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Study of a Position Indicating System of the Piston of a Power Cylinder Using Modified Inductive Pick-up Technique

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Abstract— The power cylinders are widely used in process plants mainly for the accurate and positively positioning of various plant regulators such as Dampers, ID and FD fans in boilers, throttle, etc. These are so designed so that increase in control pressure moves the piston either outward or inward. So determination of the position of the piston is really important. In this paper an improvised differential inductance mechanism is proposed so as to determine the position of the piston. The design of the circuit has been physically implemented and the results were taken at various inputs, which are also shown in the paper. The proposed Detector has been experimentally found to have a good repeatability, sensitivity as well as Linearity.

Index Terms—Differential inductance, Instrumentation Amplifiers, Op-amps, Piston, Power Cylinder, Repeatability, Transducer.

1 Introduction

POWER Cylinder either pneumatically or hydraulically actuated, and has many applications in modern industry. For example, in a burner management system of a fossil fuel furnace of a thermal power plant, flow of air through different burners is operated by means of power cylinder. The position of the piston inside the power cylinder is mechanically fed back to the position control system of the cylinder by a mechanical arrangement attached with the piston rod.

In burner management system, the force produced at the piston rod moves a damper in the air supply line to control the air flow to the furnace. In this system, it is used as an ON-OFF type control management. In induced draught fan and forced draught fan control system, the power cylinder along with the damper is used as the final control element of a PID control system. Some special precautions are needed to mount the proximity sensor w.r.t the piston element. The function of the capacitance type sensor depends on environmental conditions and so recalibration of the sensor is sometime needed. Here an inbuilt non contract differential inductive pick-up type position sensing technique of the piston of a power cylinder made of ferrous alloy material like carbon steel has been proposed. In this technique, the change of position of the piston is sensed in terms of self inductance change between two identical coils wound around the outer surface of the power cylinder. The inductance change of these coils linearly changes almost linearly with the displacement of the piston from one end of the power cylinder.

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2 Methodology

The power cylinder along with the piston is generally made of Ferrous material like Alloy steel or Carbon steel, etc. Thus when a coil is wound outside the cylinder then its inductance will change with the change of the position of the piston inside the cylinder. Thus in this present work two identical differential inductance bridge is designed to measure the small inductance change of the coils due to the change of the position of the piston.

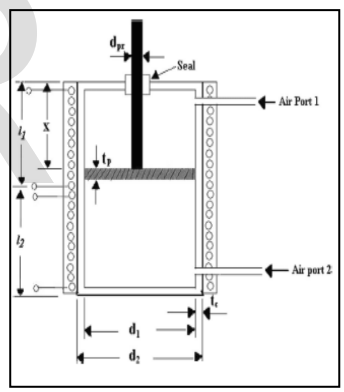

Fig 1: Power cylinder with coil

Let two identical coils of length L_1 and L_2 with inner and outer diameterD_1 and D_2 respectively as shown in fig 1.

Case I: When the piston goes upward and remains in the upper half of the power cylinder, inductance L_1 of the upper coil becomes greater than the inductance of lower coil L_2 i.e. $L_1>L_2$.

The difference of inductance (L_1-L_2) is given by:

$$L_1-L_2 = \Delta L= K_1x + K_2 \ldots\ldots\ldots. (1)$$

Where x is the displacement of the piston from the upper end of the power cylinder as shown in the fig. and K_1 & K_2 are constants.

Case II: When the piston goes downward and remain **Fig 1:** Power cylinder with coil s in the lower half of the power cylinder, inductance L_2 of the lower coil becomes greater than the inductance of upper coil L_1 i.e. $L_2>L_1$.

The difference of inductance (L_1-L_2) is given by:

$$\Delta L= (L_1-L_2) = - (L_2-L_1) = - (K_1x + K_2) \ldots\ldots\ldots. (2)$$

The difference between the output V_1 & V_2 of the of the op-

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amp A_1 and A_2 is determined by differential circuit which is formed by using op-amp A_3 keeping $R_3=R_4=R_5=R_6$ so that the output is given by

$V_3=V_2-V_1$ …………………. (3)

For a.c signal of rms voltage V_s the output V_1 & V_2 are given by

$V_1= - (j\omega L_1/R_1) * V_s$ ……….. (4)

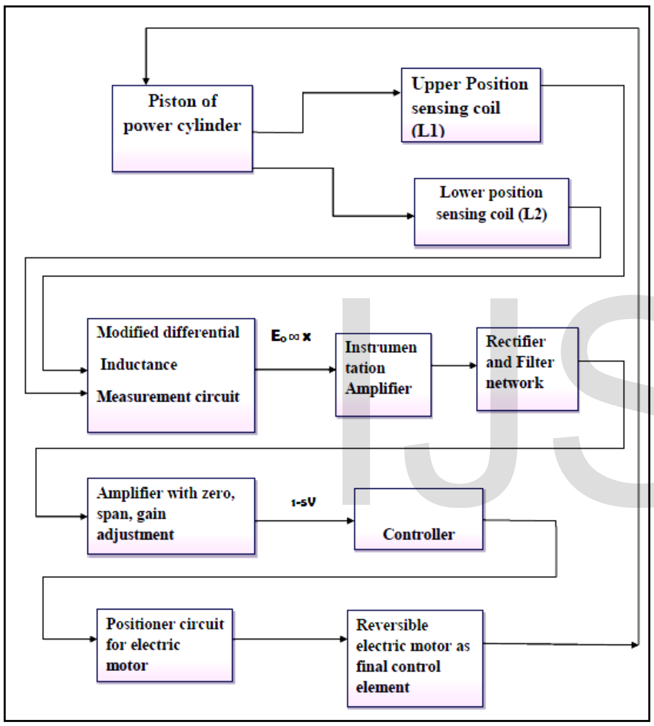
$V_2= - (j\omega L_1/R_2) * V_s$ ……….. (5)

Therefore;

$V_3=V_2-V_1$

$V_3= - (j\omega\ V_s /R_1) * (K_1x + K_2)$ ………… (6)

It can be noted that since V_3 is an ac signal, this change of phase can't be indicated in ordinary voltmeter. Thus in both cases V_3 will increase with the increase of displacement x.



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3 Operation of Various Circuit Parts of the System

Fig 2: Block Diagram of the System

3.1 Modified Differential Inductance Using Op-Amp

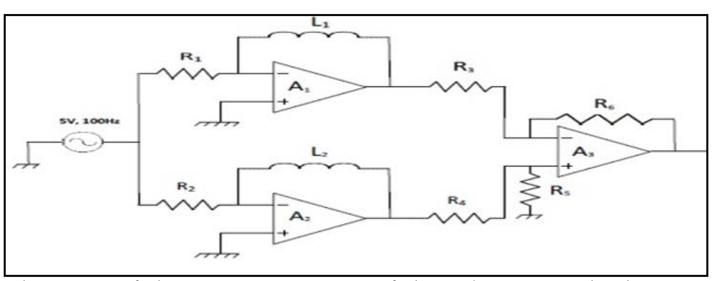
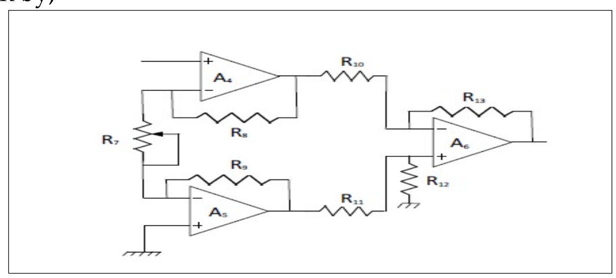


Fig 3: Modified Differential Inductance Using Op-Amp

This part of the system consists of three low noise high input impedance op-amps A_1, A_2, and A_3. As shown in the fig 3 L_1 and L_2 which are the respective inductance due to the position of the piston at upper and lower coil, connected in the feed back path of the op-amp A_1 and A_2. The input resistance R_1 & R_2 of both the op-amps are selected to be identical and are connected to common source.

3.2 Instrumentation Amplifier

The output of the differential network has very low amplitude so it needs to be amplified, thus instrumentation amplifier is being used in the system to perform such action. The instrumentation amplifier consists of op-amp A_4, A5 and A_6 as Shown in fig 4. The gain of the instrumentation amplifier is given by;



$K= 1+ 2R_8/R_7$…………………… (6)

$V_4= KV_3$ …………………… (7)

Fig 4: Instrumentation Amplifier

3.2 Rectifier and Filter Circuit

With the help of dynamic characteristics the operation of a diode as a rectifier can be explained. Since the negative half cycles of the input voltage are cut- off and are absent from the output load voltage, which uses single diode.it can also be referred to as half wave rectifier. This half wave rectifier uses a transformer at its input to set up or step down the a.c mains voltage connected to primary.

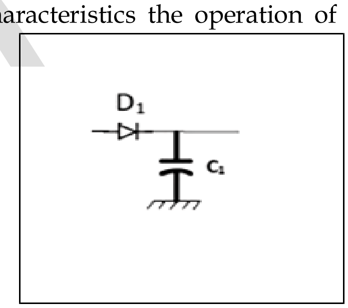


Fig 5: Rectifier & Filter Circuit

4 Design

The power cylinder used here is made up of carbon steel, and a movable piston is inside it. This is a prototype of actual pneumatic power cylinder. A circular solid piston rod is used to the piston. The dimensions of the cylinder is as follows:- Internal diameter- 0.100 m; Outer diameter- 0.104 m; Thickness- 0.002 m; Total length – 0.220 m. The thickness of the piston (t_p) is of 0.01 m and its diameter is almost equal to the inner diameter of the power cylinder. The diameter of the piston rod is (d_{pr}) is 0.01m. Two coils of equal lengths ($l_1 = l_2$) of 0.11 m having 5000 turns is wounded on the outer surface of the cylinder. The super enamel copper wire of 40 Standard Wire Gauge is used as winding wire.

Low noise operational amplifiers like op07 and ½-W registers with 1% tolerance are used to design inductance-

measuring circuit. On the breadboard the transducer circuit was mounted and was excited by the stabilized oscillator at 5V and 100 Hz. R_1=10KΩ and R=1KΩ. The value of self-inductance of the upper coil :- $(L_{1x})_{x=0}=a_1=KN^2/K_1 \approx 12$ H; where K=0.7 is the Nagoka's factor.

5 Experimental Setup

As mentioned in section 3 this system has different parts. The first part of the set-up, whose practical view is shown in fig 6, is utilized to study the variation of self-inductance of each coil for

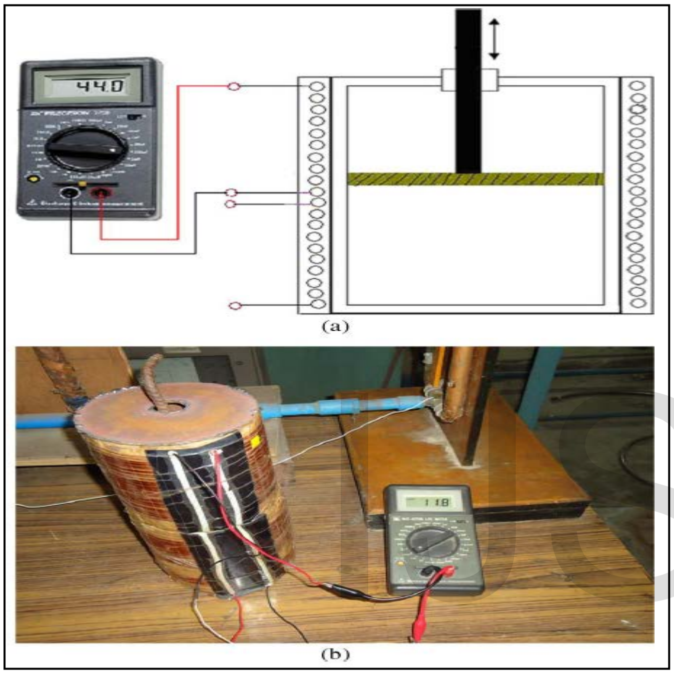


Fig 6: Experimental setup of first part of the system. (a) Schematic view of the set-up (b) Practical view of the first part

different position of the piston. Inside the cylinder the position was changed in step and each step the corresponding self- inductance was measured with the help of a digital LCR meter. The static characteristics graph i.e. self-inductance vs. piston displacement was plotted for upper as well as lower coil.

The second part of the set-up mainly deals with the conditioning of the signal and has wide usage of op-amps. The set-up is shown in fig.6.The position sensing inductance coil signal is connected to this part of the circuit as the feedback path of the op-amps A_1 and A_2 which is previously shown in fig 2. This part of the circuit is excited by a sinusodial oscillator at 5V 100Hz.with the step increse in the piston of power cylinder, the differential voltage output (ΔV) of the sensing circuit. The transducer static charecteristics curve is also drawn by plotting output agains piston position.

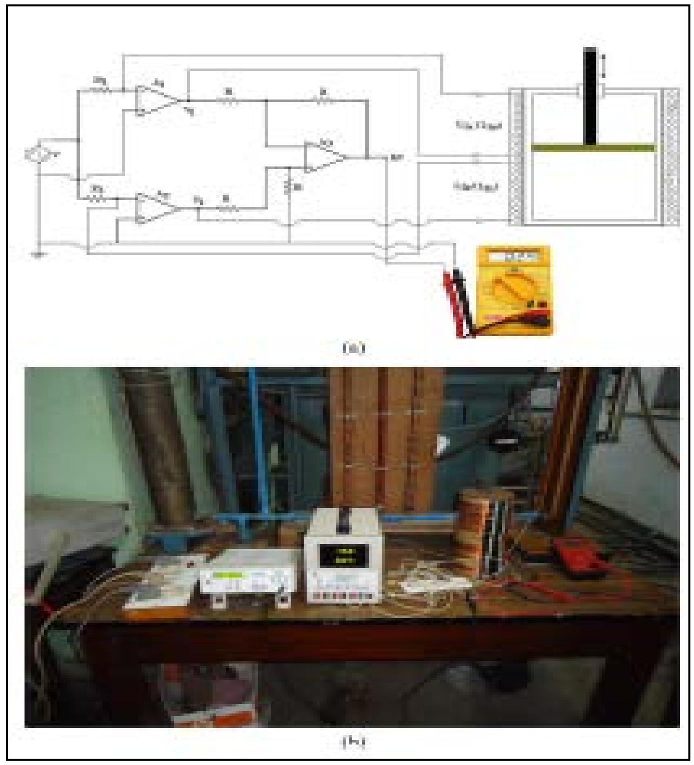


Fig: 7: Experimental set-up of second part of the system (a) Schematic view of the experiment set-up (b) Practical view of the second part.

6 Experimental Result

As the experiment was carried in two parts firstly the self inductance pick up part and secondly the signal conditioning The results of the first and second are plotted separately. The result for upper coil and lower coil are shown in fig 8. Static characteristics, respective percentage deviation curves from linearity standard deviation curves of measured data which are six set of repeated experiment in both increasing and decreasing modes for the two coils. The second part of the experimental results are also shown in Fig. 8. In Fig. 8(a) the static characteristics curves of the proposed transducer is shown and in Fig. 8(b) shows the percentage deviation curve from linearity of proposed transducer. The standard deviation of six repeated experiments in both increasing and decreasing modes of the proposed transducer is shown in Fig. 8(c). The experiments were carried out keeping in mind the practical working atmosphere of the system. The experiment aiming for Static characteristics of position transducer were also conducted and the readings were taken in the same way as before correspondingly graph was also ploted defining static charecteristics, percentage deviation, standard deviation as shown in fig 9.

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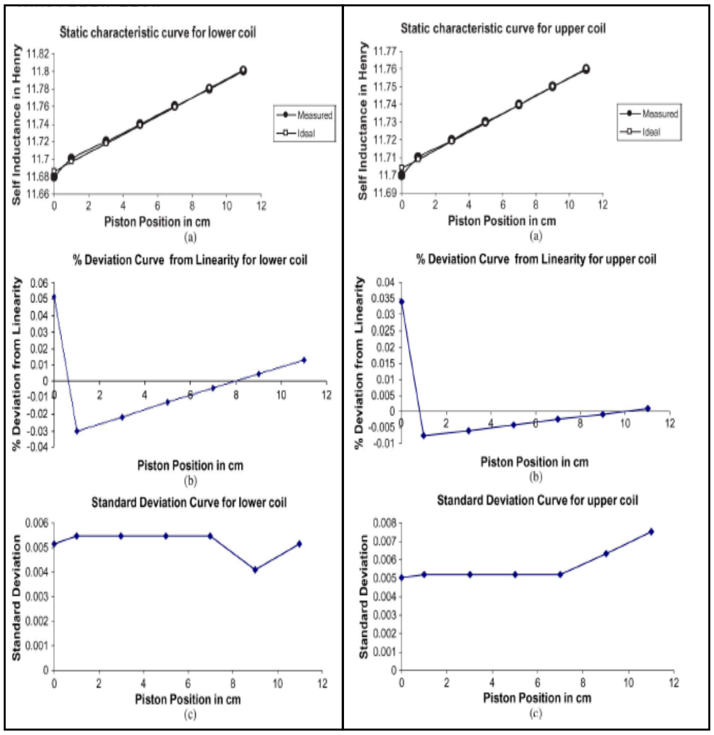

Fig 8: Static characteristics for lower coil. (a) Coil Characteristics (b) Percentage Deviation (c) Standard Deviation.

Discussions

In this experiment the proposed position sensor is shown in Fig. 1 is a modified form of LVDT for large displacement. In the mechanism or principle it says that the output increases with the increase of displacement. The linearity of LVDT depends on the excitation of the voltage and frequency of the primary windings. But in this proposed technique no excitation is required. Thus the design of the proposed sensor is simpler and more over the range of linearity is more than LVDT. As the output of LVDT depends on differential voltage and the output of the sensor depends on differential inductance.

Conclusion

A noncontact method of position measurement of piston inside a power cylinder with very good linearity and repeatability is provided by this proposed technique. It is advantageous over the conventional LVDT.

Due to different inductance measurement technique, the errors due to edge effect, mutual inductance effect etc. are equal in two identical coils and they cancel each other. The op-amp based technique reduces errors for stray capacitance effect between the two sensing coils.

The only disadvantage is that the feedback path of the op-amp provides derivative action to the input signal, and if proper precautions are not taken, the op-amp may get damaged. But this effect is also minimized by using high value input resistance.

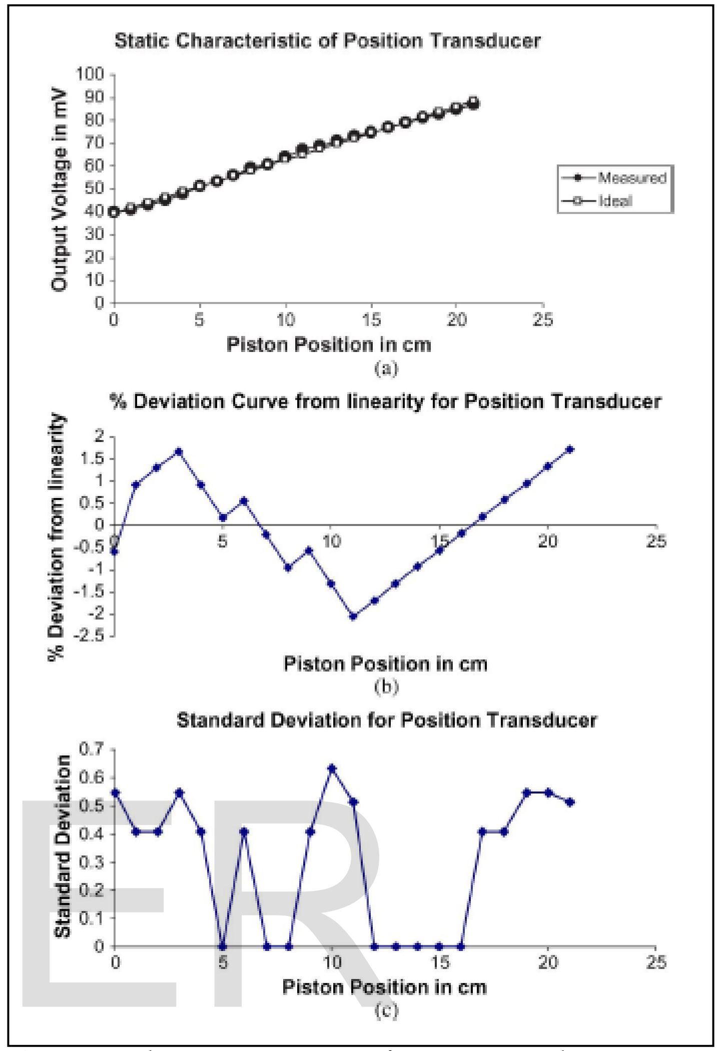

Fig 9: Static characteristics curves of Position Transducer

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