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Research Article

A modified technique of displacement measurement of a piston made of magnetic material inside a cylinder

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ABSTRACT

Movement of piston inside a cylinder has many applications in industries and measurement of its displacement inside the cylinder is very much important to study its operation and control. In the present paper a non contact type displacement measurement technique of a piston made of magnetic material inside a cylinder has been proposed. In this technique, the difference of inductances of two identical coils wound outside a cylinder due to movement of piston inside it has been found to be linearly related with the displacement. A modified differential inductance measurement circuit has been designed to develop the proposed displacement transducer. The design of the circuit along with principle of operation has been described in the paper. The operation of the proposed circuit has been experimentally studied and the experimental results are reported in the paper. The proposed transducer has been found to have very good linearity and repeatability.

1. Introduction

A piston inside a cylinder is generally made of ferrous materials or alloys which have high values of permeability. Measurement of the displacement of this piston and its transmission to a remote receiver is very important in order to monitor the actual performance of the equipment as well as to control the position of the piston. There are different well recognized techniques [1] of displacement measurement. In proximity pick up type technique the change in capacitance between a fixed metallic plate and a movable plate placed on the target is measured. In inductive pick up type technique the change in inductance of a fixed pick up coil due to the movement of ferromagnetic material fixed on the target is measured. Various works are still being reported to measure linear and angular position of a moving object from very small to large displacement. A non contact position sensor based on saturation of magnetic circuit has been proposed by Legrand et. al [3]. In this technique self inductance change of a coil wound on a saturable core is measured with the change of position of a permanent magnet used as target. The static characteristic of the sensor has an exponential nature due to the presence of eddy current. This non linearity has been removed by differential inductance measurement technique. Seco et. al [4] have proposed a novel design of a magnetostrictive linear position transducer for long range of applications. The proposed sensor is based on the measurement of time of flight of ultrasonic waves generated in a ferromagnetic waveguide. Dinulovic and Gatzen [5] have utilized the self inductance variation property of a coil with movable core material for measuring microscopic order displacement. A Hall sensor array has been utilized by Marschner and Fischer [6] to measure the position of the movable object fixed with a bar magnet. Andersson et. al [7] processed a transparent p–n junction sensor of visible light with indium tin oxide gate contact and have described how this device can be used as position sensor. Rovati et. al [8] have used a high performance opto-electronic system to minimize the measurement error and uncertainty in conventional optical encoder type angular position measurement system. George et. al [9] have developed a linear variable differential capacitive transducer for planner angular displacement measurement for the entire range of 0–360°. They have used relaxation oscillator based signal conditioning circuit to obtain the high accuracy and linearity. Salles and Monteiro [10] have proposed a modified design of optical quad cell type position sensing detector, where non-linearity of quad cell has been linearized. Lee and Shiou [11] have utilized a multi beam laser probe for non contact type position and orientation measurement of freeform surface. A self inductance detection technique has been used by Jingzhuo et. al [12] to design an integrated position measurement unit for stepper motor servo control system. Stray capacitance and

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inductance effect for measurement of self inductance have been minimized by Chattopadhyay and Bera [13]. They have utilized a modified Maxwell–Wien bridge based self inductance measurement technique. Flammini et al. [14] have proposed a novel technique of position sensing using differential variable reluctance transducer which has a smaller dimension than LVDT. The sensor is attached with DSP based spectral algorithm that intrinsically overcomes the limitations related to phase shift between excitation and sensor signals. Wu et al. [15] have developed a LVDT based linear actuator inherent with sensing devices by superposition of dc currents on high frequency excitation signals. The limitations of ultrasound pulse-echo technique based displacement measurement have been overcome by Peng and Zhang [16]. They proposed a new method utilizing the clutter signal in coded excitations to determine the displacement of an object. The method includes transmitting a pair of Golay complementary sequences, receiving echoes from the object or a region of the object, compressing the pulse, eliminating the main lobe, and determining the object displacement between the two transmissions from the residual clutter signal around the main lobe of the compressed pulse. Yang and Huang [17] have reported a novel technique of measuring radial and axial displacement of a miniature magnetically levitated rotor by using six single-axis Hall-effect sensors attached to the stator with a ring shaped permanent magnet mounted on the rotor as the magnetic flux source. Vyroubal [18] has designed an eddy-current displacement transducer based on a resonant impedance inversion method of transfer curve linearization where the displacement probe circuit is kept in resonance by the resonance control loop. The probe has an automatic tuning capability and it can be used for a wide range of application. Castelli [19] has proposed a new technique of displacement measurement based on thin dielectric film capacitive type transducer and has got a very god sensitivity and linearity.

In the present paper a modified non contact displacement measurement technique has been developed to measure the displacement of a piston inside a cylinder. Two identical coils wound on the cylinder have been shown to have different inductances due to the movement of the piston inside the cylinder. The difference between these two inductances has been found to be linearly related with the displacement of the piston. The necessary theoretical equations in support of this property have been derived and reported in the paper. A modified displacement transducer has been designed and developed utilizing this principle. The transducer has been functionally tested and has been found to follow the developed theoretical equations. A good linearity and repeatability of the transducer has been observed.

2. Method of approach

Let us consider a hollow circular cylinder wound with two identical coils in the upper half and lower half of the cylinder. A piston made of ferromagnetic material moves inside the cylinder as shown in Fig. 1(a) with its photographic view shown in Fig. 1(b).

When the piston is in the upper half of the cylinder at a distance x from the upper surface of the cylinder the self inductance of the upper coil is

$$L_{1x} = a_1 + b_1 x \tag{1}$$

where a_1 and b_1 are constants with each directly proportional to the square of the number of turns (N) of the coil.

Under this condition the inductance of the lower coil is given by

$$L_{20} = \frac{KN^2}{R_{20}} \tag{2}$$

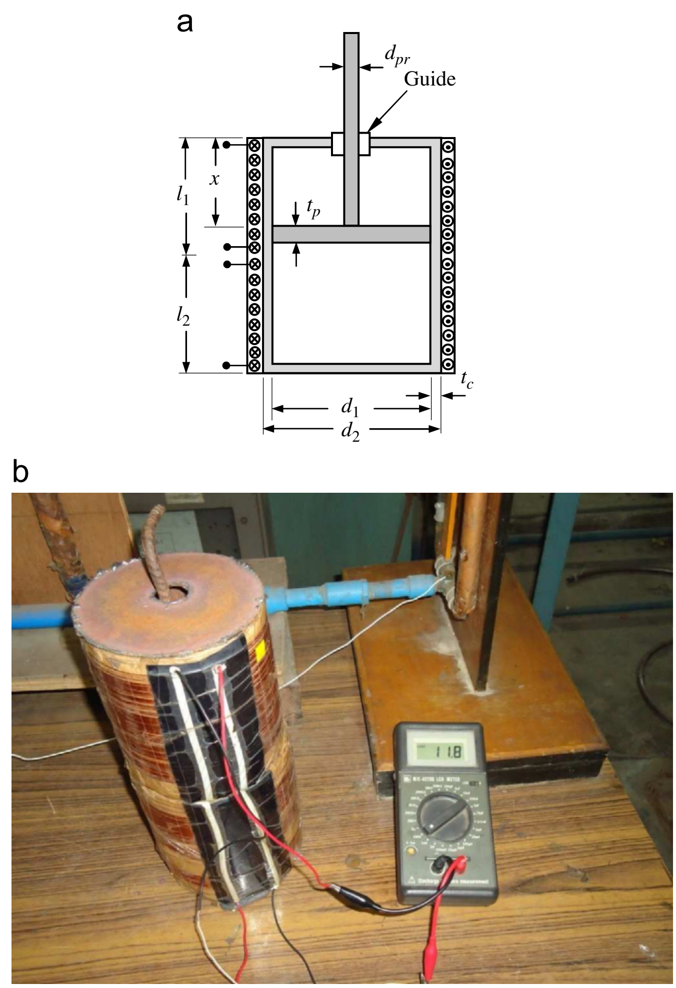

Fig. 1. (a) Schematic diagram of proposed displacement sensor. (b) Photographic view of proposed displacement sensor.

where K is constant and R_{20} is the reluctance of the magnetic circuit for the lower coil.

Hence when the piston is in upper half of the cylinder the difference in self inductances between the two coils is given by

$$\Delta L_{upper} = L_{1x} - L_{20} = (b_1 x + a_1 - L_{20}) \tag{3}$$

Similarly when the piston is in the lower half of the cylinder the self inductance of the lower coil is given by

$$L_{2x} = a_2 + b_2 x \tag{4}$$

where a_2 and b_2 are constants each being proportional to the square of the number of turns (N).

Under this condition the self inductance of the upper coil is given by

$$L_{10} = \frac{KN^2}{R_{10}} \tag{5}$$

Therefore, when the piston is in lower half of cylinder the difference in self inductances between the two coils is given by

$$\Delta L_{lower} = L_{10} - L_{2x} = -(b_2 x + a_2 - L_{10}) \tag{6}$$

So from (3) and (6), it is found that the differential inductance varies linearly with the displacement of the piston from the upper surface of the cylinder.

To measure the self inductance difference (ΔL_{upper} and ΔL_{lower}) an operational amplifier based differential inductance measurement