the same exact resistance and symmetrical capacitance distribution, therefore allows better performance (linearity, phase symmetry, lower null voltage, etc.).

Principles of operation

When the primary coil is excited with a sine wave voltage (Vin), this voltage produces a current in the windings, function of the input impedance. This variable current generates a variable magnetic flux which, channeled by the high-permeability ferromagnetic core, induces the secondary sine wave voltages Va and Vb. While the secondary windings are designed so that the amplitude of the differential output voltage (Va-Vb) is proportional to the core position, the phase of (Va-Vb) with reference to the excitation, called *Phase Shift* determines the direction away from the zero position. The zero, called *Null Position*, is defined as the core position where the phase shift of the (Va-Vb) differential output is 90 degrees.

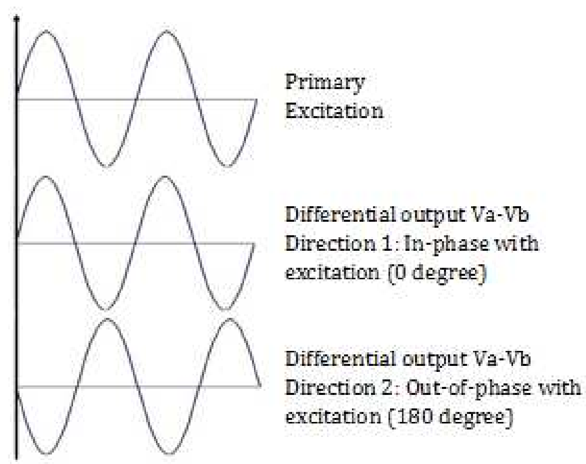


LVDT Schematic

The differential output between the two secondary outputs (Va-Vb) when the core is at null position is called the *Null Voltage.* As the phase shift is 90 degrees by definition, the null voltage is a “quadrature” voltage. This residual voltage is low; it is due to the complex nature of the LVDT electrical model, which includes the parasitic capacitances of the windings. This complexity also explains why the phase shift of (Va-Vb) is not exactly 0 or 180 degrees when the core is away from the null position.

The phase shift is very important as many signal conditioners employ synchronous demodulation to provide a DC output that is proportional to the following transfer function: **RMS voltage (Va-Vb) multiplied by the cosine of phase shift**. This is one of the best ways to provide an accurate and linear (especially around the null) position signal in a measuring system using an LVDT. It is also the method that allows the minimum numbers of electrical connections to the LVDT, as only 4 are required (2 for the excitation and 2 for the differential output; the secondary windings being connected in series opposing at the LVDT). One drawback of this technique is that the phase shift has to be low enough to avoid affecting the noise level in the demodulator, and to prevent a too large signal drop (due to the cosine in the transfer function). To avoid these adverse effects, TE Connectivity offers electronic instrumentation that includes **phase compensation electronic circuitry** to bring the phase shift back to zero.

In some cases it is beneficial to use the secondary sum, (Va+Vb) as the reference for the phase shift of (Va-Vb). However, one must ensure that the LVDT is designed with windings that provide a fairly constant sum along the stroke to be measured. The advantage of this method is that the phase shift between the secondary differential and the sum is very low, therefore there is no need to adjust it. However, only 5 or 6 wire LVDTs must be used. TE Connectivity LVM-110 and LiM-420 LVDT/RVDT signal conditioners operate this way.



LVDT waveforms

Temperature effects and their causes

While the temperature coefficient of sensitivity (sensitivity is the output per unit of displacement) is mostly determined by the number of winding turns, the resistance of the coils, the geometry of the core, and the resistivity & permeability of the metals used in the LVDT construction, the null position shift with temperature is mostly affected by the expansion coefficients and lengths of the materials. The null position is therefore a highly predictable and repeatable reference. As the mounting points in the application also have their own temperature effects, function of the materials used in the mechanical interface, an LVDT with a very low null position shift with temperature is generally not desired; a null position temperature shift that matches the temperature shifts of the mounting points is preferable.

"Ratiometric" operation for low temperature coefficient of output

An LVDT can be designed to maintain a constant sum of the secondary voltages (Va+Vb) over the measuring stroke length. By using a signal conditioning circuitry that computes the difference over sum ratio R = (Va-Vb) / (Va+Vb), one can see that the temperature coefficient (TC) could be dramatically reduced (in principle), as confirmed by the following equations:

Secondary output voltages function of temperature: **Va(t) = Va(70ºF)*Ca; Vb(t) = Vb(70ºF)*Cb**

The variable "t" is the temperature; 70ºF is the reference temperature; Ca and Cb are the temperature coefficients of Va and Vb respectively. Ca and Cb assumed equal (first order approximation Ca≈Cb≈C), then the ratio R is independent of temperature:

$$[Va(t)-Vb(t)] / [Va(t)+Vb(t)] = [Va(70ºF)*C-Vb(70ºF)*C] / [Va(70ºF)*C+Vb(70ºF)*C]$$

After simplification: $$[Va(t)-Vb(t)] / [Va(t)+Vb(t)] \approx [Va(70ºF)-Vb(70ºF)] / [Va(70ºF)+Vb(70ºF)]$$

or **R(t) ≈ R(70ºF)**

In reality the LVDT must be specifically designed for this ratiometric function to achieve the best performance, including the TC, as several other parameters have to be taken into account.

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