Performance Evaluation of Functional Mechanism/Principles of Inductance Transducer

Olumoko Olayinka Eric[1] Nwozor Obinna Eugene[2]
[2]Department of Electrical and Computer Engineering
[1]Hydraulic Equipment Development Institute, Kumbotso, Kano, Nigeria
[2]Federal University of Technology, Minna, Niger State, Nigeria

Abstract— In this work effort is geared toward evaluation of functional characteristics of inductive transduction with consideration on inductive transducer as the major principal device. The operational mechanism of the component was critically evaluated with intensive inspection of the inductance uniqueness of the major components with which the transducer is composed. The electrical behavior of the transducer was modeled and analysed to reveal the inherent constituting variables upon which the functionality of the device is based with a graphical illustration that divulges the operational interdependency of these variable. This was adequately investigated to disclose the operational contribution of the parameters with respect to practical effectiveness of the inductance transducer.

Keywords: Functional Mechanism, Inductance, Transducer, Evaluation

I. INTRODUCTION

Generally, the principle of energy transduction involves the transformation of energy from one form to another. This process entails sensing with precession the input energy from the measurand by means of a "sensing element" and then transforming it into another form using a transducer The sensor-transduction-element combination can henceforth be referred to as the "transducer" .The word ''Measurand'' relates to the quantity, property, or state that the transducer seeks to translate into an electrical output. Transducers may be classified as self-generating or externally powered. Self-generating transducers that develop their own voltage or current and in the process absorb all the energy needed from the measurand. Externally powered transducers, as the name implies, must have power supply from an external source, though they may absorb some energy from the measurand.

Capacitive	Thermoelectric effects (Seebeck and peltier)
Inductive and electromagnetic Resistive	Ionization effects
Resistive and thermoresistive	Photoelectric effect
Piezoresistive effect	Photoresistive effect
Hall effect	Photovoltaic effect
Lateral effect	Acoustooptic effect
Extrinsic, interferometric and evanes- quenching cent effects in optical fiber	Fluorescence and fluorescence
Magnetoresistive effect	Field effect
Tunneling effect	Doppler effect

Table 1: Transducers' Transduction Mechanisms

A. *Work Format:*

This article is composed of many sections of work, starting from section I which features the introduction, the work preamble that constitutes an open door through which the fundamental constituents of this thesis are built. Following section I is a brief mathematical evaluation that actually presented a model work out of which the theoretical explanation of inductive transduction principles are established. These are seen in section II. Section III looks into a few number of inductive transducers as listed in this work and exposes some special functional components upon which the operational responsibilities of the devices are constituted. There various functional characteristics are discussed to establish a route for clear understanding of each of the named transducers. We allocated section IV to illustrating a real life sample of Inductive transducer and show cased an LVDT as a typical example. The illustrative diagram of the device shows the various body structure of the transducer with some component composition whose functional behavior are demonstrated with the accompanied graphs.

II. MATHEMATICAL MODEL OF ELECTRIC TRANSDUCTION PRINCIPLE OF AN INDUCTIVE TRANSDUCERS

Just like resistance and capacitive transducers, almost all inductive transducers base their operational mechanisms on influence of the functional properties of the constituting or manufacturing materials.

Inductances of an electric material arouse an account of flux that links the materials. This is called flux linkage. A current carrying conductor can produce a flux which can impinge on other conductive materials in a circuit. In a situation where the flux links the conductor from where it is produced, we referred to such as self-flux linkage; and this is due to current flow in the conductor. Thus, L for self-inductance can be represented as

$$L = {}^{N^2}/_{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{But, } S = {}^{L}/_{\mu_0 \mu_r A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Which by substitution results

$$L = {}^{N^2}/_{1} \div {}^{L}/_{\mu_0 \mu_r A}$$

$$= {}^{N^2}/_{1} \times \frac{\mu_0 \mu_r A}{L}$$

$$= \frac{N^2 \mu_0 \mu_r A}{L} \text{ (in henry)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where,
N = Number of the coil turns
L = the length of coils in meter
A = Cross-sectional Area of the coil (m^2)
μ_r = Relative permeability
μ_o = Permeability of the free space

A. *Different Types of Inductive Transducers*

From the mathematical relationship as demonstrated among the component variables in the equation, inductance, L of electric circuit can be varied using any of the expression variables – L, A or the number of turns, N. This is a very important feature upon which every inductance transducers functional behavior is tied.

There are many number of inductance transducers which can exhibit angular or translational motion. This follows the alteration of inductance parameters of the transducer component which may be either self-inductance dependent as in the case of a one – coil inductance transducer or mutual inductance dependent as in a two or more coil transducer device.

Any of these can be arranged into a differential structure with four arms and a central output terminal for output display whenever there is input displacement on a specified branch. The output response due to self or mutual inductance variation is not always responsive to any magnetic field in the surrounding, temperature variation, changes in the bridge supply voltage or frequency variation. Good examples of inductance transducer are

1) Air core inductance transducer
2) Ferromagnetic or iron core inductance transducer
3) Eddy current inductance transducer.

B. Structural Composition and Mechanism of Operation

In the case of air core inductance transducer, there is no material medium as a core. Instead, the wound coil is within the air medium; hence, the name, air core inductance transducer. The changes in inductance; in this transducer, are very small compared with the ferromagnetic type. This could be due to absence of metallic material. Thus the operating frequency is very high.

Unlike the air core type, the iron or ferromagnetic type of inductance transducer has an inbuilt iron- core which is flux linkage enhancing. There are always large inductance changes with this transducer. Inductance can vary correspondingly with variation in current along the coil length. There is a noticeable effect on coil impedance due to core losses when the frequency is very high.

Eddy current type is built with a conducting plate that is closely situated to the alternating current carrying coil. The generated flux from the coil spreads across the plate which induces eddy current on the plate conductor. The magnetic field due to the eddy current on the plate interacts with the field created by the current along the coil to vary the effective inductance of the circuit. As a consequence, the small gap due to the relative position of the coil and plate changes.

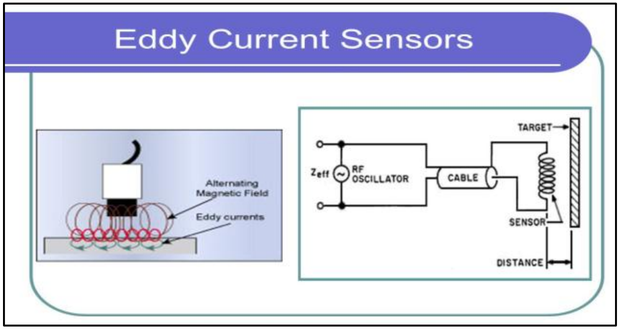

Fig. 2: Schematic circuit diagram of an eddy current transducer

A typical type of inductance transducer is the linear variable differential transformer, which is commonly known as LVDT in short form. The structure of this transducer accounts for two distinct sections of the device. The primary section shows a set of coils which are homogenously wound along the entire transducer length. Over the primary wound coils are the secondary wires that occupy either side of the transducer middle with a centrally located magnetic core which is free to move within the surrounding coil arrangement. The position of the coils with the core allows little or no fiction at the time of core movement.

To fight the induced eddy current in the circuit, a nickel alloy T rod core is always inserted in a longitudinal manner. This is in a magnetic field environment that exists within a longitudinal slot along the field line.

Adjustment of the magnetic core at the center of the wound coil length brings about the variation of the output voltage, V_0 which is the outcome of the two generated voltages, V_1 and V_2 of the secondary coil just as an alternating current is fed into the primary coil.

The output voltage, V_0 equals the differential value of V_1 and V_2 (i.e $V_0 = V_1 - V_2$) in series and counter connection of the two secondary coils. However, the core at the mid – point of the coil length ideally makes the output voltage, V_0 equal to zero (i.e $V_0 = V_1 - V_2 = 0$)

In real sense of the field work, it is always difficult to obtain an absolutely balanced arrangement, and as such there is often times a development of a residual voltage along the core.

There are translational and rotary LVDTs with sensitivity of about 0.1V/cm – 40mV/µm and in order of 10mV/degree respectively

Fig.2.2: Diagram showing a pictorial view of an air core inductive transducer

Also this equipment can be divided into self-generating and passive transducer. The self-generating nature of inductive transducer is actually coined from its capability to make use of fundamental electric voltage generating principles to develop an induced voltage on the device coil when there is a relative movement between the coil and a magnetic field. Such phenomenon as speed or velocity conversion to electrical signal which can be processed and conditioned for further electrical use is a good example. Tachometer is one of the devices with this mechanism. In the contrast, passive inductance transducers; unlike the self-generating types, are among the transducer equipments that operates with external power source.

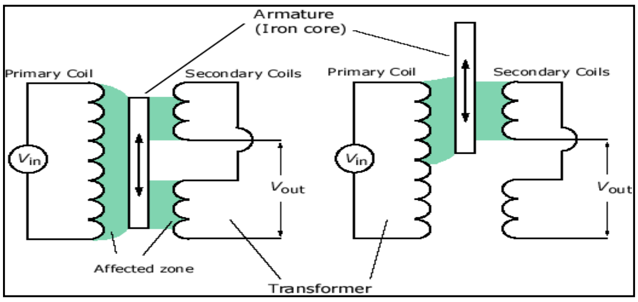

Fig. 2.1: Schematic diagram of a Linear Variable differential Transformer

The differential transformer is among the passive inductance transducers that operates this way. Linear Variable Differential Transformer (LVDT) as it is known is basically composed of a primary winding with two secondary windings that are coiled round a hollow tube and situated in a way that the primary is established to occupy a position in-between the two of its secondary of its output windings.

III. GRAPHICAL AND FUNCTIONAL ILLUSTRATION OF AN LVDT – A TYPICAL SAMPLE OF AN INDUCTIVE TRANSFORMER

Functionally, Linear Variable Differential Transformer, is primarily built with an iron core sliding material that is meant to move within the in-built tube on the device. This movement, as a result is aimed to alter the magnetic coupling effect between the primary and secondary windings of the transducer.

Linear Variable Differential Transformer operates in a way that the condition of the two output voltages is determined by the position of the movable iron core slider within the tube. As the slider is positioned at the center of the space between the secondary and primary winding, the two output voltages of the transducer become equal to each other (ie $V1 = V2$).

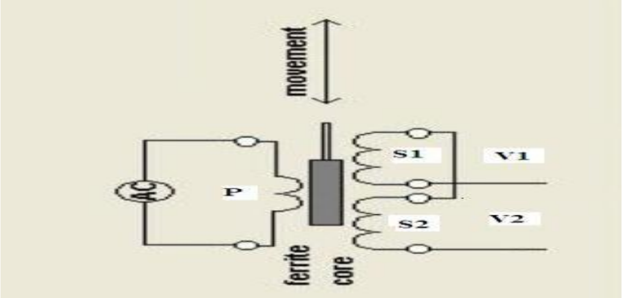

Fig. 3: Diagram showing a schematic view of an LVDT inductive transducer

See the diagram above. Now as the iron sliding core is adjusted away from the center towards one direction of the winding, the two output voltages of the device correspondingly adjust ; with one being greater than the other. It is important to know that the two output voltages developed on the output coils owns a reason on the ferromagnetic effect of the sliding iron core. The magnetic field generated due to the primary winding as AC quantity flows from the source is strengthened feromagnetically as it is being coupled to the secondary winding.

This, in effect results the induction of the secondary voltage on the secondary winding. It is this induced voltage of the secondary output that is split into two output voltages of the device; following the manner in which the secondary coil is designed. Practically speaking, the difference in the two output voltages of the device obviously accepts much explanation on the motion and relative position of the iron core with respect to the respective coils of the two output voltages.

Being that the core enhances the field that consequently induces the voltages, it therefore means that the magnitude of the magnetic field gets larger at any point to which the core is moved, and this ;as a matter of facts induces larger voltage magnitude on the output winding that occupies the point compared to the weaker field and the smaller voltage magnitude (due to the weaker field) of the section of the coil from where the core is moved As such, the variation in outputs voltages (V1 and V2) of the secondary windings is as a result of the difference in magnitude of V1 and V2 and this is a highly considered factor for functional evaluation of the Linear Variable Differential Transformer (LVDT) in field analysis of practical inductance transduction of the transducer equipment. We summarize the points as follows:

- By construction, the output coils is designed into two different windings each developing an induced voltage designated as V1 and V2 respectively.
- The magnetic field between the secondary and primary windings of the device is enhanced by a ferromagnetic material introduced in-between the two windings.
- As the ferromagnetic core is positioned at the center of the windings, the two output voltages of the device are equal (ie $V1=V2$, $V1-V2 = \Delta V = 0V$) ,as a result, the differential output of the LVDT becomes nill. (ie $\Delta V = 0V$).See the graph of fig.3.1 below

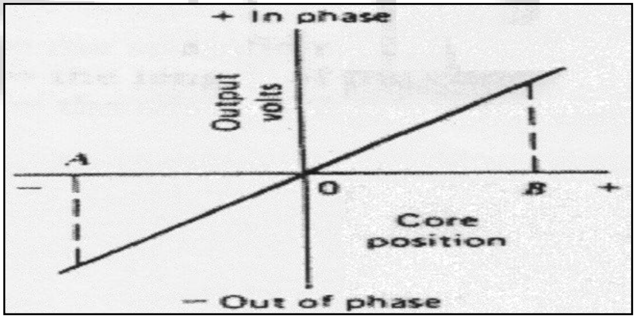

Fig. 3.1: Diagram showing a graphical illustration of the output voltage of an LVDT inductive transducer

- As the core is adjusted away from the center to one direction, the output of the transducer becomes the voltage difference of the two output windings. Then the voltage whose winding the ferromagnetic core is adjusted to becomes greater than the voltage whose output winding the core is adjusted away from.(ie $V1 – V2 = \Delta V = X$; X is a real number). See graph of fig.3.1 above The reverse is the case when the ferromagnetic core is moved to the direction opposite to the former. As such, $V2 – V1 = \Delta V = X$. See the same graph.

A. Merits of Linear Variable Differential Transformer – A typical Example of an Inductive Transducer

1) Development of high amplitude of output voltage upon a little distance displacement of the associated movable object.

2) The cost of construction of this device is considerably low
3) High operational efficiency is assured irrespective of variation in environment where the equipment may be used
4) Tendencies for permanent damage is quite nil even when the desired output measured quantity is beyond the design range.

IV. CONCLUSION

Inductive transduction is an outcome of ability of the inductance related transducer to produce some useful electric related output. The phenomenon is naturally desired for application of inductance properties inherent in winding turns of the equipment to initiate an electrical condition which could be applicable for electricity and electronics circuit construction. That a movable core object attached to the device in the case of LVDT could be adjusted for a given required output effect is an added characteristics for improvement of the equipment dynamism. For instance the output magnitude of LVDT is actually a function of the covered distance of the movable core. In a situation where the core is tied on a mobile object within the device, a displacement of the core to any desired position can be judged relative to the effect due to the covered length, the attained position and the resulting magnitude of the output voltage of the transducer. And this feature could be so harnessed to actualize some Engineering design objectives.

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