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Temperature Influence on Position Transducer for Pneumatic Cylinder

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***Abstract*—In this paper, temperature sensitivity of inductance position transducer of a pneumatic cylinder system is presented. The magnetic solid iron rod and aluminum piston position changes the inductance of the tubular coil around the aluminum pneumatic cylinder. The measurement and finite element method are used to evaluate inductances versus piston position at different frequencies. Temperature effect on the coil inductance is analyzed. Temperature of the iron rod and the aluminum cylinder are changed for the temperature sensitivity analysis. The measured temperature dependence is in the order of 0.5 %/°C. Finally a small compensating solenoid coil is used at one side of the cylinder (entrance side for piston) to compensate temperature dependency effects.**

Keywords—temperature; transducer; pneumatic; cylinder

I. Introduction

Different methods for the piston position sensing are used with internal and external sensors. Internal sensors inserted into the piston rod are mechanically complicated and expensive and not reliable. The same problem applies for the microwave and optical sensors inside the cylinder [1]. External sensors with permanent magnet on the piston can be used for aluminum cylinder. Using permanent magnets has disadvantages. The first disadvantage is that these sensors require non-magnetic stainless steel rod, which is expensive. The non-magnetic iron rod is used to avoid distorting of permanent magnet fields. Second disadvantage is difficult mounting of permanent magnet on the piston. Third disadvantage is high temperature dependency of permanent magnet fields. We recently developed AC contactless piston position transducer with axial excitation and detection of radial magnetic field associated with the end of rod made of magnetically soft iron. The disadvantage of this sensor is its short linear stroke which leads to the necessity of using linear sensor array, making the device rather complicated [2]. In order to improve previous method, we returned to the simple concept of variable inductance sensor. This type of sensor was already used for hydraulic cylinders with composite non-conductive shell [3]. We have shown that variable inductance sensors can also be used to measure position of the piston in pneumatic cylinder with aluminum shell. The inductance of the solenoid wound on outer surface of the cylinder is changing with piston position even though the cylinder is made of conducting material, which partly shields the AC field [4].

In this paper, theoretical analysis and experimental results of piston position transducer for pneumatic cylinder are presented. The inductance of axisymmetric wound solenoid around cylinder is used for piston position measurement. Temperature dependency of inductance is investigated at different piston positions and solenoid excitation frequencies. 2D axisymmetric time harmonic finite element method (FEM) is used for theoretical inductance analysis of solenoid coil on the outer surface of the conducting cylinder. The FEM inductance calculations and comparison with experimental results could help for better understanding of physics of inductance analysis. The calculations and measurement are performed at different temperatures of cylinder-piston system components to analyze sensitivity of inductance versus temperature and to select optimum excitation frequency.

II. Inductance Transducer of Pneumatic Cylinder

Fig. 1 shows the schematic model of inductance transducer for pneumatic cylinder. It shows that magnetic iron rod and piston movement changes magnetic reluctance for the coil flux, which affects inductance of the coil. Iron rod length, iron rod diameter, aluminum cylinder length, aluminum cylinder outer diameter, aluminum cylinder thickness, aluminum piston thickness and number of turns of mail coil are 700 mm, 20 mm, 500 mm, 60 mm, 2 mm, 10 mm and 800, respectively. The electrical properties of iron rod and aluminum cylinder versus temperature are given as following:

$$
\begin{aligned}
&\rho_{\mathrm{i}}(\theta^{\mathrm{o}}\mathrm{C}) = \rho_{\mathrm{i}}(20^{\mathrm{o}}\mathrm{C})\cdot(1+c_{\mathrm{i}}\cdot(\theta-20))\\
&\rho_{\mathrm{i}}(20^{\mathrm{o}}\mathrm{C}) = 22.18\cdot10^{-8} \rightarrow \sigma_{\mathrm{i}}(20^{\mathrm{o}}\mathrm{C}) = 4.509\,\mathrm{MS/m}\\
&c_{\mathrm{i}} = 0.0027356\\
&\rho_{\mathrm{Al}}(\theta^{\mathrm{o}}\mathrm{C}) = \rho_{\mathrm{Al}}(20^{\mathrm{o}}\mathrm{C})\cdot(1+c_{\mathrm{Al}}\cdot(\theta-20))\\
&\rho_{\mathrm{Al}}(20^{\mathrm{o}}\mathrm{C}) = 3.28\cdot10^{-8} \rightarrow \sigma_{\mathrm{Al}}(20^{\mathrm{o}}\mathrm{C}) = 30.5\,\mathrm{MS/m}\\
&c_{\mathrm{Al}} = 0.0041
\end{aligned} \tag{1}
$$

The relative magnetic permeability of the soft iron used for the piston rod at low magnetic fields was estimated as 50 to 100, but the precise measurement would be affected by necessary machining during the preparation of the sample.

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More precise evaluation of permeability can be made by measuring the inductance as shown in the next section.

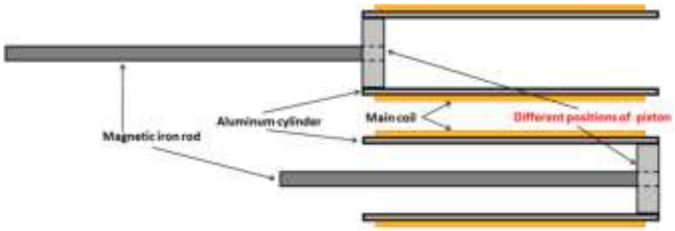

Fig. 1. Schematic model of inductance transducer for pneumatic cylinder

III. ONE PRELIMINARY EXAMPLE

In order to evaluate rod permeability, one preliminary example is analyzed before main topic of inductance transducer is presented. The model is a simple structure with short coil shown in Fig.2 and Fig. 3. First we measured and calculated inductance value of the coil without the piston rod (case 1). Then we adjusted the value of permeability so that the FEM results [5] fit the measured values of room-temperature inductance (Case 2). The resulting relative permeability was 77.5. With the same value of permeability we calculated and measured inductance at elevated temperature (case 3). The results are presented in Table. 1. The FEM results coincide well with experimental results for all three cases, showing the validity of the model and evaluated permeability. The measurements suggest that the temperature dependence of permeability plays minor role.

TABLE I. INDUCTANCES BASIC MODEL - CASE 1 : WITHOUT IRON ROD, CASE 2: WITH IRON ROD AT ROOM TEMPERATURE AND CASE 3 : WITH IRON ROD AT 68 °C

Cases	f = 100 Hz	
	Experimental **(μH)**	***FEM*** **(μH)**
1	257.5	253.0 (98.3%)
2	407.0	385.0 (94.6%)
3	415.5	390.0 (93.9%)

IV. TEMPERATURE DEPENDENCE

At very low frequencies, below 30 Hz, inductance of the long solenoid coil sensor is increasing with inserting the rod due to its permeability. However, the dependence is opposite for higher excitation frequencies: with inserting the rod the coil inductance is decreasing due to the eddy currents [4]. Fig. 4 shows the magnetic field distribution in the piston rod. Low field values allow using model with constant permeability. Despite lower sensitivity, the inductances at 100 Hz and 200 Hz are most relevant for the intended application because the values linearly change with iron rod and piston position and the response of position sensor excited at these frequencies would be fast enough to detect fast movements of the iron rod and piston position in comparison with 20 Hz-30 Hz excitation. We will show that the temperature dependence of the device is low at these frequencies. In order to understand temperature dependence of the device we separate the individual effects. The pneumatic aluminum cylinder and iron rod were heated up separately to evaluate temperature dependency of sensor inductances. Fig. 5 and Fig. 6 show that pneumatic aluminum cylinder temperature has much higher influence on sensor inductances than the temperature of the piston rod.

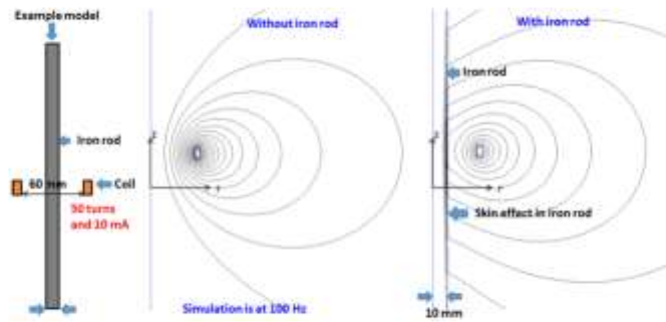

Fig. 2. The model (left), magnetic flux distribution without iron rod (middle) and magnetic flux distribution with iron rod (right)

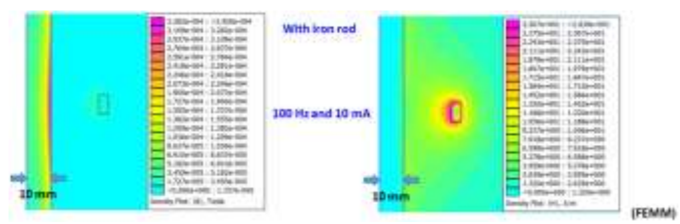

Fig. 3. Magnetic flux density distribution (left) and magnetic field strength distribution (right)

The FEM results for inductances show same tendency versus temperature. Only cylinder and iron rod electrical resistivity have been changed in FEM, which shows iron relative magnetic permeability has not been affected by changing temperature.

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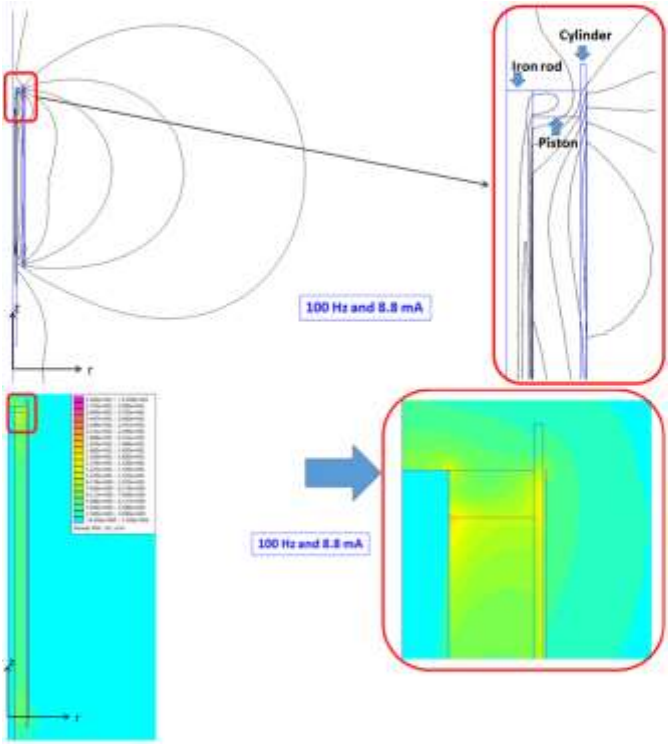

Fig. 4. Magnetic flux distribution (up) and magnetic field strength distribution (bottom) in inductance transducer of pneumatic cylinder

The signal from the short compensation coil located at the beginning of the cylinder can be used to compensate for the temperature effects. Fig. 7 shows that with the exception of the beginning area, the inductance of this coil does not depend on the piston position. The number of turns in the compensating coil is 10 and inductances values are in μH. The compensating coil inductance versus iron rod temperature is shown in Fig. 8, when iron rod and piston position is at end of cylinder. The compensating coil inductances linearly increase with temperature. The linear changing of compensating inductance versus temperature helps to find iron rod temperature and compensate main coil inductance error at higher temperatures.

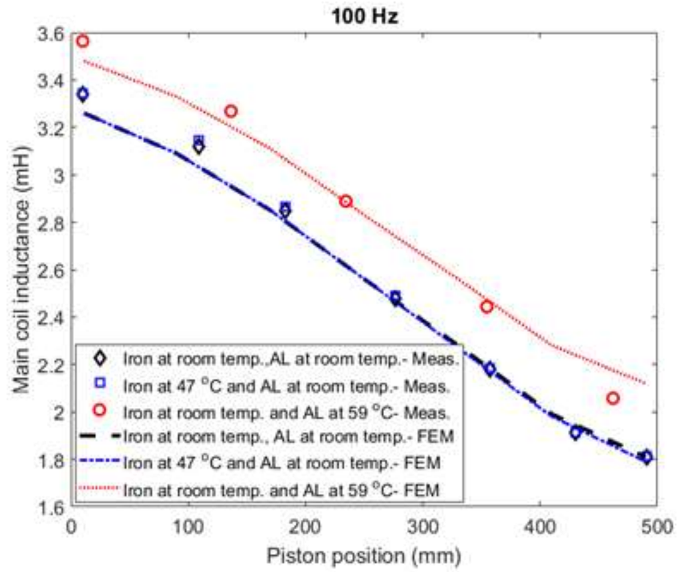

Fig. 5. Inductances at different temperatures for main coil - 100 Hz

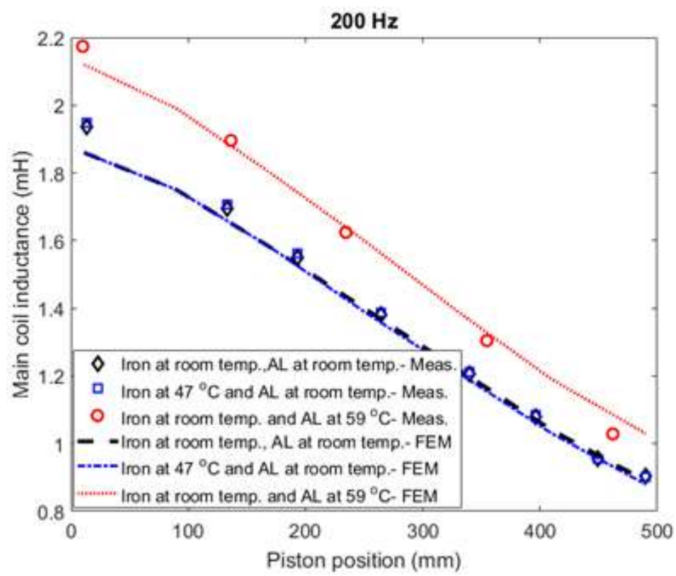

Fig. 6. Inductances at different temperatures for main coil - 200 Hz

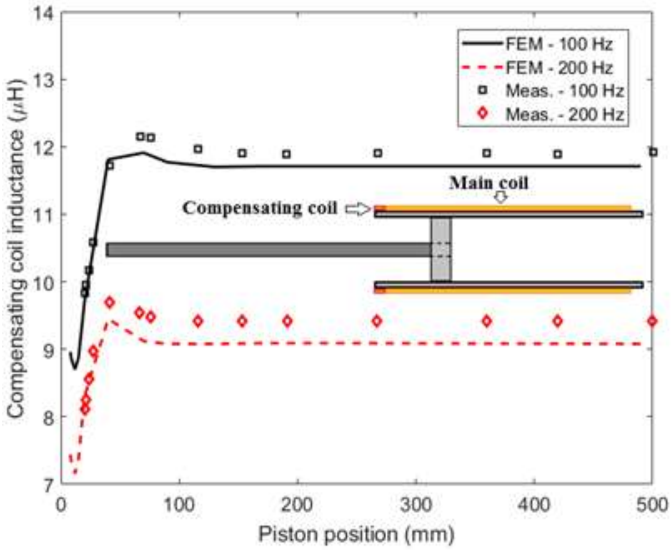

Fig. 7. Inductances versus piston position for compensating coil

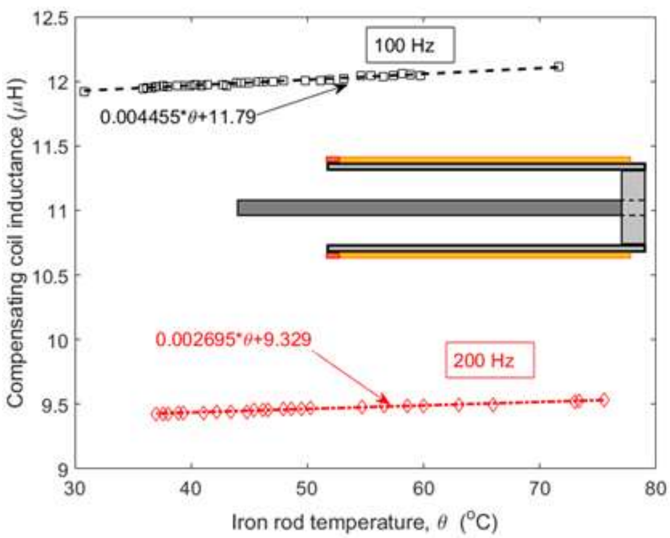

Fig. 8. Inductances versus iron rod temperature for compensating coil - measurement

V. Conclusions

We evaluated temperature dependence of inductive position sensor for piston in pneumatic cylinder. FEM calculation results coincide well with the measurement. The electrical conductivity temperature dependence is the main factor in the inductance variation versus temperature. The iron rod permeability variation effects versus temperature are negligible. The device is less temperature dependent for higher excitation frequencies, but the temperature dependence is very high in the order of 0.5 %/°C. The main coil inductance variation versus temperature can be corrected using compensating coil because compensating coil inductance is less dependent on the iron rod and piston position and depends linearly on temperature.

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