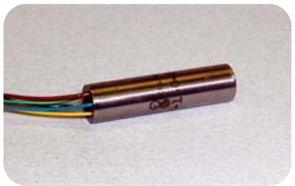

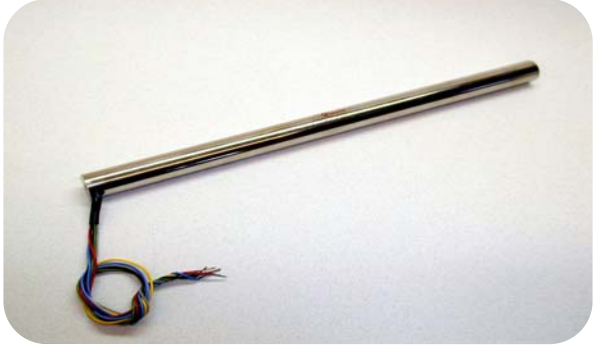

Linear Variable Differential Transformers Technology

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Theory and Applications of Linear Variable Differential Transformers

Operating Principles

Differential transformers are electromagnetic devices for translating the displacement of a magnetic armature into an AC voltage, which is a linear function of the displacement. They are basically composed of primary and secondary coils wound on an air core and a movable armature is used to control the electrical coupling between them. Fig. 1 shows the basic winding configuration of a 3 coil winding type.

While the analysis of each type are essentially similar they differ through the maximizing or minimizing of certain parameters. When the primary is energized by an AC source, voltages are induced in the two secondary coils. The secondary windings are usually connected series bucking so that the transducer output is the vector difference of the two voltages induced in the secondaries. At null the output voltage approaches zero. When the core is displaced from null the voltage induced in the coil toward which the core is moved increases while the voltage in the opposite coil decreases resulting in a differential voltage output from the transformer which can be designed to vary linearity with core motion. A phase reversal in output occurs in passing through the null. Fig. 2 shows output voltage vs. displacement with phase reversal indicated by voltage polarity.

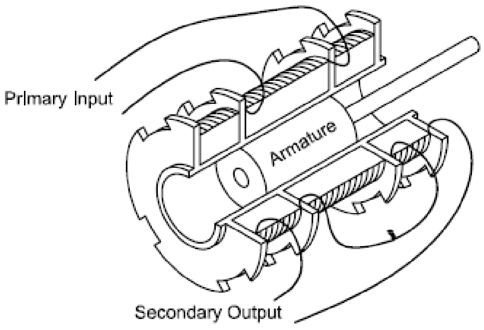

Fig. 1—Three Coil Configuration

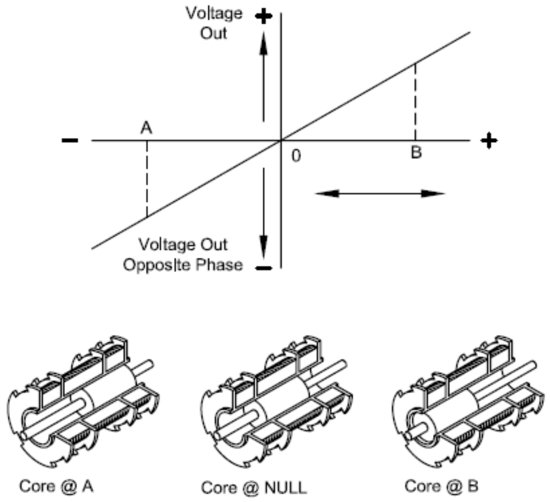

Fig. 2—Output Voltage and Phase vs. Displacement

Differential Transformer Characteristics

Linearity and Linear Range

The output voltage of a differential transformer is a linear function of core displacement within a limited range. Beyond this range the characteristics start to deviate from a straight line. The degree of linearity within the linear range is defined as the maximum deviation of the output curve from the "best fit" straight line passing though the origin, expressed as the percentage of output at nominal range. The linearity and linear range are usually specified for a given resistive load. Because the output impedance of a differential transformer is relatively constant, the output loading will not seriously affect linearity although it will modify sensitivity and phase shift.

Sensitivity and Output

The rated sensitivity is usually stated in terms of millivolts output per thousandths of an inch core displacement per volt input (commonly written as mV output/0.001" core displacement//v input.) Since the voltage sensitivity varies with frequency, except in some designs over a limited frequency range, the frequency should be stated when specifying sensitivity. The actual output voltage for a given core displacement is determined by multiplying the sensitivity by the displacement in thousandths of an inch, then multiplying this product by the input voltage. The differential transformer is similar to an ordinary transformer in many of its output characteristics. At low frequencies its output impedance is approximately resistive, while at higher frequencies it may assume high reactive values. Therefore, the sensitivity and output generally increase with frequency particularly in the low frequency portion of the range specified for a particular differential transformer. However, the sensitivity at the higher frequencies is appreciably affected by the load, since the output impedance of the transformer increases with frequency.

Resolution

The output voltage variation of a differential transformer is stepless. Therefore, the effective resolution depends entirely on the minimum voltage or current increment, which can be sensed by the associated measuring system.

Excitation

The fundamental inductive arrangement of the differential transformer with a straight movable magnetic core can be designed for operation at any AC frequency in the range from 60 cps to 20,000 cps. When the transformer is used to measure static displacement or to sense linear motion, which does not include oscillatory components above approximately 6 cps, the common 60 cps power frequency is generally convenient. The 400 cps aircraft power frequency is widely used and highly suitable for many applications. Accurate response to vibration and rapid mechanical movement requires the use of an excitation frequency at least 10 times the highest suitable frequency present as a component of the mechanical motion or preferably higher. The excitation power required to produce useful sensitivity in different types of transformers vary with transducer size and application. In many applications this power is only a fraction of a watt. In practice this power is usually limited by the maximum hot spot temperature produced within the primary winding under the maximum ambient temperature condition of the particular application. Due to the high reluctance of the magnetic path, core saturation generally does not occur with any current value that does not eventually overheat the primary winding. When a differential transformer is excited at a fixed voltage the primary current will vary downward with increasing frequency.

Since the heating affect is proportional to the square of the current of all practical purposes the maximum input voltage may be increased at higher frequencies by the amount required to maintain the primary current at a fixed value, limited by the maximum absolute voltage of the winding and circuit insulation. A constant current power source rather than a constant voltage source is often preferable for accurate operation; particularly, when using an input level which produces a substantial temperature rise in the transformer. A constant current source eliminates any output variation directly due to the normal primary resistance variation with temperature. This primary resistance variation is important at low frequencies but may be insignificant at higher frequencies where the primary impedance is highly inductive. Therefore, it is evident that a differential transformer is to be used with a voltage source over a wide temperature range, it is recommended that a high frequency carrier be used for optimum temperature stability.

Variations in Differential Transformer Characteristics Due to External Variables

Fluctuations of input Voltage and Frequency

Fluctuation of the input voltage of a differential transformer is reflected in a corresponding proportional fluctuation of its output voltage. Therefore, to avoid any error due to fluctuation in the source voltage, a regulating device should be utilized.

The same considerations that apply to fluctuation of input voltage hold with regard to input frequency fluctuation. In general, percent changes in frequency result in smaller percent changes in sensitivity that would result with input voltage fluctuation.

Displacement Measurement

The use of an LVDT to sense and display linear motions requires the use of auxiliary electronic instruments. The simplest arrangement, providing minimal accuracy, would require an AC excitation source of proper amplitude and frequency to supply the primary winding of the LVDT and a high-impedance, AC voltmeter monitoring the secondary output voltage. This arrangement would indicate a voltage proportional to the core positions. Since the voltmeter can indicate only voltage levels, no directional sense would be provided.

To generate a bi-polar output proportional to linear displacement about the null position, a “demodulator” is required. The demodulator electronically converts the AC output signal from the LVDT to a variable DC voltage which is an analog representation of the core position. This DC voltage varies from a maximum positive value at the maximum “positive” displacement from the core, through zero voltage at the null position, to a maximum negative voltage at the maximum “negative” displacement. Positive displacement is by convention defined as a core movement from null toward the lead-wire end of the LVDT body. The simplest form of bi-polar demodulation consists of two half-wave rectifiers, one of each secondary winding, with the common secondary lead or leads returning to the mid-point of the output filter capacitors. The output signal becomes the algebraic sum of these two rectified signals, as illustrated in Fig. 3(a). Fig. 3(b) shows a full wave version of this method of demodulation. The circuit of Fig. 3(b) is seldom used because of its additional complexing and higher rectification losses.

Fig. 4 Demodulators-Direction Sensitive

Half Wave Demodulation

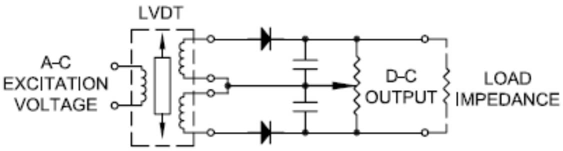

Fig. 4(a)

Full Wave Demodulation

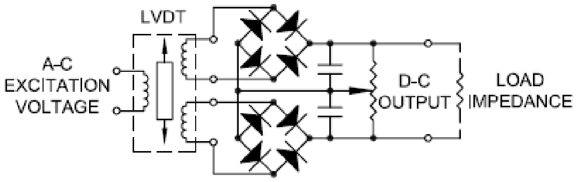

Fig. 4(b)

The following are some of the advantages of this method.

a) The output maintains the direction sense of core motion

b) The circuits are relatively simple

c) In view of the fact that recertification of each secondary output takes place the diodes usually operate above the threshold level and do not introduce non-linearities

D) Phase Shifts do not appreciably affect the linearity

The following are some disadvantages of this method.

A) In order to maintain the symmetry of the whole circuit, the load must be balanced or ungrounded

B) The mixing of the two secondary rectified outputs into one DC output which is based on the resistance mixing principle causes large output power losses

C) In certain LVDTs due to space savings, the output of each secondary at the end of the travel range may be appreciably below the threshold level of the diode. In this case non-linearity will be introduced into the DC output. These demodulator techniques are used extensively with LVDTs in that they have very good results when operated with non-conventional transformers.

Synchronous Demodulators

To overcome the limitations of the simple diode rectifier, the synchronous or phase-sensitive demodulator is often used with LVDT and similar AC operated transducers.

These circuits utilize the basic principal of phase detectors, synchronous demodulators and phase comparators. They are based on the idea of rectifying an artificially created difference voltage rather than the signal itself. Since the diodes are utilized to rectify the difference signals by proper selection of the referenced voltage the rectification takes place at voltage values well above the threshold of the diodes.

The conventional circuit utilizing this principle is shown in Fig. 4. However, this demodulator has the disadvantage of being sensitive not only to amplitude changes but also to phase variations of the signal versus the reference voltage. This may cause serious deterioration in performance when used in conjunction with certain differential transformers specifically those designed for a long travel. Various methods have been devised to overcome this difficulty introduced by LVDT phase shifts.

For maximum convenience, an instrument combining an AC excitation source with an output signal demodulator is often employed. These instruments may employ simple diode demodulators or elaborate synchronous with provisions for phase shift compensation. Gain or normalization controls are often incorporated in these instruments.

Synchronous Half Wave Demodulator

No Phase Compensation

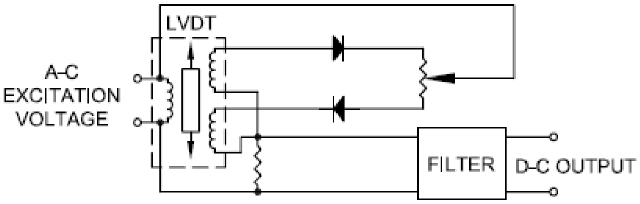

Fig. 5 Demodulators