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Design of a PC Based Pressure Indicator Using Inductive Pick-up Type Transducer and Bourdon Tube Sensor

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Abstract: Bourdon tube is a mechanical type pressure sensor and the bourdon gauge measures gauge pressure of a process pipe line or a process tank. But it is a local indicator and special costlier techniques are required to transmit the reading of bourdon gauge to a remote distance. In the present paper, a very simple inductive pick-up type technique has been developed to transmit the reading of bourdon gauge to a remote distance in the form of 1-5 Volt D.C. signal. This signal has been optically isolated to design a PC based pressure indicator using Labtech Note Book Pro software. The theoretical analysis of the whole technique has been presented in the paper. The instrument developed using this technique has been experimentally tested and the experimental results are reported in the paper. A good linearity and repeatability of the instrument has been observed. *Copyright © 2009 IFSA.*

Keywords: Gauge pressure, Bourdon tube, Inductive pick-up type transducer, Opto-isolator, PC based indicator

1. Introduction

Pressure is one of most important process variables which are required to be measured and controlled in a process industry. The absolute pressure at a point inside a fluid is the force exerted normally per unit area surrounding that point and the gauge pressure is the difference between the absolute pressure and the local atmospheric pressure. The absolute pressure can be measured in terms of height of a liquid column in a manometer whereas the gauge pressure is measured by different types of sensors [1-4] whose one or more parameters vary due to the difference between the absolute pressure of a fluid and the atmospheric pressure. As for example bourdon tube, diaphragm, capsule, bellow element etc. operate as primary sensing elements for measuring positive or negative gauge pressure. The sensors like strain gauge, piezoresistance, LVDT, capacitive element, inductive element etc. act as secondary sensors to measure positive or negative gauge pressure. The negative gauge pressure or vacuum pressure can also be measured by many other sensors like pirani gauge, ionization gauge, McLeod gauge etc. In industrial application it is required to transmit the measured pressure to a remote distance. So in a pressure transmitter, the change of sensor parameter due to the change of fluid pressure is converted into an electric or pneumatic signal by using a suitable transducer and that signal after amplification is transmitted to a remote receiver. Hence the pressure transducer is a vital part of any pressure transmitter and its performance determines the reliability of operation of the transmitter. So many works on development of reliable pressure transducer are still being reported by different groups of workers. Universal frequency-to-digital converter (UDFC) technique has been used by S. Y. Yurish [5] to develop an intelligent digital pressure transducer and multiplexed frequency transmitter technique has been used by R. Vrba *et. al* [6] to design a reliable pressure transducer using ceramic diaphragm. R. Shunmugham *et. al* [7] have proposed continuous gain observer and sliding mode observer technique to measure pressure on both sides of a pneumatic cylinder actuator. S. Vlassis *et. al* [8] have developed a CMOS operational amplifier based interfacing circuit which converts the pressure signal of a piezoresistive pressure sensor into an output frequency signal independent of temperature. Another temperature compensated pressure sensor designed by M. A. Taslakov [9] operates on the principle of converting pressure change into oscillator frequency shift. V. S. Beshliu *et. al* [10] have used voltage to frequency conversion technique to convert silicon gauge pressure into output frequency signal. A. Yasukawa *et. al* [11] have shown that a circular silicon pressure sensor with center boss can measure very low pressure. J. C. Greenwood *et. al* [12] have utilized the effect of strain produced by the applied pressure on the resonant frequency of a silicon crystal to measure pressure from vacuum to 1 bar. P. E. Thoma *et .al* [13] have developed a modified capacitance type pressure sensor for measurement of low pressure. K. Ara *et. al* [14] have developed a pressure transducer by utilizing the inverse magnetostrictive sensitivity property of a martensitic stainless steel material AISI-410.The bourdon tube widely used in industry as pressure sensor has a very simple construction with almost linear scale but the major drawback of this sensor is that it can only be used as a local indicator and special arrangement is needed to convert the bourdon movement into electric signal, so that its reading can be transmitted into a remote location.

In the present paper, design of a PC based pressure indicator using inductive pick-up type transducer for a bourdon tube sensor has been described. A very simple inductive pick-up type technique has been developed to convert the bourdon movement into an equivalent 1-5 volt D.C. signal. This signal has been optically isolated to design a P.C. based pressure indicator using Labtech Note Book Pro software. Mathematical equations have been derived to explain the operation of this transducer. A prototype unit along with the signal conditioner has been designed and fabricated. The experiments have been performed to find out the static characteristic of the unit. The experimental results are reported in the paper. A very good linearity and repeatability of results has been observed.

2. Method of Approach

Let us assume that AB is a C type bourdon tube with its tip (B) attached with a U- type bent wire (BCD) made of ferromagnetic material as shown in Fig. 1. The diameter of the wire is selected to be a very small so that its weight does not affect the free movement of the tip of the bourdon tube. Let the mean radius of the bourdon tube at zero gauge pressure be r which changes to $r+\Delta r$ when the bourdon tube is subjected to a gauge pressure P with its tip rotating through an angle $\Delta\theta$. As a result the tip (B) of the bourdon tube rotates to a position B' and the ferromagnetic wire BCD shift to the position to $B'C'D'$ as shown in Fig. 1.

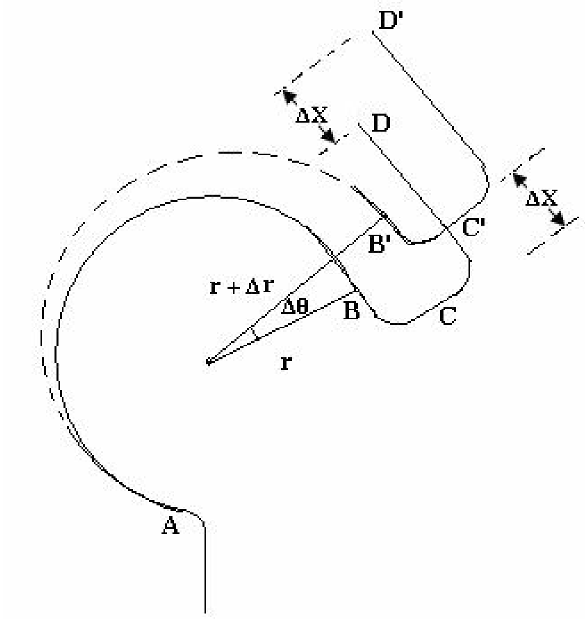


Fig. 1. C-type bourdon tube.

So this circumferential movement by the tip is given by,

$$\Delta X = (r + \Delta r)\Delta\theta \tag{1}$$

Since Δr and $\Delta\theta$ are very small so the above equation is reduced to

$$\Delta X = r\Delta\theta \tag{2}$$

Now,

$$\Delta\theta \propto P \tag{3}$$

$$or, \quad \Delta\theta = K_1 P,$$

where, K_1 is the constant of proportionality.

Therefore,

$$\Delta X = r K_1 P \tag{4}$$

Since the ferromagnetic wire is rigidly attached with the tip of the bourdon tube, so the linear movement (between D and $D^{'}$) of the tip of the ferromagnetic wire may also be assumed to be equal to the circumferential movement ΔX as shown in Fig. 1. So, if the ferromagnetic wire be allowed to move through a solenoid coil as shown in Fig. 2, then the effective inductance of the coil will increase with increase in gauge pressure. This change in inductance is measured by a Maxwell's bridge as shown in Fig. 3.

In Fig. 3, L_0 is the air cored dummy inductance coil having same number of turns as the measuring coil (L_X) so that when the applied gauge pressure is zero the self inductance of the measuring coil becomes equal to that of the dummy coil.

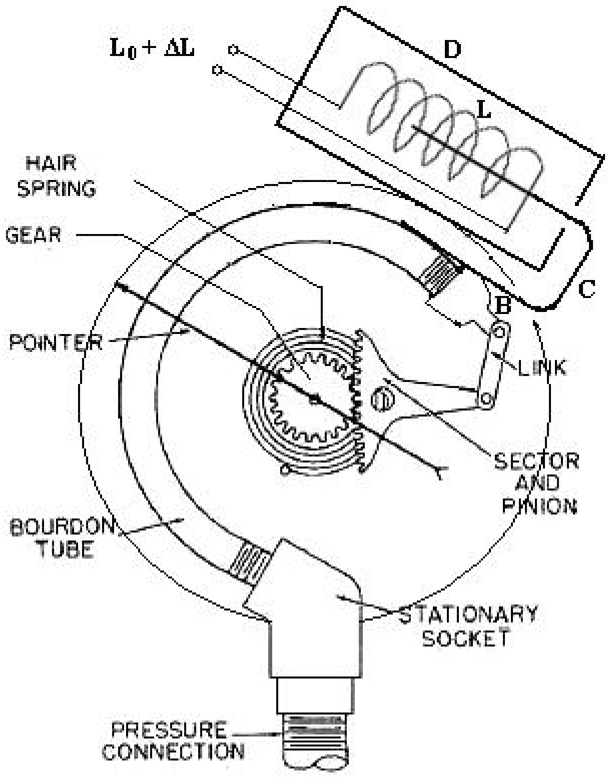


Fig. 2. C-type bourdon gauge with inductive pick-up type transducer.

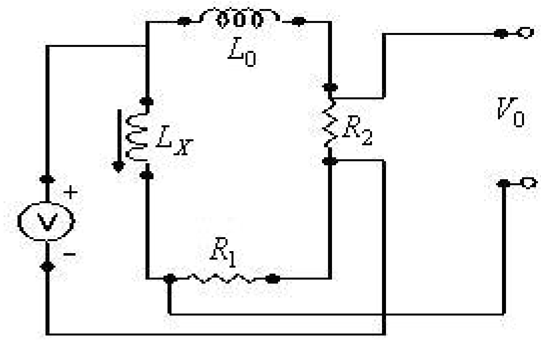


Fig. 3. Maxwell's Bridge.

So if the ratio arm resistances R_1 and R_2 be selected to be two equal standard resistances then the bridge output will be zero or minimum when the applied gauge pressure to the bourdon tube is zero. Let R_0 be the resistance of the dummy inductance coil. If we assume that no current is drawn from the bridge network through the output terminals and the self inductance of the measuring coil (L_X) increases from L_0 to $L_0 + \Delta L$, when the gauge pressure is increased from 0 to P, then the bridge output equation for stabilized bridge supply voltage V at circular frequency ω will be given by,

$$V_0 = \frac{VR_2}{R_2 + R_0 + jL_0\omega} - \frac{VR_1}{R_1 + R_X + jL_X\omega}$$

$$or,\ V_0 = \frac{\left[(R_2R_X - R_1R_0) + j\omega(L_XR_2 - L_0R_1)\right]}{(R_1 + R_X + jL_X\omega)(R_2 + R_0 + jL_0\omega)}\ V \qquad (5)$$

Assuming $R_1 = R_2$, $R_X = R_0$ and $R_1 + R_X = R_2 + R_0 >> jL_X\omega$ *or* $jL_0\omega$, the above equation is reduced to

$$V_0 = \frac{jR_1\omega(L_X - L_0)}{(R_1 + R_0)^2} \tag{6}$$

Now the movement (ΔX) of the ferromagnetic wire *(BCD)* due to pressure *(P)* is very small. So, if this ferromagnetic wire is inserted into an inductance coil of small diameter then the inductance L_X of the coil will almost vary linearly with ΔX i.e.

$$L_x = L_0 + K_2\,\Delta X\,, \tag{7}$$

where K_2 is a constant.

Combining the equations (6) and (7), we have,

$$V_0 = \frac{j\omega K_2 R_1 \Delta X}{(R_1 + R_0)^2} \tag{8}$$

Combining the equations (4) and (8), we get,

$$V_0 = \frac{j\omega r\, K_1 K_2 R_1}{(R_1 + R_0)^2} P \tag{9}$$

Therefore, output voltage signal will be linearly related with pressure. Thus the bourdon gauge movement is converted into the electrical signal by the above transducer. The amplified signal is converted into 1-5 volt D.C. signal by a signal conditioner circuit. This signal is then sent to a particular channel of DAS card of a PC through an analogue opto-isolator as shown by the block diagram in Fig. 4 and is displayed in the PC monitor in engineering unit.

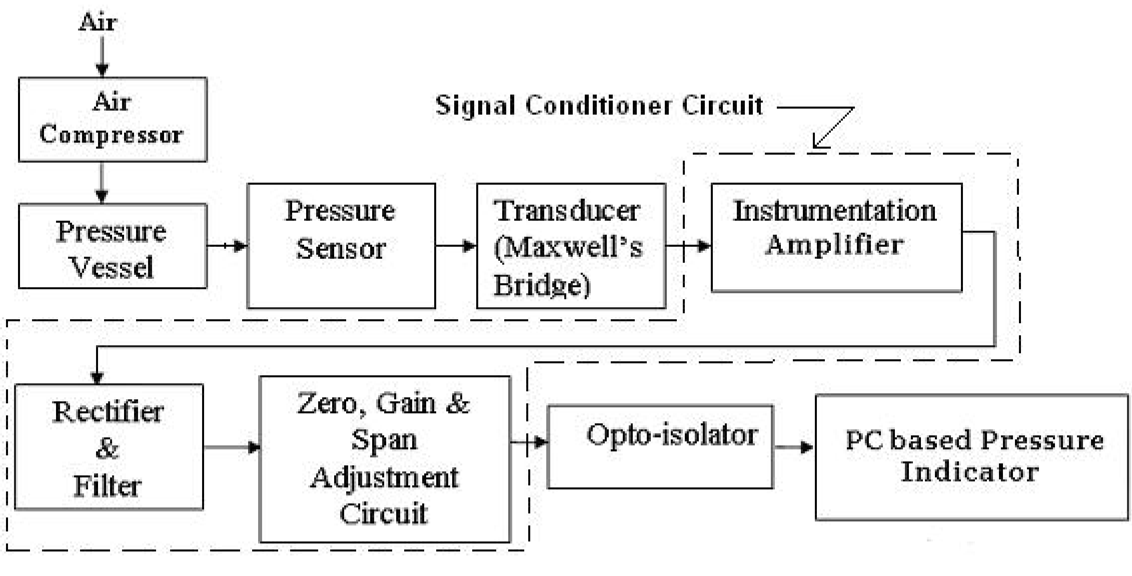


Fig. 4. Block diagram of the signal conditioner circuit of the proposed PC based pressure indicator.

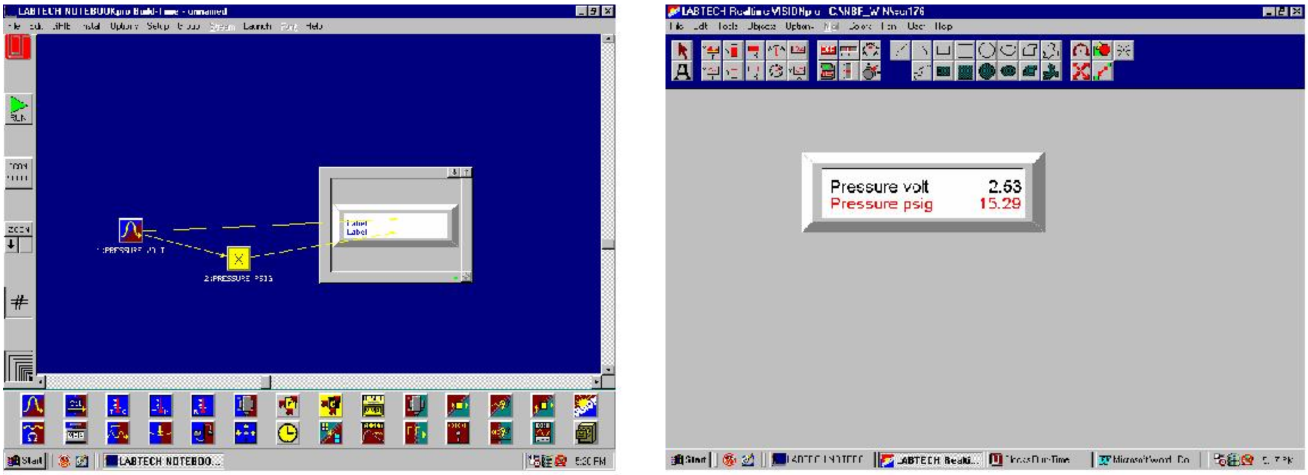
3. Design

Commercially available GI wire of 2 mm diameter and 30 mm length was selected as the ferromagnetic wire of the proposed pressure transducer. This was bent in the form of U-tube with arms of unequal length. The shorter arm is fixed on the tip of the bourdon tube by brazing technique and the longer arm is inserted into the core of the inductance coil. Inductance coil is fabricated by using 10000 turns of 46 SWG super enamel copper wire uniformly wound on an insulating former of inner diameter 7 mm, outer diameter 9 mm and length 75 mm. The whole coil was placed inside an aluminium cover tube of inner diameter 15mm, outer diameter 16.1 mm and length 75 mm with end faces covered by aluminium disc, so that the coil is protected from a mechanical damage as well as from external time varying magnetic field. The aluminium cover tube with the coil was fixed on the outside metallic cover of the bourdon gauge by brazing and the ferromagnetic wire was brought out through a small hole of the cover plate as shown in Fig. 2, so that it can move freely with the movement of the tip of bourdon tube. The Maxwell's bridge network along with the signal conditioner circuit as shown in Fig. 2 and Fig. 3 was fabricated on a PCB. A stabilized sinusoidal oscillator at 25 V, 1000 Hz was selected as the bridge supply source. From the measurement of self inductance of the coil by a LCR meter the self inductance was found to be about 150 mH, so that the inductive reactance of each coil was about 942 Ω. So R_1 was selected to be $1K\Omega$ standard resistance and R_2 was selected to be a linear $4.7\ K\Omega$ potentiometer. The PC based indicator was designed using icon based LAB Tech Note Book Pro Software as shown in Fig. 5 (a) and (b). Fig. 5 (a) shows the design of the pressure indicator by using three icon blocks and Fig. 5 (b) shows the digital output after running the software of Fig. 5(a). The analogue signal coming from opto-isolator is converted into digital signal in the DAS card by ADC and this digital signal is displayed in PC monitor in "volt" and "psig". The voltage reading is obtained from analog icon block "pressure volt" and psig reading is obtained from scalar icon block "pressure psig". In the scalar block the pressure signal in volt is converted into psig signal by using $Y = mx + b$ formula.

4. Experiment

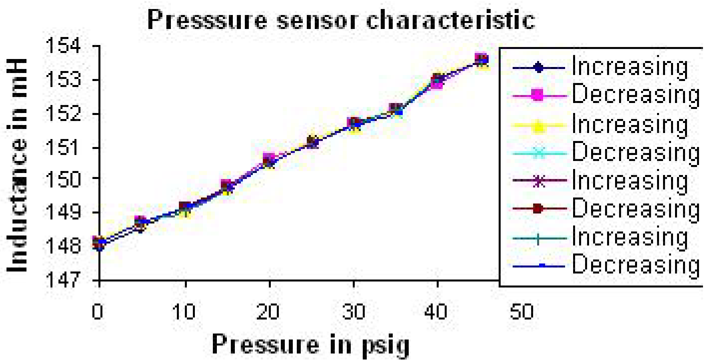
The experiment is performed in the following steps. In the first step, the proposed transducer was designed, fabricated and assembled on the outside cover plate of a bourdon gauge in the range 0-45 psig. The bourdon gauge with the above sensor was first fitted with a dead weight tester and the self inductance of the sensor coil was measured by a LCR bridge. The dead weight of the dead weight tester was increased in steps and in each step the self inductance of the coil was measured by MIC-4070D LCR meter having ± 0.5% accuracy. Now the static characteristic graph of the sensor was drawn by plotting self inductance of the coil against dead weight tester reading *i.e.* pressure in psig. The static characteristic graph of eight repeated experiments in increasing and decreasing modes is shown in Fig. 6 (a) and the corresponding standard deviation curve is shown in Fig. 6 (b).

In the second step, the sensor terminals are connected with the Maxwell's bridge as shown in Fig. 3 which is a part of the whole circuit diagram as shown by block diagram in Fig. 4. Now dead weight of dead weight tester was increased in steps and in each step the bridge output AC voltage, the signal conditioner output D.C. voltage and the reading of the PC based indicator were recorded. Now the static characteristic graphs were drawn by plotting each of bridge output voltage, signal conditioner output voltage and PC based pressure indicator reading against applied pressure. The characteristic graphs for six repeated experiments along with their standard deviation curves are shown in Fig. 7, Fig. 8 and Fig. 9 respectively.

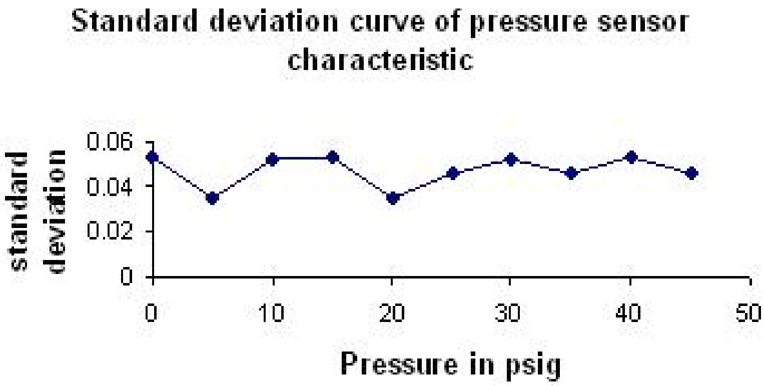


(a) (b)

Fig. 5. PC based pressure indicator.

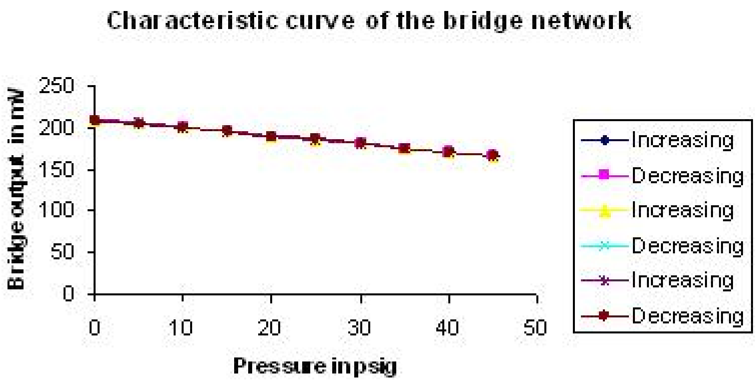


(a)

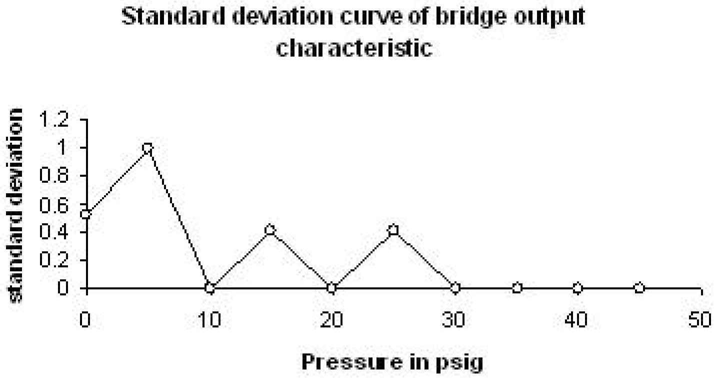


(b)

Fig. 6. Static characteristic graph of the proposed pressure sensor.



(a)



(b)

Fig. 7. Static characteristic curve of the bridge network.

5. Discussions

From Fig. 6, it is observed that the proposed pressure sensor has a good linear characteristic with very good repeatability. The linear nature of the curve is due to the fact that the movement of the tip of the bourdon gauge for the entire pressure range is generally very small and the small change of self inductance of the coil lies almost in the linear zone. The bridge network characteristic, signal conditioner characteristic and PC based pressure indicator characteristic curves also have very good linearity and repeatability as shown in Fig. 7, Fig. 8 and Fig. 9 respectively. The design of the hardware part of the circuit is very simple and involves very low cost. Thus the proposed transducer may be considered to be a reliable transducer for transmitting bourdon gauge reading to a remote distance and controlling pressure in a process plant by using simple bourdon gauge indicator in stead of costlier electronic transmitter.

The pressure gauge used in the present work was a commercially available gauge with bourdon tube made of stainless steel. So small deviation from non-linearity of the characteristic graphs shown in the above figures may be due to the non-linearity of the bourdon tube itself.

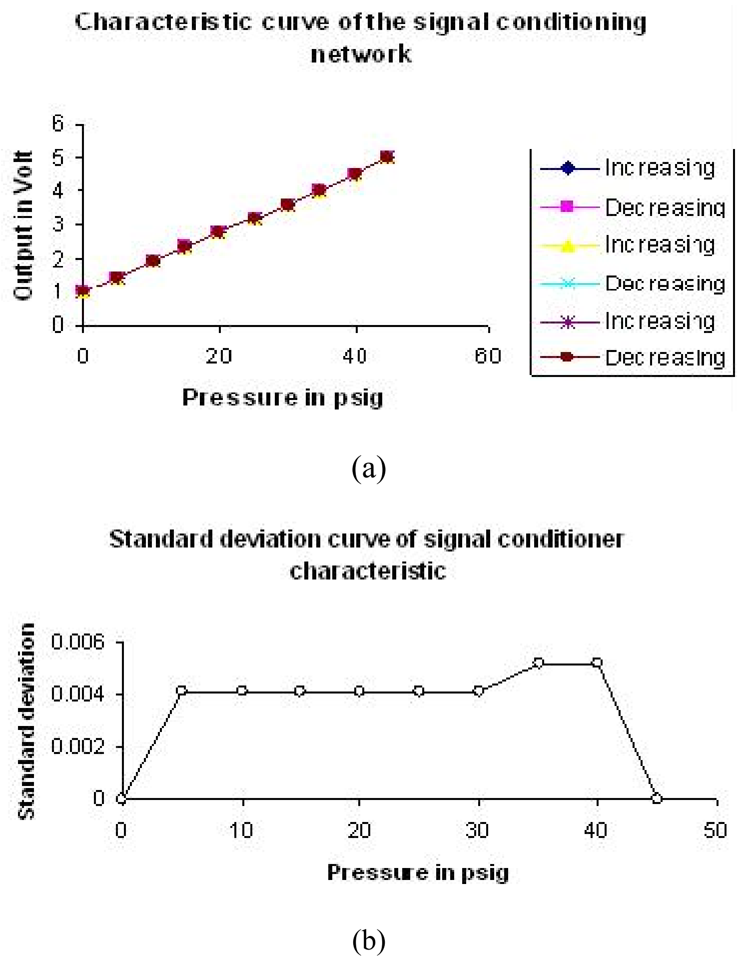


Fig. 8. Static characteristic curve of the signal conditioner network.

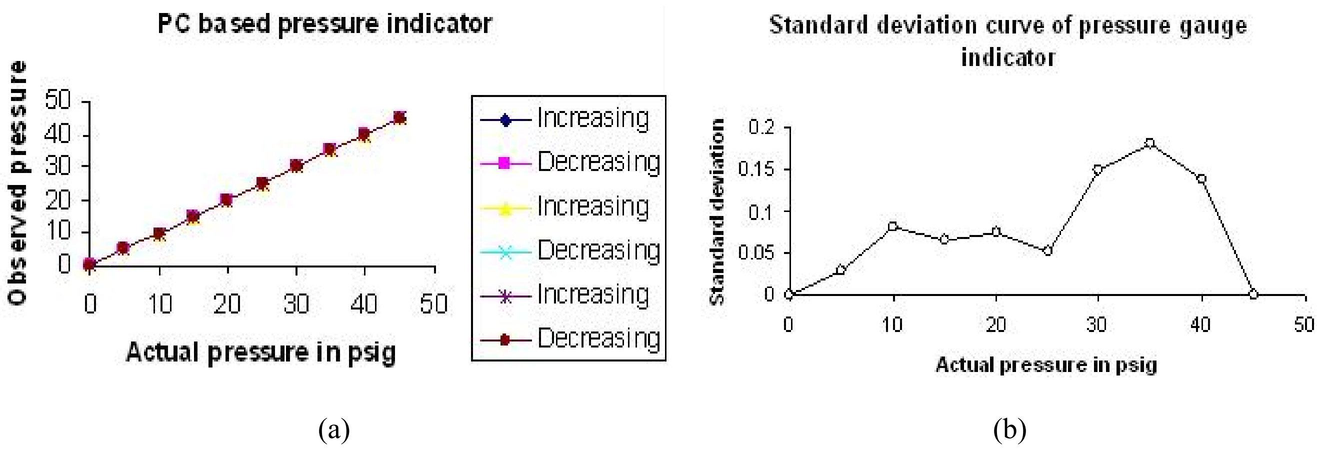


Fig. 9. Static characteristic curve of the PC based pressure indicator.

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