Sensors & Transducers, Vol. 206, Issue 11, November 2016, pp. 88-94

www.sensorsportal.com

Sensors & Transducers

Published by IFSA Publishing, S. L., 2016

http://www.sensorsportal.com

Development of LVDT Signal Conditioner Using Waveguide Acoustic Resonance Tube

Tariq M. Younes

Al Balq'a Applied University, 15008 Amman 11134 Jordan

Tel.: +9622776108619, fax: (+962 6) 4790350

E-mail: tariqmograbi@bau.edu.jo

Received: 16 October 2016 /Accepted: 16 November 2016 /Published: 30 November 2016

Abstract: In this paper, a novel signal conditioning technique for Linear Variable Differential Transformers (LVDT) is presented. This technique considers the usage of waveguide acoustic resonance tube as signal conditioner. The induced voltages of the LVDT coils are converted into sound waves by loudspeakers, and then the waves are traveling within a resonance tube in a force mode of operation, where the position information of the core is presented as a signal acquired by microphone placed in the opposite side of the resonance tube. Signal measurement and processing is achieved utilizing LabVIEW software. A plot which illustrates a relationship between the core position and the measured voltages via sound card is obtained by measuring the amplitude, frequency and phase of the acquired signal.

Keywords: LVDT secondaries, Virtual instrument (VI), Forced resonance, DC characteristics, Opposite series connection.

1. Introduction

LVDT transducers are used in industry to measure position, distance and direction of moving targets. Various types of LVDT signal conditioners play an important role in industry . The LVDT transducer is an electro-mechanical transducer based on electromagnetic filed variation, the input to which is a physical movement of the transducer core, and the output is a change in magnetic coupling between the internal windings [1]. The output voltage of LVDT is measured using suitable conditioning electronic circuits, which include: oscillator circuit, rectifier, phase detector and differential measurement technique such as differential or instrumentation amplifier [2]. The output of the conditioning electronics is a stable DC voltage which is proportional to the core position [3].

The LVDT transducer produces output voltage signals e_{01} and e_{02} when excitation voltage is applied to the primary coil. The output amplitude of e_{01} and e_{02} are mutually different due to the polarity of displacement in the zero position of the LVDT. The displacement quantity is obtained by the differential signal between e_{01} and e_{02} in the secondary coils with series opposing connection [4].

A simple LVDT signal conditioner acquires the output voltages generated by LVDT secondary coils and converts them into a DC voltage which is proportional to the displacement of LVDT spindle [2]. In addition to that, most of these conditioners have a phase detector block which indicates the direction of the spindle.

Modern Information technology has significantly changed the way of measurement and control. The present evolutions of computer technology can be used to develop computer based measuring transducers and signal conditioners which are capable to work in industrial environment [5-9].

In works [5-9], the authors explored the possibility of using the acoustic standing wave phenomenon to measure linear displacements in the small – scale range of motion.

The measurement achieved by these transducers was realized by measuring the amplitude and/or the frequency of acoustic standing wave generated in the tube in forced mode of oscillation. The transducers include the same components introduced in work [7]: acoustic transmitter which is placed at one end of resonance tube, the acoustic receiver which is placed at distance 1/4λ from the acoustic transmitter [8, 9], and the microphone output is connected to the MIC plug of a sound card.

Utilizing sound card for measurement electrical parameters such as voltage, current and frequency are also presented in works [10-12].

In these studies [10-12] the authors proposed a signal conditioning circuits which allows to scale the analog input of the signal to be introduced into the MIC input and then they used special developed software to acquire the analog signal and making the suitable signal processing to achieve the required measurement.

The aim of this work is to present a trial of measurement LVDT voltage using sound card based on waveguide acoustic measurement. This technique is based on connecting the LVDT outputs to the loadspeaker within an acoustic waveguide in forced resonance mode [13]. This can be realized by conveting the electrical signal into an acoustic signal and then measuring the signal paramters of microphone which is connected directly into the PC sound card. The further signal processing will be done using LabView software. This allow to measure the LVDT output signals without additional circuitry.

2. Physical Background of LVDT and LVDT signal conditioners

Measuring linear displacement with a high degree of accuracy can be done by using a type of electro-mechanical transducer which is called LVDT (Linear Variable Differential Transformer).

LVDTs have been used since 1930 to measure process variables in chemical process and then they found use in several industrial, military and medical applications [14].

The LVDT produces an electrical output proportional to the displacement of a separate, moveable magnetic core. It consists of three coils:

- One input coil which is called **Primary coil**: it looks like s the primary of the transformer.
- Two output coils, each of them is called **Secondary coils** and they are usually symmetrical about the primary coil.

The electrical circuitry of an LVDT is shown in Fig. 1.

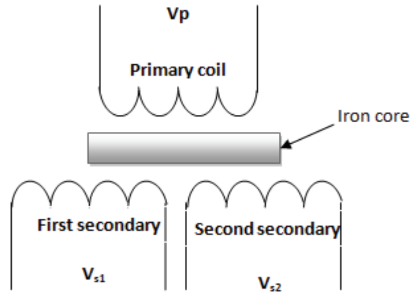


Fig. 1. Electrical circuitry of an LVDT.

A simple method to measure LVDT outputs is to connect the two outputs into the two channel of an oscilloscope, and then recording the variation the voltage (polarity and amplitude) output and phase of the LVDT outputs and make a lookup table to estimate the relationship between displacement change and produced output voltage [15].

Conventionally, the two outputs of an LVDT are connected in series opposing to form one secondary. When the core is located at the center of the two coils (further we will say, two secondaries), the induced voltage of the two secondaries have the same amplitude but not of the same polarity or phase, and in this case the difference between the produced voltages of the LVDT outputs will therefore be around zero (null or central position). The output of one of the secondaries will increase if the iron core is moved from the central position, and this produces a differential voltage as a function of displacement. The amplitude and the phase of the produced voltage depend on the location of iron core within the LVDT. The phase of this output voltage changes by 180° as the core is moved from one side of null to the other. Experimentally it was shown that, the relationship between displacement and output voltage of LVDT is linear and given by the following formula

$$D = KVout,, \qquad (1)$$

where D is the displacement of the iron core with respect to the transformer, K is the sensitivity of the transformer (slope of the displacement-voltage curve), Vout is the output voltage of an LVDT and equals to voltage difference between the two secondaries (V_{s1}-V_{s2}).

A simple signal conditioning technique for LVDT can be realized using a radiometric method. In which the difference of the two signals produced by the two secondaries , the signal of interest is measured with respect to a second signal as a ratio[14,16]. For LVDT, this ratio is given by

$$R = \frac{V_{S1}-V_{S2}}{V_{S1}+V_{S2}}, \qquad (2)$$

Substituting equations (2) in equation (1) , the final relationship between displacement and produced output voltage is given by

$$D = K \frac{V_{s1} - V_{s2}}{V_{s1} + V_{s2}}, \qquad (3)$$

Equation 3 found applications in many industrial LVDT signal conditioners. AD598 manufactured by Analog Devices Company and AP605 product from Action Pak are good examples of this application.

The widely used LVDT signal conditioners consist of the following blocks [17]:

- Oscillator circuits;
- Demodulators;
- Phase detector;
- Differential amplifier.

Fig. 2 shows the common block diagram of LVDT signal conditioners.

The literature review of existing signal conditioners for LVDT shows that this issue is still developing. This explains why research and development in this field is a viable continuous process. This work describes the possibility of using waveguide acoustic resonance tube in order to build and test a novel LVDT signal conditioner.

Waveguide acoustic measurement technique is used to measure molecular mass and gas concentration [18], displacement [5], temperature [6]. This technique is based on creating of an acoustic standing wave within a resonance tube in free or forced resonance and the distributed standing wave is introduced into microphone input of a sound card then, the signal processing is carried with LabVIEW software.

3. Materials and Methods

Utilizing waveguide acoustic resonance tube the proposed signal conditioning circuit allows to convert the output signal, i.e. electrical signal of each secondary into sound signal within a waveguide. The design of the proposed signal conditioning is will be based on forced waveguide acoustic resonance [5].

In the forced waveguide acoustic resonance, the leads of LVDT output(s) (Fig. 3(a), Fig. 3(b)) is/are directly connected to the loudspeaker(s) and a sound signal(s) is(are) generated within the waveguide. Fig. 3 shows a connection of the LVDT outputs into the loudspeaker(s).

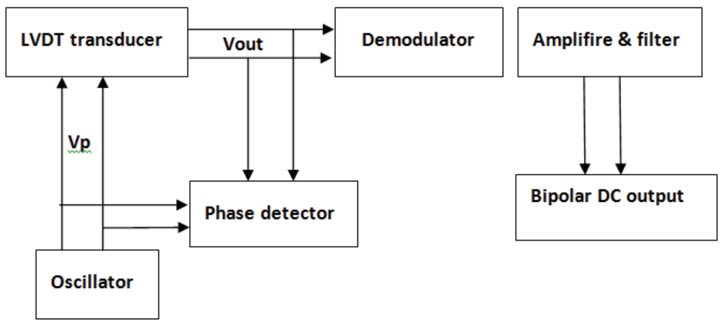


Fig. 2. The common block diagram of LVDT signal conditioners.

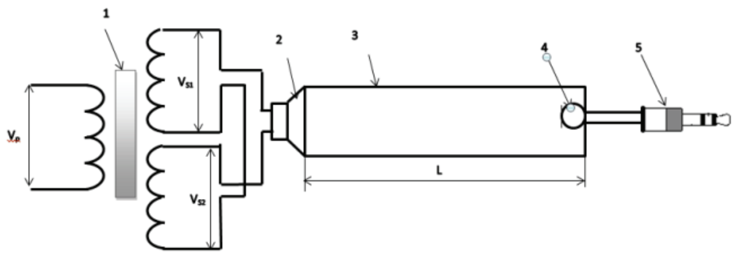


Fig. 3 (a). Opposite series connection of LVDT to waveguide signal conditioner.

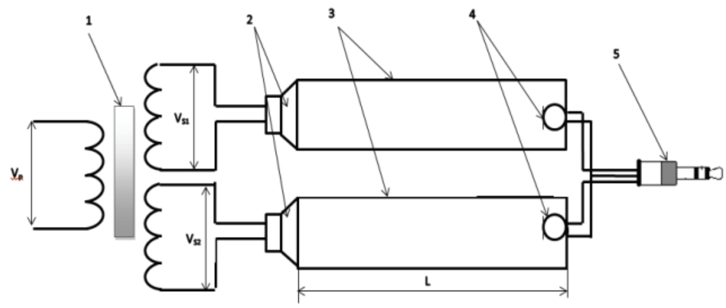


Fig. 3 (b). Connecting the output of each secondary of LVDT to waveguide signal conditioner.

Where 1 is the core of LVDT, 2 is the loudspeaker, 3 is the resonance tube, 4 the microphone and 5 is the microphone jack.

The operation principle of the conditioning circuit is follow. The LVDT secondaries produce and electrical signal proportional to displacement. The electrical signal is converted into sound signal which is received by microphone. The microphone output is connected directly to the microphone input of the sound card of personal computer or laptop. Labview software is used to measure the amplitude of sound wave and for signal processing. In this measurement, demodulator, differential amplifier and phase detector circuits are to be replaced by standard LabVIEW VIs.

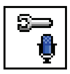
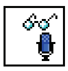
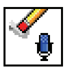
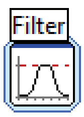
4. Development of LabVIEW Software

LabView 2014 is used to carry out the software development process. This process can be dividing into three stages:

1. Acquiring microphone signal stage;
2. Signal measurement stage;
3. Signal processing stage.

Table 1 shows the used VIs (the word VI states for Virtual Instrument, i.e., The LabVIEW blocks or code) [19], for each stage.

Table 1. VIs used for acquiring microphone signal stage

Stage	VI	Description
1		Sound Input Configure VI
		Sound Input Read VI
		Sound Input Clear VI
2		It returns the single tone frequency, amplitude, and phase
3		Smoothing filter

Acquiring algorithm for measuring and processing of a Microphone signal using LabVIEW is shown in Fig. 4.

The Front panel and the block diagrams of LabVIEW VI used to measure the acquired signal by microphone are shown in Fig. 5 and Fig. 6.

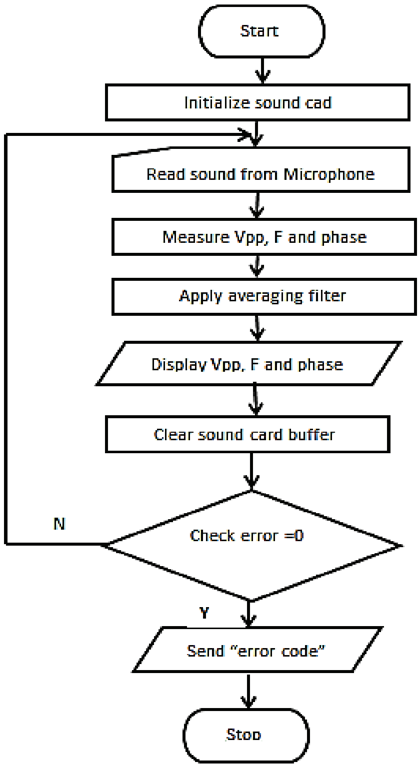


Fig. 4. Measuring and processing of an LVDT signal.

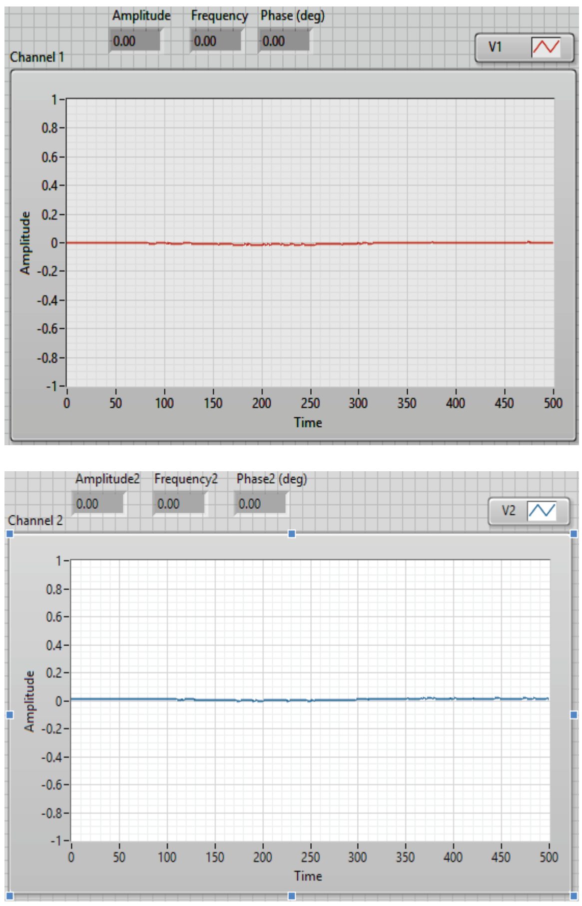


Fig. 5. The Front panel of developed VI.

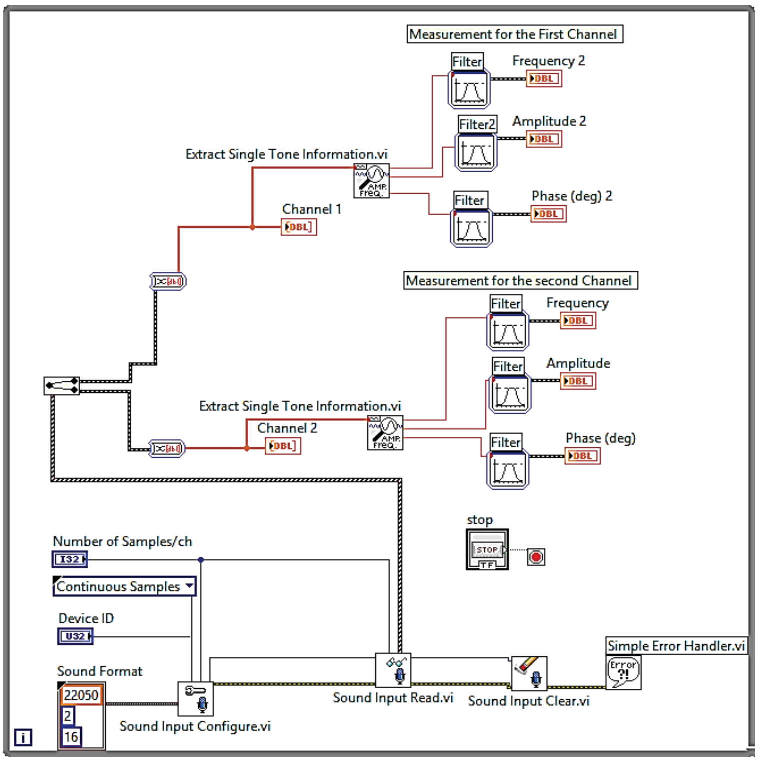


Fig. 6. Block diagram of developed VI.

The Front panel of developed VI contains the following VIs

- Two waveforms VIs , which are used to display the measured voltage by the first channel of sound card.
- Six numerical indicators to display the measured signal parameters for each channel, i.e. Amplitude, Frequency and Phase

Fig. 5 shows the block diagram of the developed VI, and the components used to develop such VI are given in Table 1.

5. Experimental Setup and Procedure

The experiment setup consists of the following:

- LVDT transducer with micrometer and distance marker;
- Two Microphones;
- Two tubes (made from glass);
- Oscillator;
- PC or Laptop;
- Connection wires;
- Two loudspeakers.

The oscillator is connected into the primary coil of LVDT, which generates a sinusoidal signal with adjustable parameters.

When opposite series connection of LVDT is applied, the two wires are connected to the speaker mounted into one side of glass tube and the microphone is placed in the opposite side of the glass tube.

When differential measurement is applied, each secondary is connected into a loudspeaker.

Two microphones are used to detect the generated sound signal with the tube.

In works [20-22], the authors proposed an experimental procedure which can be used to determine DC characteristics of an LVDT. In this work we will illustrate the experimental procedure when opposite series connection of an LVDT is applied. The general procedure is follow:

a) Connect the LVDT transducer in opposite series connection as shown in Fig. 7.

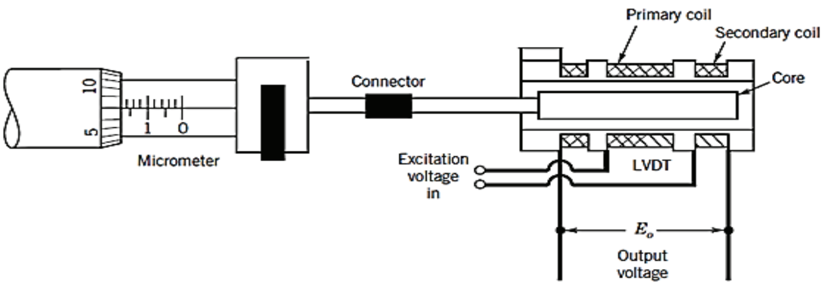


Fig. 7. Opposite series connection of an LVDT.

b) Connect the Vout of LVDT to the Loudspeaker(s).

c) Adjust the null position using micrometer and measure the Vpp displayed on a waveform.

d) Record the Vout of LVDT when the core is located in the central position.

e) Use the micrometer to move the LVDT core to the right side , step = 1 mm, reach the maximum core position, make records for Amplitude for each step

f) Return into Null position

g) Use the micrometer to move the LVDT core to the Left side, step = 1 mm, reach the maximum core position, make records for Amplitude for each step

6. Experimental Results

The experiment was operated under the following conditions (Table. 2)

Table 2. Operation condition.

$V_{primary}$, [V]	2
Oscillator F, [Hz]	500
Input range x, [mm]	0 to 25

The experimental results when the output of each secondary of an LVDT is connected to individual loudspeakers are shown Table 3.

The plot between displacement of LVDT core and the difference of the measured voltages via sound card is shown in Fig. 8.

7. Conclusion

In this paper, a simple measurement technique utilizing waveguide acoustic resonance tube is developed to determine the LVDT characteristics. The work utilizes LabVIEW for signal acquisition and processing. Experimentally it was shown that LVDT DC characteristics can be obtained and plotted without additional signal condition circuits. Utilizing such measurement technique allows monitoring and measuring LVDT movement in several industrial applications where LVDT is used.

Acknowledgements

This work has been carried out during sabbatical leave granted to the author (Tariq Younes) from Al-Balqa' Applied University (BAU) during the academic year 2015-2016. I'd like to thank Al-Balqa' Applied University for their support and Philadelphia University for their logistic aid.

Table 3. Experimental results.

x, (mm)	V1, (V)	V2, (V)	ΔV, (V)
0	0.154	0.852	-0.698
1	0.156	0.956	-0.800
2	0.158	1.000	-0.842
3	0.162	0.980	-0.818
4	0.163	0.912	-0.749
5	0.166	0.822	-0.656
6	0.176	0.724	-0.548
7	0.194	0.645	-0.451
8	0.217	0.567	-0.350
9	0.246	0.497	-0.251
10	0.278	0.448	-0.169
11	0.310	0.398	-0.088
12	0.369	0.337	0.031
13	0.416	0.305	0.110
14	0.465	0.276	0.190
15	0.529	0.249	0.280
16	0.608	0.224	0.385
17	0.697	0.205	0.492
18	0.796	0.193	0.604
19	0.891	0.187	0.704
20	0.965	0.186	0.778
21	1.000	0.190	0.810
22	0.955	0.189	0.766
23	0.851	0.187	0.664
24	0.723	0.186	0.536
25	0.525	0.172	0.353

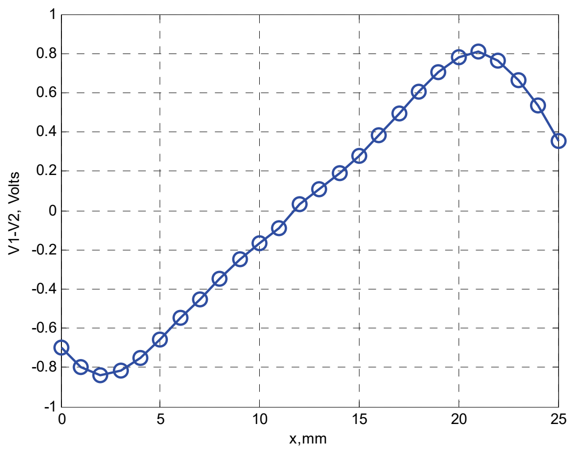


Fig. 8. The plot between the core displacement in mm and difference of measured voltages in LabVIEW.

References

[1]. Blejan Marian, Ilie Ioana, Marin Alexandru, Signal conditioner for LVDT sensor to analogue signal and

RS 232 (RS 485) bus, *Mecatronica Academic Journal*, Issue 3, 2004, pp. 21-24.
[2]. Mihail Hristov Tzanov, Filip Todorov Koparanov, Emil Dimitrov Manolov, Simulink modeling of signal conditioning circuit for inductive displacement transducer, in *Proceedings of the Electronics'08,* Sozopol, Bulgaria, 26 September 2008.
[3]. Richard Poley, Signal Conditioning an LVDT Using a TMS320F2812 DSP, Application Report SPRA946, *Texas Instruments,* August 2003, pp. 1-27.
[4]. Ju-Ho Choi, Sung-Soo Hong, Joon Lyou, A Development of Recoil & Counter Recoil Motion Measurement System Using LVDT, ICASE: The Institute of Control, *Automation and Systems Engineers,* Korea, Vol. 2, No. 3, September 2000.
[5]. Tariq Al Mograbi, Mohammad A. K. Alia, Mohammad Abuzalata, Design of an Acoustic Displacement Transducer, *Sensors & Transducers Journal*, Vol. 112, Issue 1, January 2010, pp. 1-9.
[6]. Tariq M. Younes, Mohammad A. K. Alia, Shebel Al-Sabbah, Acoustic Temperature Transducer, *Sensors & Transducers*, Vol. 119, Issue 8, August 2010, pp. 46-57.
[7]. Tariq M. Younes, Computer-Based Acoustic Detector for Determining the Type and Concentration of a Solution, *Journal of Applied Research and Technology*, Vol. 10, No. 6, 2012, pp. 859-864.
[8]. RU 2533, 2002 Acoustic linear displacement transducer, Tariq Younes, Ilyasov L. V.
[9]. RU 2593, 2002 Acoustic sensor for high temperature measurement, Tariq Younes, Ilyasov L. V.
[10]. Biljanović Petar, Skala Karolj, editor(s), MIPRO Croatian Society, in *Proceeding of the 28th International Convention MIPRO 2005/Opatija*, 2005, pp. 165-167.
[11]. Doug Mercer, Analog Dialog, *Analog Devices*, Vol. 45, No. 4, November 2011, pp. 3-6. http://www.qsl.net/om3cph/sb/dcwithsb.htm
[12]. Zoltán Gingl, Róbert Mingesz, Péter Makra, János Mellár, Review of sound card photogates, *European Journal of Physics*, Vol. 32, No. 4, 2011, pp. 905-924.
[13]. Tariq Younes, Mohammad Al Khawaldah, Ibrahim Al-Adwan, Resonance Mode Acoustic Displacement Transducer, *Sensors & Transducers,* Vol. 172, Issue 6, June 2014, pp. 34-38.
[14]. Marian Blejan, Ioana Ilie, Mircea Comes, Bogdan Lupu, Signal conditioner for LVDT displacement sensors, in *Proceeding of the SPIE 7297, Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies IV*, 72972E, 7 January 2009.
[15]. Ford R. M., A DSP-based modified Costas receiver for LVDT position sensors, in *Proceedings of the 17th IEEE Conference on Instrumentation and Measurement Technology*, Vol. 3, 2000, pp. 1448-1452.
[16]. Measuring Position and Displacement with LVDTs, *National Instrument,* 12 September 2016. http://www.ni.com/white-paper/3638/en/
[17]. Ch. V. Suresh, G. Ramu, Real Time Measurement of Position as well as Direction using Linear Variable Differential Transformer, *International Journal of Engineering Research and Applications (IJERA)*, Vol. 2, Issue 3, May-Jun 2012, pp. 246-252.
[18]. Shebel A. Alsabbah, Tariq Mughrabi, Neural Network-Based Waveguide Acoustic Gas Detector, in *Proceeding of the 5th International Symposium on Mechatronics and its Applications (ISM'08)*, Amman, Jordan, 27-29 May 2008, pp. 1-4.
[19]. A. Bruce Buckman, A Course in Computer-based Instrumentation: learning LabVIEW™ with Case Studies, *International Journal of Engineering Education*, Vol. 16, No. 3, 2000, pp. 228-233.
[20]. T. Meydan, G. W. Healey, Linear variable differential transformer (LVDT): linear displacement transducer utilizing ferromagnetic amorphous metallic glass ribbons, *Sensors and Actuators A: Physical*, Vol. 32, Issue 1-3, April 1992, pp. 582-587.
[21]. K. V. Santhosh, B. K. Roy, A Smart Displacement Measuring Technique Using Linear Variable Displacement Transducer, *Procedia Technology*, Vol. 4, 2012, pp. 854-861.
[22]. Ashline George, Ashly Sunny, Jerin Cyriac, Manu Francis, Signal Processing in LVDT for automatic calibration, in *Proceeding of the International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT'16)*, 2016, pp. 1-5.