Sensitivity Determination of Linear Variable Differential Transducer (LVDT) in Fluid Level Detection Techniques

Article · May 2018

2 authors:

Umar Kangiwa Muhammad
Kebbi State University of Science and Technology

Sadik Umar
Universiti Sains Malaysia

International Journal of Modern Engineering Sciences, 2013, 2(2): 73-83

International Journal of Modern Engineering Sciences ISSN: 2167-1133

Journal homepage:www.ModernScientificPress.com/Journals/IJMES.aspx Florida, USA

Article

Sensitivity Determination of Linear Variable Differential Transducer (LVDT) in Fluid Level Detection Techniques

U. K. Muhammad*, S. Umar

Department of physics, Kebbi State University of Science and Technology, Aliero, Nigeria

* Author to whom correspondence should be addressed; E-Mail: umarkangiwamuhammad@yahoo.com

Article history: Received 26 November 2013, Received in revised form 16 December 2013, Accepted 24 December 2013, Published 27 December 2013.

Abstract: The fluid level measurement technique has a wide range applications at home, schools, in automobiles and industries. It determines the levels of water in a domestic's services tanks and the levels of fuel in our mobile and stationary Vehicles. A small scale Linear Variable Differential Transducer (LVDT) was locally constructed and used to detect the levels of water, petroleum and gasoline. The sensitivity of the LVDT due to linear displacement and induce Electromotive Force (EMF) in each case was investigated. The result showed that while water was used as reference fluid, the transducer displayed (2.63V) output EMF due to (11.86**μ**Weber) flux linkage while a ferrite core was displaced for about (12.86cm) at sensitivity of (2.99V/cm). But by considering petroleum as reference fluid the transducer displayed (2.43V) induced EMF due to a flux linkage of (11.02 **μ**Weber) for a core displacement of (12.75cm) at a sensitivity of (2.79V/cm) and when gasoline was considered, an EMF of (2.96V) was displayed due to a flux linkage of (11.86**μ**Weber) for (12.53cm) displacement at sensitivity of 3.46V/cm). The result also showed that for water, petroleum and gasoline level measurements, the transducer works with good precision as the linear displacement of ferrite core is proportional to flux linkage, induced EMF as well as the sensitivity of the LVDT.

Keywords: Transducer, Displacement, Electromotive force, Magnetic flux, Sensitivity

1. Introduction

Transducer is defined as an electronic device that used to convert one form of energy into another. Instrument transducers used for measuring physical quantities by electrical means are referred to as sensors or detector. The term transducers are supplied to any device which converts a mechanical or other measurable phenomenon in to electrical ones or vice versa. Example, in electrical generator, mechanical energy is converted to electrical energy, in electrical motor, electrical energy is converted to mechanical energy. Moreover, in microphone, mechanical energy is transform in to electrical signal, in loudspeaker, electrical signal is transform in to mechanical energy, in solar panels, and solar radiation is transform in to electrical energy, in computer, handset and calculator keyboard, mechanical energy is transform in to electrical signal etc.

Transducers are categorized in to input and output transducers, according to Ulaby F.T (2004), Edward Arnold (1990) categorized transducers in to passive and active transducers. Passive transducer is the type of transducer that does not require an external power supply to the effect of the conversion of one form of signals into another such as photovoltaic cells, piezoelectric transducers, thermoelectric, and electromagnetic transducers. Active transducer is the type of transducers that have a good requirement to an external power supply to the effect of the conversion one form of energy into another such as variable resistance, hall effect, optoelectric, and variable reactance. In this case the variable resistance is divided into photoconductors, strain gauge, and magneto resistive. Optoelectric is categorized into photo emissive and photo junction. And variable reactance is divided into inductive and capacitive transducer. However, Ruocco S.R (1987) categorized transducers according to their function as position, light, force and velocity transducers.

Transducers have a wide range of applications in school, at homes and for industrial activities. In school we use electrical generators, computers microphone, motors, loudspeaker, thermistor, and solar cells, resistance thermometer, differential transformer e.tc. as transducers. In industries we use generator, motors, robots control, thermistor and differential transformer, etc. as transducers. In home we use electrical generators, lamps, microphone, loud speaker, electric stoves, refrigerators, and electric fans etc. as transducers.

Linear Variable Deferential Transformer (LVDT) is an inductive, passive and input transducer that measure linear displacement directly proportional to induce Electromotive Force (EMF). An LVDT is an electromechanical transducer that produces an electrical output proportional to the displacement of a separate movable core. A linear variable differential transformer (LVDT) is a type of electro-mechanical transducer capable of measuring linear displacement with a high degree of accuracy. Such a system can be used as a force measuring transducer and can be employed to measure spring deformation in weighing system (Pratiksha, 2006). It works on the principle of mutual induction LVDT illustrated in figure consist of three symmetrically spaced coils bound out and illustrated bobbin. A magnetic core, which moves through the bobbin, provides a path for magnetic flux linkage between coils. The position of the magnetic core controls the mutual inductance between the primary coils and two secondary coils (Yañez-Valdez *et al.*, 2012). The LVDT sensor is basically a transformer. It comprises one primary coil, two secondary coils, symmetrically spaced with respect to the primary one; and a movable core (Lamar, 2010). The coils are wound onto a tubular coil form. This coil assembly is usually the stationary element of the sensor. The moving element of an LVDT is a separate tubular armature of magnetically permeable core which is free to move axially within the coil's hollow bore, and mechanically coupled to the object whose position is being measured. To obtain a position signal from an LVDT, the primary coil must be driven by an AC power source, and the voltages from the secondary coils must be demodulated. LVDTs operate on the principle of transformer.

As shown in figure 1, an LVDT consists of a coil assembly and a core. The coil assembly is typically mounted to a stationary form, while the core is secured to the object whose position is being measured. The coil assembly consists of three coils of wire wound on the hollow form. A core of permeable material can slide freely through the center of the form. The inner coil is the primary, which is excited by an AC source as shown. Magnetic flux produced by the primary is coupled to the two secondary coils, inducing an AC voltage in each coil. This association of a signal value to a position occurs through electromagnetic coupling of an AC excitation signal on the primary winding to the core and back to the secondary windings. The core causes the magnetic field generated by the primary winding to be coupled to the secondary.

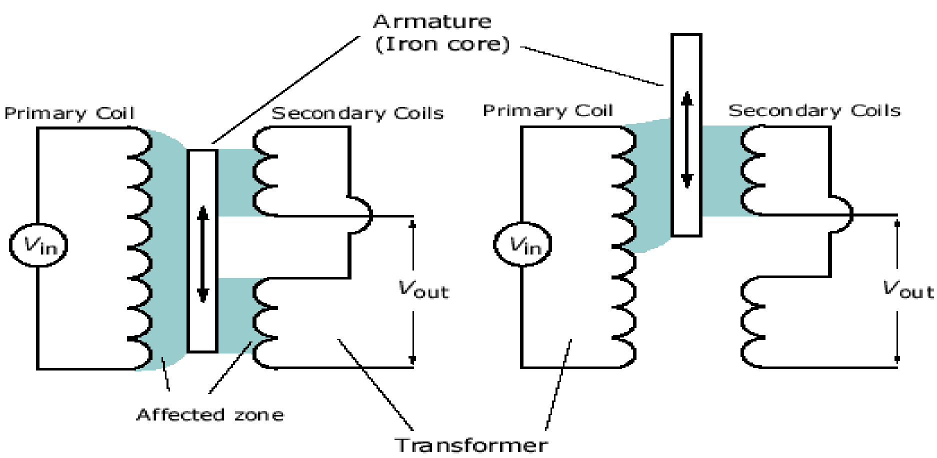

Figure 1: Schematic diagram of LVDT

The basic transformer formula, which states that the voltage is proportional to the number of coil windings, is the backbone of the LVDT as:

$$\frac{V_{Out}}{V_{In}} = \frac{N_{Out}}{N_{In}} \qquad (1)$$

Where *N* is the number of coil windings and *V* is the voltage

When the iron core slides through the transformer, a certain number of coil windings are affected by the proximity of the sliding core and thus generate a unique voltage output. The position of the core determines how tightly the signal of the primary coil is coupled to each of the secondary coils.

Moreover, the LVDT, being a transformer, operates based on electromagnetic induction obey principles of faraday's law, which state; induced EMF is proportional to the rate of change of magnetic flux as:

$$V = \frac{d\varphi}{dt} \tag{2}$$

Where φ is a flux linkage and $\frac{d\varphi}{dt}$ is the rate of change of flux, from which the primary and secondary EMF of the transformer is derived as:

$$V_{in} = 4.44NF\varphi \tag{3}$$

$$V_{out} = 4.44NF\varphi \tag{4}$$

Where F is the frequency (H_z) and from this, the flux that links the secondary winding of the transducer which result induced EMF at the output is given as:

$$\varphi_{out} = \frac{V_{out}}{4.44NF} \tag{5}$$

Since the number of coil windings is uniformly distributed along the transformer, the voltage output is proportional to the iron core displacement when the core slides through the transformer. This is given as:

$$D = MV_{\text{Out}} \tag{6}$$

Where *D* is displacement of the iron core with respect to the transformer, and *M* is the sensitivity of the transformer (slope of the displacement-voltage curve).

Sensitivity of the transducer is defined as the ratio of output to input and therefore, it is given by the following equation as:

$$\text{Sensitivity (M)} = \frac{(V_{out*}\, V_{in})}{V_{ex}*\, D} \tag{7}$$

Where V_{out} is the output EMF of LVDT, V_{in} is the input voltage from the main, V_{ex} is the excitation voltage to LVDT, and D is the displacement of the core.

According to Howard (2003), LVDTs have certain characteristics features and benefits, most of which derive from its fundamental physical principles of operation or from the materials and techniques used in its construction. These characteristics are: Friction-Free Operation, Unlimited Mechanical Life, Separable Coil and Core, Environmentally Robust, Fast Dynamic Response and Absolute Output. According to Montrose G. (2003) LVDTs are used in a wide variety of applications: These are used to measure displacement ranging from fraction millimeter to centimeter. Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc. Several of the more common methods of use have been documented in detailed articles. Although the LVDT is a displacement sensor, many other physical quantities can be sensed by converting displacement to the desired quantity via thoughtful arrangements. Several examples will be given. Crankshaft Balancer, Automation Assembly Equipment, Portable Friction Welder, Robotic Cleaner , Borehole Extensometer, Bottle Height Inspection, Weighing Systems, Deflection of Beams, Strings, or Rings, Thickness Variation of Work Pieces and Fluid Level detection. The figures 2-4 below show LVDTs functions (a) as a pressure, thickness and fluid level gauge.

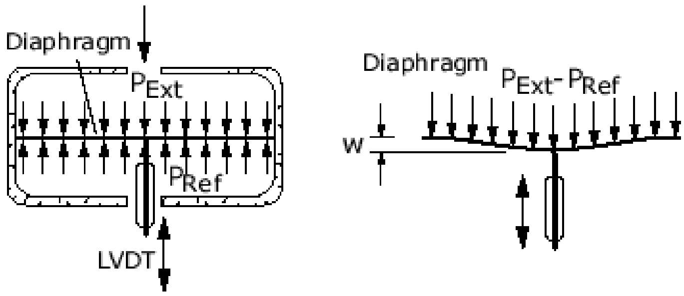

Figure 2: LVDT as pressure measuring device

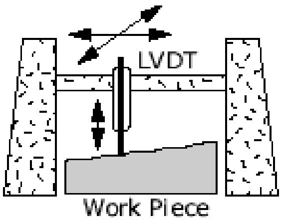

Figure 3: LVDT as thickness measuring device

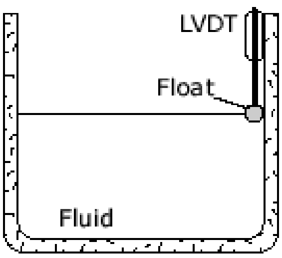

Figure 4: LVDT as Fluid Level gauge

(Courtesy of Montrose, 2003)

Fluid level measurement technique is an essential task that has numerous applications in our day to day activities. The drivers of stationary and mobile vehicles would like to know the gauge of the fuel in the tanks and at home, we wish to know the gauge of water in our service and toilet reservoirs. This enables effective controls over these components without direct contacts so as to avoid the effects of fuel shortage and over flow of water when reservoirs got full. It is therefore, requires some electrical and electronics components for effective controllability and suitable operations. LVDT is an electrical device that converts of linear displacements of fluid into electricity and sense the electronic sensors to detect the gauge of the fluid. However, in this research a conventional LVDT was constructed and used up to measure the level of petrol, gasoil, and water. Its sensitivity, due to induced EMF and displacement was investigated.

2. Materials and Methods

The LVDT which is the basic electrical system for this research comprised a 220V/ 15VAC, $50H_Z$ step down transformer, a transducer coils a ferrite core, a floating object (plastic ball) and a sensor (multimeter). The LVDT has been locally constructed using components that are available in our road side shops. A transducer primary coil was made by winding 1000 turns of an enamel copper wire on a non magnetic cylindrical air core (aluminium core). Two, 500 turns was made in series on the insulated primary coil to form a secondary coil of the transducer. The input of the step down transformer was connected to the AC mains, while its output to the transducer primary coil through a switch. The output of the transducer (primary coil) was connected to the (DT9205A) multimeter. The ferrite core was joining to the plastic ball and placed in a plastic calibrated bucket such that it can pass the transducer core when it has been displaced by a fluid poured in the bucket. The figure 5 shows the schematic diagram of the constructed system.

The step down transformer been connected to the AC mains, steps down the 220V, $50H_Z$ AC to 15VAC. As the switch is on, the 15VAC would pass to the primary coil of the transducer, and excited it. The primary coil would generate flux and distributed it into the air gap but no EMF at the output. When fluid was poured into the bucket through the funnel, the plastic ball floats on the fluid and rose up causing the ferrite core to be displaced in the air gap. The ferrite core had been a magnetic material, when being displaced in the air gap caused flux to be changing and resulted induces EMF at the output through the multimeter. Due to fact that water, petrol and gasoil have different densities of $1{,}000kgm^{-3}$, $881kgm^{-3}$ and $835kgm^{-3}$ respectively, they were all used up as a fluid in this work and determined the sensitivity of this constructed LVDT. The figure 6 captured the picture of LVDT system under operation.

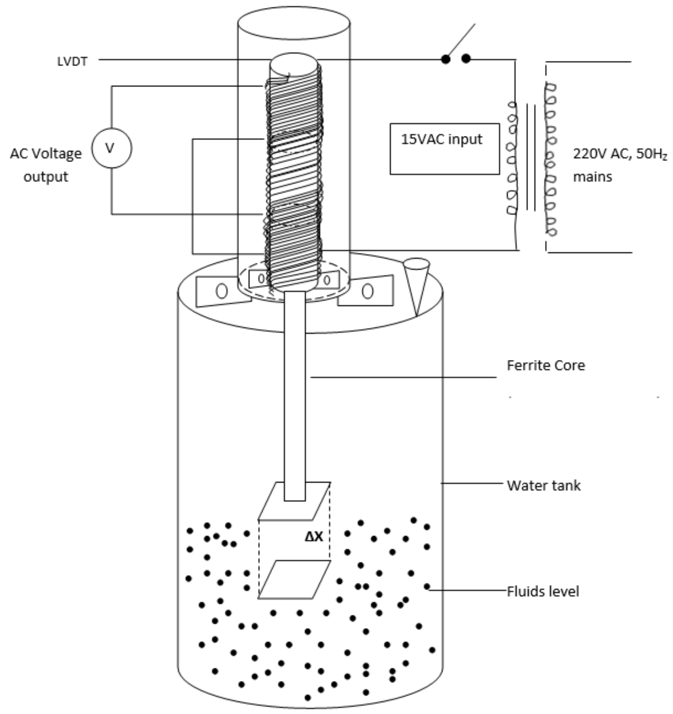

Figure 5: Schematic diagram of the constructed LVDT system

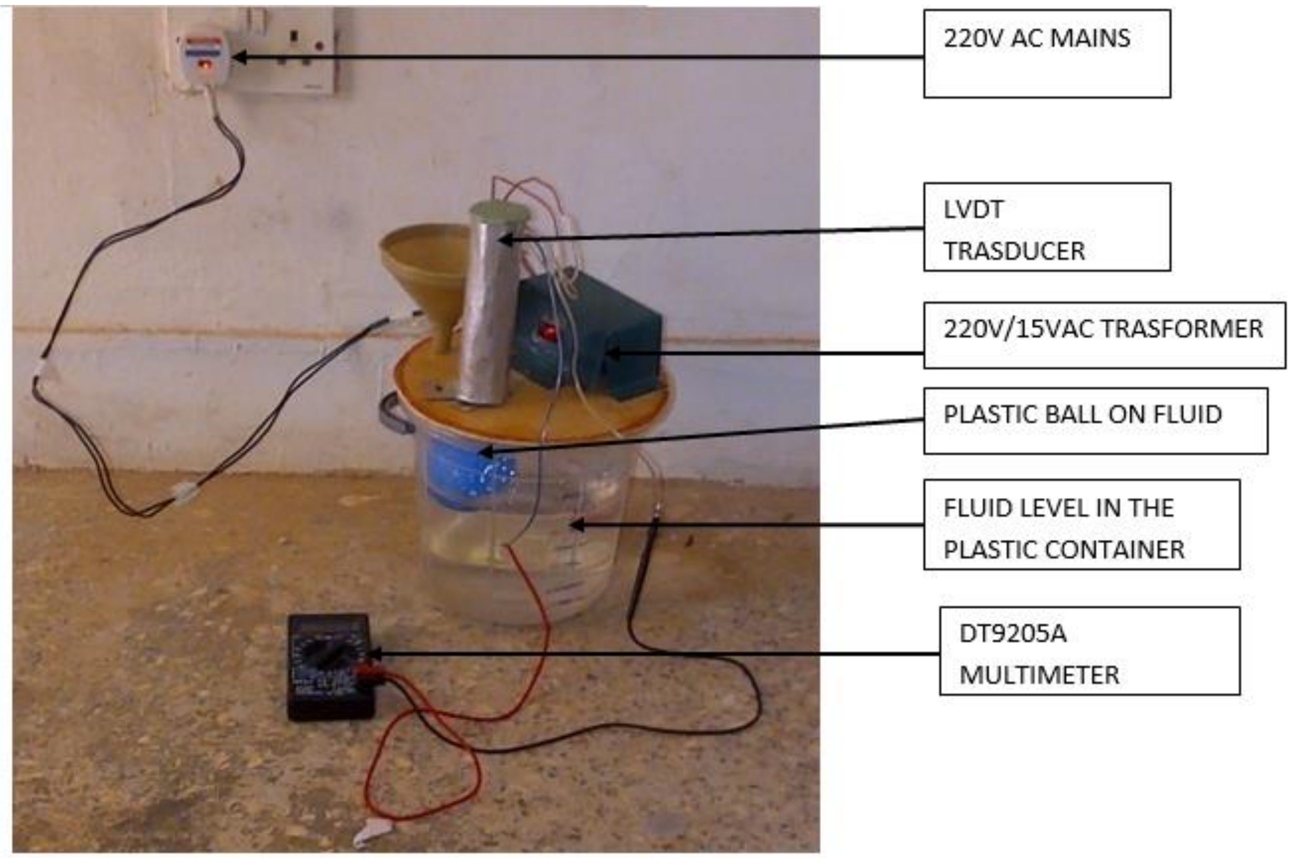

Figure 6: Picture of LVDT system

The displacement (D) of ferrite core through the air gap due to increase of fluid level in the container and the respective EMF (V_{out}) would be recorded as the fluid is being poured in to the container through the funnel. The flux (φ_{out}) that caused the induce EMF would be evaluated by using the EMF induced, number of turns of secondary coil of LVDT and AC frequency in equation (5). The sensitivity (M) of the transducer in each case would be evaluated by using the values of displacement and induce EMF in equation (7). Three experiments were conducted for each of three fluid, averages were taken and recorded in tables (1.0), (2.0) and (3.0). The results were analyzed by using a Microsoft Excel. The graphs of averages displacement and fluid levels against flux linkage, induced EMF and Sensitivity are being plotted for analysis.

3. Results and Discussions

Despite the fact that, the total density of the plastic ball and ferrite core been attached to it is less than the density of the fluids, they floated on the fluid surface and the ferrite core displaced linearly through the LVDT coils. As the coils were excited by the output of the step down transformer, flux is produced and linked the secondary coils. When the level of fluid (Litre) is increased, the ferrite core has further displaced in the coils, it changed the flux linkage and the EMF generated is detected through the multimeter. With water as a reference, the result shows that when water being poured in to the tank reached 3.5litre, the core displacement was at 12.36cm which induced EMF of 2.63V due change in 11.86**µ**Weber flux linkage at a Sensitivity of 2.99V/cm. these were shown in figure 7. It has also shown that the flux linkage and EMF are proportional to displacement.

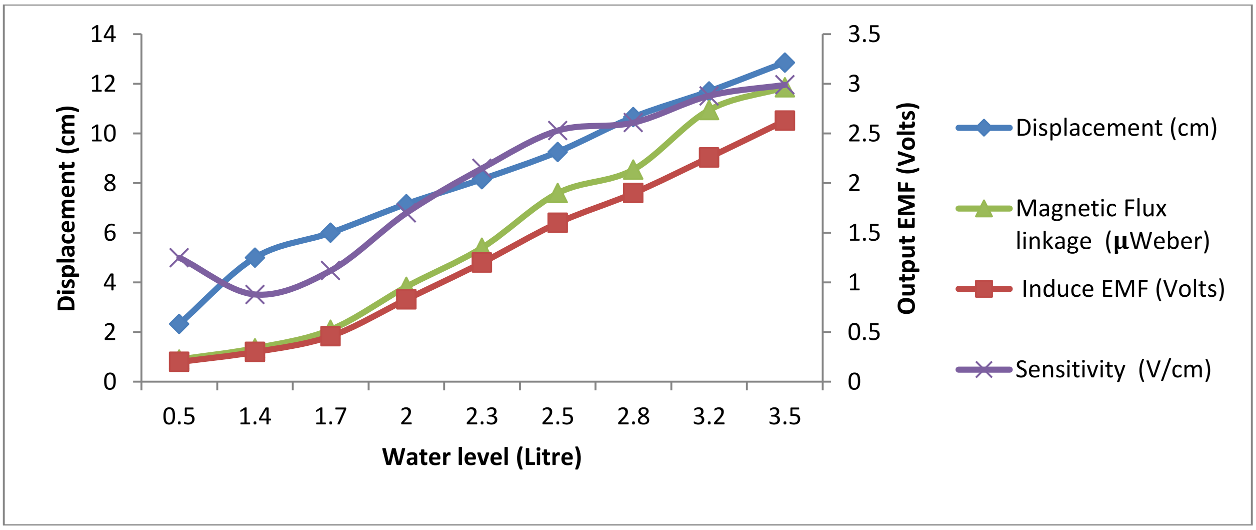

Figure 7: Graph of LVDT performance using water as reference fluid

The figure 8 is a result analysis of LVDT test by using petroleum as a reference fluid. The result shows that when 3.5litre of petroleum was poured into the tank, the ferrite core was displaced for about

12.75cm through the coil which changed the flux linkage of 11.02**µ**Weber and induced an EMF of 2.43V at a Sensitivity of 2.97V/cm. However, the flux linkage, the EMF generated and sensitivity are proportional to displacement.

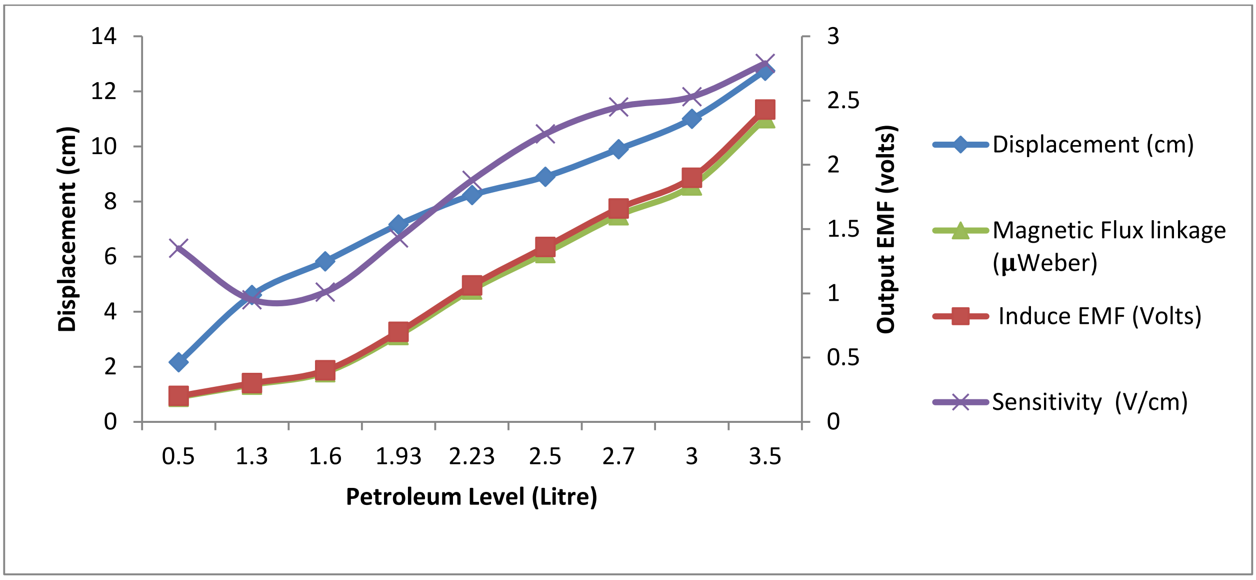

Figure 8: Graph of LVDT performance using petroleum as a reference fluid

The figure 9 is an analysis of LVDT performance by using gasoline as a reference fluid. The result shows that when 3.5 litre of gasoil was poured into the tank, the ferrite core was displaced for about 12.53cm through the coil which changed the flux linkage of 11.86**µ**Weber and induced an EMF of 2.96V at a Sensitivity of 3.46V/cm. However, the flux linkage, the EMF generated and sensitivity are proportional to displacement.

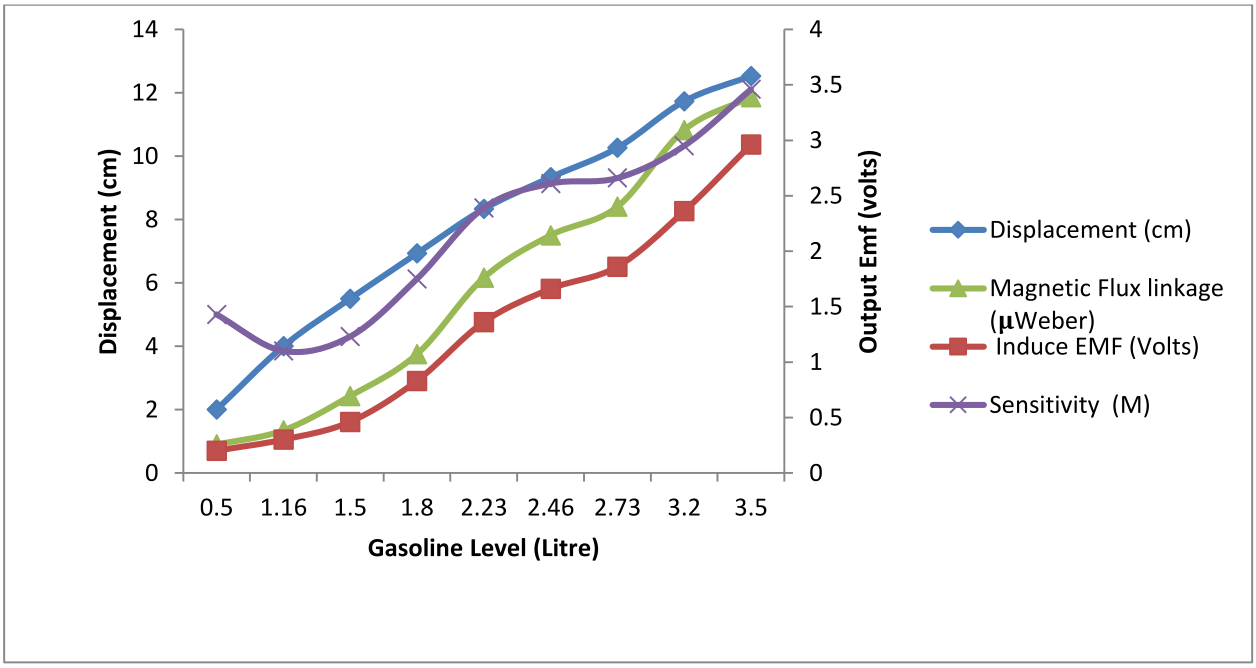

Figure 9: Analysis of LVDT performance by using gasoline as a reference fluid

However, when the maximum displacements, EMFs and the maximum capacity of the tank of this conventional LVDT were considered as parameters for functional sensitivity in (V/cm) and (V/litre), the meter displayed (0.205V, 0.191V and 0.236V) for water, petrol and gasoil respectively, when a magnetic core was displaced linearly for 1cm through the air gap. So also, it displayed (0.75V, 0.69V and 0.85V) for water, petrol and gasoil respectively when the fluid level in a tank reached about 1litre. Moreover, the theoretical maximum output EMF of this conventional LVDT is 7.5V by virtue of its windings. But due to the fact that the EMF output of a transducer has also depends on the relative permeability of the magnetic (ferrite) core and the air gap, a ferrite core of 750 relative permeability and 1.2cm^2 cross- sectional area, when been displaced in an air gap of 2.2cm^2 cross- sectional area induced maximum EMFs of (2.63V, 2.43V and 2.96V) for water, petrol and gasoil respectively. Despite these results, the conventional LVDT was (35.06%, 32.4% and 39.5%) efficient for water, petrol and gasoil level detection technique respectively.

4. Conclusion

The application of electrical, electronics and control engineering in physics advanced the use transducers for measuring and detecting the level of fluid in our domestic water tanks (reservoirs) and our mobile and stationary vehicles fuel tanks. This enables us to know the level and amount of fluid in our tanks without direct contact, so as to switch off the pump supplying the fluid when it's full tank. Although this LVDT is conventional, but it could be improved and integrate with electronic control device and this provides a means of automatic control if connected to the switch of the water or fuel pump. Conclusively, an automatic LVDT was found in motor cars fuel pump, in fuel filling stations, in building constructions and industrial robot controls.

References

[1] Edward, A., *Principles of Electronics Instrumentation*, Chapman and Hall, HC. New York, **1990**, pp.183-191

[2] Greg, M., *American Sensor and Technology*, LVDT Technology Elevates Differential Pressure Transducer, **2003**, (Online) at www.LVDTtechnology.com, 20/3/2013, 02:11pm

[3] Howard, S., A., *Micro sensors, LVDT Basis, Innovation in a Sensing Position*, USA, **2003**, (Online) at www.macrosensors.com, 23/5/2013, 02:07pm

[4] Lamar, H., *Fluid level gauge*, University of London, **2010**, (Online) at www.hydac.com 18/4/2013, 1:21pm.

[5] Pratiksha S., and Bordoloi, P., K., Design of LVDT Based Digital Weighing System, *International Journal of Electronics and Computer Science Engineering*, 1(4)(**2006**): 2100-2106.

[6] Ruocco, S., R., *Robot sensor and transducers,* John Willy and sons New York, **1987**, pp.26-33

[7] Ulaby, F., T., *Fundamentals of Applied Electromagnetic*, Pearson Prentice Hall, New Jersey, **2004**, (Online) at www.wikpedia.org/wik/transducer 15/03/2013. 12:47pn

[8] Yanez Valdez, R., Gallegos, R., Caballero, A., Ruiz, L., Selection of Soft Magnetic Core Materials Used on an LVDT Prototype, *Journal of Applied Research and Technology*, (**2012**): 195-205.