Linear Variable Differential Transformer

The Linear Variable Differential Transformer is a very accurate and frictionless positional transducer used for measuring the linear displacement of an object with an output voltage proportional to the position of its moveable core

A **Linear Variable Differential Transformer**, or **LVDT** for short, is an electromechanical position transducer (sensor) which provides accurate and frictionless positional feedback information about the linear mechanical position of an external force or object. As its name suggests, the *linear variable differential transformer* works on the same principle as the AC transformer but instead of supplying a load current or high voltage, it uses basic transformer principles of mutual inductance to measure linear movement.

In our tutorial about mutual inductance we saw that when two or more long solenoidal coils are wound together onto the same former or core, the magnetic flux produced by anyone of the coils links to the others with the magnetic flux produced by the driving coil aiding or opposing the flux produced by the other coils. Thus any AC current flowing through one coil will induce a voltage into the other magnetically-coupled coils, and this is the basic principle of the LVDT.

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Then the LVDT is a passive inductive transducer that requires an external source of power to operate. It uses coils and an alternating magnetic field to produce an analogue output voltage making it a *variable inductive transducer*. Thus the “linear variable differential transformer” measures distance along a linear axis.

The LVDT consists of three individual coils wound sequentially around a hollow, non-magnetic insulated tube. One coil of magnetic wire is classed as the primary coil and the other coils forming two identical secondaries.

The two secondary coils are connected together in a series-opposing configuration, that is they are electrically 180^{o} out-of-phase with each other. Hence the *Differential* part if its name.

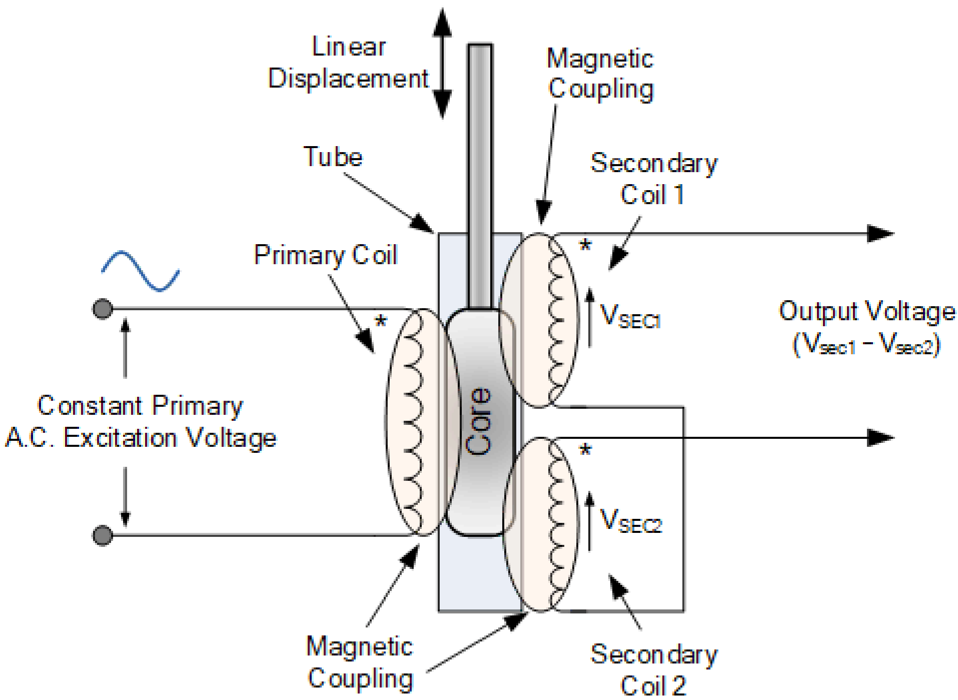
The LVDT's single centrally located primary coil is energised by a constant AC sinusoidal waveform source with a frequency ranging between about 1kHz to 10kHz. The magnetic flux produced by the primary winding is coupled through the core to one or both of the two secondary coils placed either side of it.

This arrangement produces a differential output voltage proportional to the core's displacement, thus giving it the additional name of "dispacement sensor". Then the linear variable differential transformer consists of one primary excitation coil and two secondary coils connected in "series opposing" (Differential).

A Typical Linear Variable Differential Transformer Sensor

A soft iron ferromagnetic core, called a "core", "slug", "plunger" or "armature", is allowed to move freely inside the central hollow tube in a straight line as a result of the displacement of the connected object increasing or decreasing the mutual inductance between the primary and the secondary coils which inturn increases or decreasing the voltage induced in each secondary coil. Producing a very accurate device for measuring linear displacement and whose output is proportional to the position of its moveable core. Hence the *Linear Variable* part of its name.

Linear Variable Differential Transformer



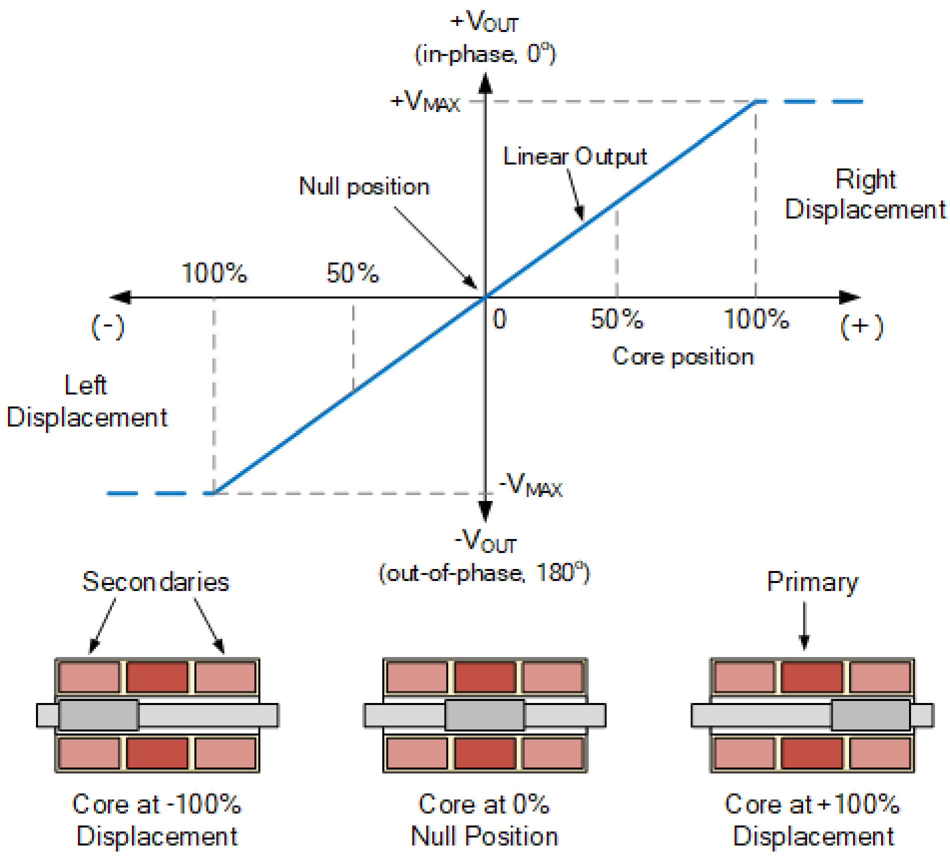
The image above shows the generalised principle of the LVDT. When the moveable soft iron ferromagnetic core in positioned in the center of the two secondary coils, "null position", the amount of primary magnetic flux induced into each of the two secondary coils is exactly the same. As the two secondary coils are wound 180^o out-of-phase with each other, the two induced emf's in the two secondary windings cancel each other out as value of V_{SEC1} = V_{SEC2}, so the resultant secondary output voltage is zero (V_{OUT} = 0). Thus zero volts means that the core is fully centered in its null position.

As the core is displaced slightly to one side or the other from this null or zero position, there will be a greater amount of magnetic flux induced in one of the secondary coil than the other due to the coupling effect of the ferromagnetic core. This causes the two secondary coils to become out-of-balance as the voltage induced into the secondary coil further away from the core becomes smaller, while the voltage induced into the secondary coil nearest the core becomes greater. This magnetic inbalance between the two secondary windings produces an output voltage (V_{OUT}) relative to the sinusoidal frequency of the peak voltage applied to the winding of the primary excitation coil.

Clearly then the differential voltage between the two secondary outputs, $V_{SEC1} – V_{SEC2}$ in one direction and $V_{SEC2} – V_{SEC1}$ in the other direction will be an RMS voltage multiplied by the cosine of phase shift. Therefore the greater the displacement of the moveable core from its central null position to one end or the other, (its stroke length) the greater will be the resulting output voltage.

The polarity and magnitude of the output signal depends upon the direction and amount of displacement of the moving core which itself is determined by the movement of the connected object. This displacement results is a differential voltage output which varies linearly with the cores position. Therefore, the rms output voltage from this type of position sensor has both an amplitude that is a linear function of the cores displacement and a polarity that indicates direction of movement as shown.

LVDT Output Voltage



We can see from the position-versus-voltage graph above that as core moves from one end of its range to the other through the center position, a greater magnetic linkage between the primary and whichever of the two secondary coils occurs. The output voltages changes from maximum to zero and back to maximum again in the opposite direction by an amount that is related to how far the core has been displaced from zero. This enables the LVDT to produce an output AC signal whose magnitude represents the amount of movement from the center “null” position and whose phase angle represents the direction of movement of the moveable core.

Connecting an object to the core allows the linear variable differential transformer transducer to provide quite precise information about the object's position. The range or stroke can be from a few millimeters to many hundreds of millimeters as their output is calibrated to produce a specific voltage per millimeter, for example, 20 or 200 mV/mm. That is a core displacement of one millimeter will produce a voltage output of 200 mV. If the phase angle of the output voltage (0^o or 180^o) is compared against that of the primary coil excitation voltage (0^o) it is possible to know which half of the secondary coil the core is located and thereby know the direction of travel.

A variable differential transformer has many advantages and uses for positional measurement compared to a resistive potentiometer-based transducers. LVDT's have very good linearity, that is its voltage output to displacement is excellent, very good accuracy, good resolution, high sensitivity as well as a frictionless operation due to the fact that there is no mechanical connection between the coils and core, so no friction and no parts to wear out. Also the *Transformer* part of its name means that there is electrical isolation between the primary and secondary windings allowing for greater electrical connectivity.

As the only interaction between an LVDT's primary, secondary windings and core is magnetic coupling, the LVDT's primary and secondary windings are usually sealed in an epoxy encapsulation with the whole sensor being encased in a metal housing allowing it to be used safely in a wide variety of damp or harsh environmental conditions.

Typical uses of the **linear variable differential transformer** transducer is mainly in industrial applications as pressure transducer, where the pressure being measured pushes against a diaphragm to produce a linear movement which is converted into a voltage signal by the LVDT, or in robotic measuring heads used in inspection tools and gauges where the inner core of the LVDT is spring loaded allowing it to return to some preset reference point. They also have many uses as null position sensors in servo or closed-loop control systems were null point repeatability is reuired.

LVDT Example No1

A linear variable differential transformer has a stroke length of ±150mm and produces a resolution of 40mV/mm. Determine: a) the LVDT's maximum output voltage, b) the output voltage when the core is moved 120mm from its null position, c) the core position from center when the output voltage is 3.75 volts, d) the change in output voltage when the core is moved from +80mm to -80mm displacement.

a). The maximum output voltage, V_{OUT}

If 1mm of movement produces 40mV, then 150mm of movement produces:

$$V_{OUT} = 40\text{mV} \times 150\text{mm} = 0.04 \times 150 = \pm 6 \text{ Volts}$$

b). V_{OUT} with 120mm of core displacement

If a core displacement of 150mm produces an output of 6 volts, then a movement of 120mm produces:

$$V_{OUT} = \frac{\text{Core Displacement} \times V_{MAX}}{\text{Length}}$$

$$V_{OUT} = \frac{120\,\text{mm} \times 6\,\text{V}}{150\,\text{mm}} = \frac{120 \times 6}{150} = 4.8\,\text{Volts}$$

c). Core position when V_{OUT} = 3.75 volts

$$V_{OUT} = \frac{\text{Core Displacement} \times V_{MAX}}{\text{Length}}$$

$$\therefore \text{ Displacement} = \frac{V_{OUT} \times \text{Length}}{V_{MAX}}$$

$$D = \frac{3.75\,V \times 150\,mm}{6\,V} = \frac{3.75 \times 150}{6} = 93.75\,mm$$

d). Voltage change from +80mm to -80mm displacement

$$V_{CHANGE} = \frac{+80\,mm - (-80\,mm) \times 6\,V}{150\,mm} = \frac{80 - (-80) \times 6}{150} = 6.4\,\text{Volts}$$

Thus the output voltage changes from +3.2 volts to -3.2 volts as the core moves from +80mm to -80mm respectively.

Displacement transducers come in many lengths and sizes for measuring a few millimeters to ones that can measure long strokes. But while LVDT's are able to measure linear movement in a straight line, there is a variation of the LVDT which can measure angular movement called the **Rotary Variable Differential Transformer** or **RVDT**.

Rotary Variable Differential Transformer

Potentiometer-based transducers are easy and simple to use but resistive potentiometers suffer from mechanical wear due to contact between the sliding wiper and its resistive track as well as producing electrical noise as the wiper slides along and bounces over the resistive track. Rotary variable differential transformers operate on the same basic principle as the previous LVDT, except that a rotary ferromagnetic core is used.

Here the transformers core is not straight, but forms part of a circle (the same as for toroidal transformers) which allows the sensor to measure the angular displacement of the attached object. The ferromagnetic moveable core of the RVDT couples with the secondary coils based on its angular position, thus allowing for the measurement of angular displacement.

The electrical operation of an RVDT is exactly the same as for the linear version in that it is based on altering the mutual inductance coupling between primary and secondary coils. The primary coil is still driven by an AC excitation current (typically in the kilo-hertz, kHz range), which induces an AC current in each of the series-opposing secondary coils. The movable ferromagnetic core rotates instead of slides within the body.

One of the main disadvantages of the *rotary variable differential transformer* is that it can only operate over a relatively narrow range of angular rotation. Although in theory they are capable of continuous rotation and speed measurement, typical RVDT's output is only truely linear over a range of about $\pm 60^o$ or less from their zero null position (0^o) due mainly to limitations in the magnetc coupling. Beyond this the output signal starts to become nonlinear and less useful. Also their sensitivity is much smaller that their linear cousins producing about 2 to 5mV per degree of rotation.

Linear Variable Differential Transformer Summary

We have seen in this tutorial about the *linear variable differential transformer* that the LVDT is a positional sensor used to measure small linear (straight-line) displacements from a few millimters to many hundreds of millimeters. The LVDT has no direct sliding mechanical contact or moving parts to wear out, thus making it virtually friction free, offering a greater electrical performance and life-span compared to the resistive linear potentiometer type displacement sensor.

The LVDT consists of a transformer with a single primary winding and two secondary windings which are electrically out-of-phase from each other by 180^{o}. The LVDT also consists of a movable core. When the core is at its central position, the voltages induced in the two secondary windings are equal and opposite giving zero output signal. As the core moves away from its center position, the induced voltage in one half secondary winding will be greater than the other, giving a signal whose amplitude is proportional to the amount of linear displacement and whose phase represents the direction of travel. Thus the LVDT produces a differential voltage output that varies linearly with the cores position with the phase angle of the output voltage changing by 180^{o}as the core is moved from one side of the null position to the other.

If the measured displacement of the internal core of an LVDT is changed from a linear movement to rotary or angular movement, then the device becomes a rotary variable differential transformer (RVDT). However, the output signal of an RVDT is truely linear over a relatively small range of angular rotation and is not suitable for measuring a full 360^{o} of rotation.