Identification of Nonlinearity in Linear Inductive Transducer

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***Abstract* - Linear Variable Differential Transformer (LVDT) is most widely used linear inductive transducer for translating the linear motion into electrical signal. It is observed that LVDT exhibit nonlinear input-output characteristics. Due to such nonlinearities direct digital readout is not achievable and their practical range gets limited due to the presence of nonlinearity. Presence of nonlinearity in LVDT also affects the accuracy of measurement. This paper proposes the presence of nonlinearity in inductive sensor. It is observed that the experimental data from two different LVDTs and its characteristic curves were drawn.**

Keywords: LVDT, Nonlinearity

I.INTRODUCTION

The role of transducers is very vital in all fields of engineering and industries for the purpose of measurement, monitoring, recording, and control. Transducers are exposed to different types of environments during the course of measurement. The performance of a transducer is adversely affected by variations in excitation quantities and changes in ambient and winding temperatures. There is the utmost necessity for development of transducers which are smart and intelligent enough to provide a self-compensated output. The performance of the LVDT is influenced by transducer geometry, arrangement of primary and secondary windings, quality of core material, variations in excitation current and frequency, and changes in ambient and winding temperatures. The primary excitation quantities influence the coil impedance and temperature distribution in the coil assembly. The core permeability is also influenced by the temperature changes and also by variations in excitation current and excitation frequency.

The performance of the control system depends on the performance of the sensing element. It is observed that many sensors exhibit nonlinear input-output characteristics. Due to such nonlinearities direct digital readout is not possible. As a result we are forced to employ the sensors only in the linear region of their characteristics. In other words their usable range gets restricted due to the presence of nonlinearity. If a sensor is used for full range of its nonlinear characteristics, accuracy of measurement is severely affected. Similar effect is also observed in case of LVDT. The nonlinearity present is usually time-varying and unpredictable as it depends on many uncertain factors. Nonlinearity also creeps in due to change in environmental conditions such as temperature and humidity. In addition ageing of the sensors also introduces nonlinearity.

II. LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

The LVDT consists of a primary coil (of magnet wire) wound over the whole length of a non-ferromagnetic bore liner (or spool tube) or a cylindrical coil form. Two secondary coils are wound on top of the primary coil for “long stroke” LVDTs (i.e. for actuator main RAM) 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 “opposite series” (or wound in opposite rotational directions).

A ferromagnetic core, which length is a fraction of the bore liner length, magnetically couples the primary to the secondary winding turns that are located above the length of the core. Even though the secondary windings of the long stroke LVDT are shown on top of each other with insulation between them, on the above cross section, Measurement Specialties actually winds them both at the same time using dual carriage, computerized winding machines.

This method saves manufacturing time and also creates secondary windings with symmetrical capacitance distribution and therefore allows meeting customer specifications more easily.

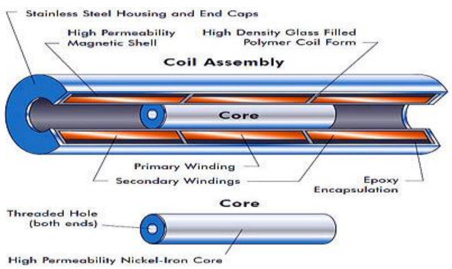

Fig.1 Constructional view of LVDT

When the primary coil is excited with a sine wave voltage (V_{in}), it generate a variable magnetic field which, concentrated by the core, induces the secondary voltages (also sine waves). While the secondary windings are designed so that the differential output voltage (V_a-V_b) is proportional to the core position from null, the phase angle (close to 0 degree or close to 180 degrees depending of direction) determines the direction away from the mechanical zero.

The zero is defined as the core position where the phase angle of the (V_a-V_b) differential output is 90 degrees. The differential output between the two secondary outputs (V_a-V_b) when the core is at the mechanical zero (or "Null Position") is called the Null Voltage; as the phase angle at null position is 90 degrees, the Null Voltage is a "quadrature" voltage. This residual voltage is due to the complex nature of the LVDT electrical model, which includes the parasitic capacitances of the windings. This complex nature also explains why the phase angle of (V_a-V_b) is not exactly 0 degree or 180 degrees when the core is away from the Null Position.

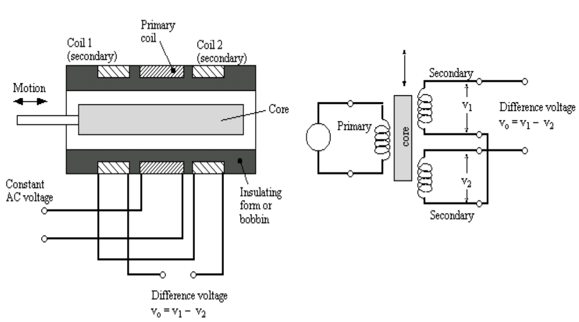

Fig.2 Equivalent circuit of LVDT

While the temperature coefficient of sensitivity (output per unit of displacement) is determined by the number of winding turns, the resistance of the windings, the geometry of the armature, and the resistivity & permeability of the metals used in the LVDT construction, the null shift with temperature is solely affected by the expansion coefficients and lengths of the materials used in the construction of the transducer.

For the lowest temperature coefficient of sensitivity, the LVDT can be designed so that the sum of the secondary voltages (V_a + V_b) remains constant over the displacement measuring range. By designing the signal conditioning electronic circuitry to measure the difference over sum ratio (V_a - V_b) / (V_a + V_b), one can see that the first order of the temperature coefficient of sensitivity is eliminated.

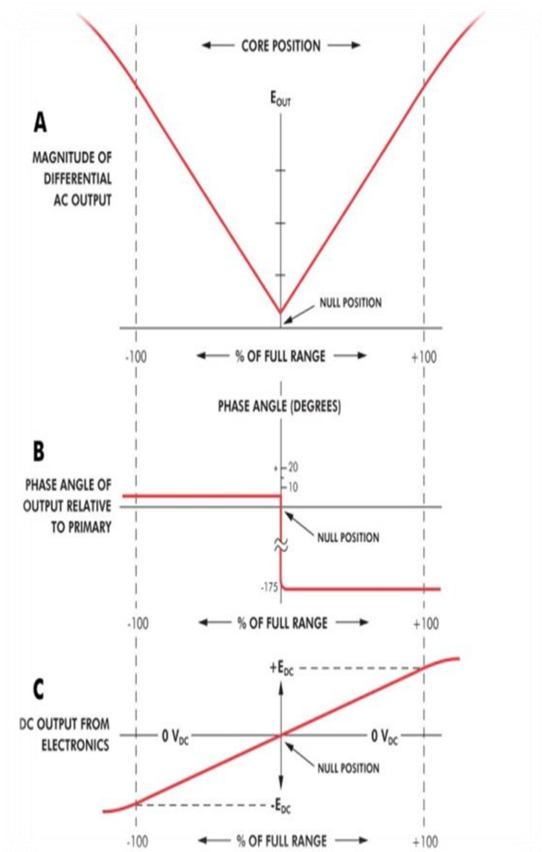

Fig.3 Output characteristics of an LVDT vary with different positions of the core

1. *LVDT Specifications:*

ABLE.I LVDT Construction materials

Component	Material
Core	17-4PH stainless steel
Case	304 stainless steel
Coil form	304 stainless steel
Magnetic shield	Silicon steel-Ams 7714M36
Coil wire	Silicon Alloy 406 with Type E high temperature insulation
Primary and secondary lead wire	Stainless steel sheath, nickel-clad copper
Cements	Yellow cerro ceramic cement

TABLE.II LVDT Specifications

Design Specifications	
Primary coil length	0.0254 m
Secondary coil length	0.0381 m
Core length	0.0381 m
Number of primary coil turns	615 to 655
Number of secondary coil turns	615 to 655
Case length	0.139 m
Case diameter	0.016 m
Performance Specifications	
Linear range	±0.0127
Linearity	0.02%
Sensitivity	12.99 V/m
Accuracy	0.0001 m
Response time	0.003 s
Excitation frequency	3000 Hz
Excitation voltage	3 volts rms
Normal operating temperature	602 K
Maximum operating temperature	741 K
Normal operating pressure	15.5 MPa

III. EXPERIMENTAL OBSERVATIONS AND RESULTS

TABLE.III Observation-I

Core Displacement (mm)	Secondary Output Voltage (mv)	Signal Conditioned Output Voltage (mv)
-6.13	0.068	-2.77
-5.02	0.06	-2.26
-3.86	0.052	-1.761
-2.81	0.043	-1.249
-1.73	0.036	-0.745
-0.71	0.028	0.233
0.36	0.021	0.283
1.42	0.015	0.773
2.45	0.01	1.276
3.52	0.01	1.784
4.57	0.013	2.29
5.62	0.02	2.78
6.7	0.027	3.3
7.87	0.034	3.86
8.81	0.043	4.31
9.91	0.051	4.82
11.08	0.059	5.34
11.92	0.067	5.82
13.02	0.075	6.34
14.02	0.084	6.85
15.24	0.092	7.36

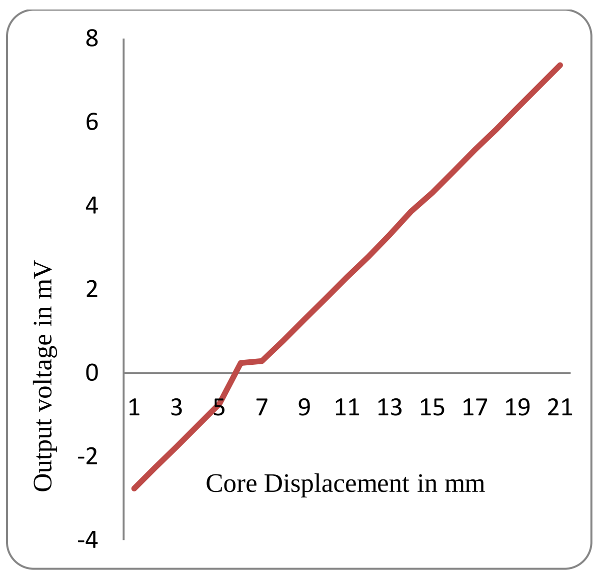

Fig.4 Output results of Observation-I

TABLE.IV Observation-II

Core Displacement (mm)	Secondary Output Voltage (mv)	Signal Conditioned Output Voltage (mv)
-6.13	0.068	-2.77
-5.02	0.06	-2.26
-3.86	0.052	-1.761
-2.81	0.043	-1.249
-1.73	0.036	-0.745
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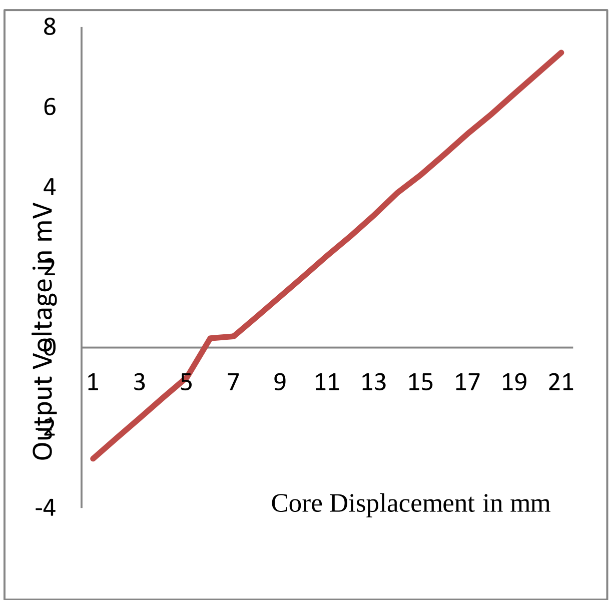

Fig.5 Output results of Observation-II

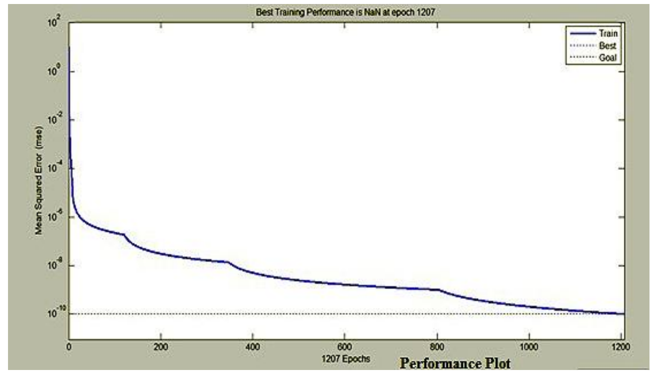

Fig.6 Performance Plot

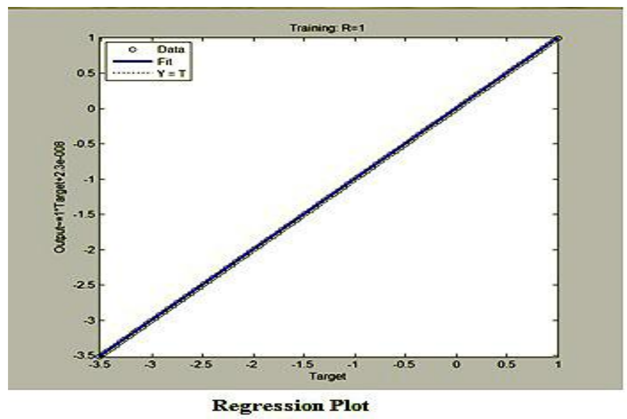

Fig.7 Regression Plot

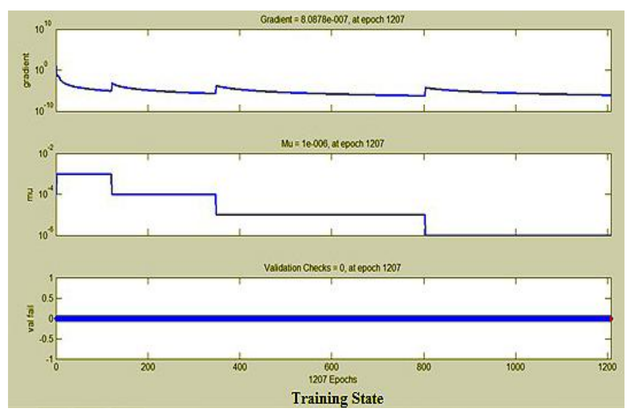

Fig.8 Training State

IV.CONCLUSION

This paper proposed the presence of nonlinearity in inductive sensor and it is tested through calculation. We have observed the experimental data from two different LVDTs and its characteristic curves were drawn. The characteristic curve shows that there is a presence of nonlinearity.

Further the nonlinearity is compensated using ANN in future. If the nonlinearity of a sensor is time varying, the compensator can also be made intelligent to keep track of the nonlinearity changes.

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