Sensors and Actuators A 229 (2015) 42–49

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

The theoretical and experimental investigation on the vertical magnetic fluid pressure sensor

Jun Xie, Decai Li*, Yansi Xing

School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Article history:
Received 8 October 2014
Received in revised form 4 March 2015
Accepted 4 March 2015
Available online 12 March 2015

Keywords:
Vertical
Magnetic fluid
Pressure sensor

ABSTRACT

In this paper, an innovative pressure sensor exploiting magnetic fluid is presented. The device consists of a compound magnetic core, a glass pipe and a couple of sensing coils. The sensing coils detect the position of the compound magnetic core at a particular frequency. Then a theoretical analysis of the sensing methodology is performed, along with experiments on the laboratory-scale prototype of the vertical magnetic fluid pressure difference sensor. The open type magnetic fluid pressure sensor shows the satisfactory linearity and high reliability, and the enclosed type exhibits the characteristics of wide-range and low-cost. All these results indicate the feasibility of the vertical magnetic fluid pressure sensor.

1. Introduction

A deep research of the magnetic fluid sensor indicates the possibility of adopting the magnetic fluid and compound magnetic core to develop the promising magnetic fluid sensor. Magnetic fluid is composed by colloidal suspensions of ultrafine (5–10 nm) single-domain magnetic particles [1], which possesses both ferromagnetism of solid and flow property of liquid. There are many application fields of magnetic fluid, such as magnetic fluid damper [2], magnetic fluid sealing [3], magnetic fluid sensor [4,5] and so on.

Magnetic fluid sensor is a relative novel application field among them. In the literature, more and more sensors adopting magnetic fluid have been proposed. A successful example of inclinometer has been presented by Olaru and Dragoi [6]. The device consists of a mobile compound magnetic core inside the cylinder. The magnetic fluid is attached on both ends of the core to reduce the friction and make the movement of the core smoothly. Two magnets outside the cylinder are used to provide restoring force to the compound magnetic core. The compound magnetic core will move if the cylinder tilts. In addition to this device, another architecture of the inclinometer is studied in 2007 [7], what presented in this paper is a new configuration that exploits two exciter coils to move the magnetic fluid drop around its equilibrium position. This strategy prevents the adhesion of the magnetic fluid to the pipe and reduces the friction. What is more, a low-cost inertial sensor based on shaped magnetic fluid has been researched in 2012 [8]. The device consists of a glass pipe filled with deionized water where a mass of magnetic fluid is fixed to the pipe to form a spike, which is located by a suitable magnetic field. The free end of the spike will move if there is an external perturbation, which will be sensed via an infrared readout strategy.

All these experiments show the feasibility of adopting magnetic fluid to sensors. The magnetic fluid pressure sensor has been researched since 1992 [9] by De Sabata et al. The principle of the sensor has been presented in the paper. There are identical coils on the two arms of the U-tube. When a pressure difference applied, there will be a height difference of the magnetic fluid in the two arms, which will break the equilibrium of the bridge circuit. Then there will be an output voltage. In a particular range there is a linear relationship between the pressure difference and the output voltage.

The advantage of the magnetic fluid pressure sensor presented above is the satisfied linear relationship between the input pressure and the output voltage in the whole measuring range. Meanwhile, the disadvantage of the sensor is obvious too. The size of the magnetic fluid pressure sensor presented above is big, and the usage amount of the magnetic fluid is big, which will increase the cost of the device. Moreover, the relative permeability of the magnetic fluid is just a little bigger than the air, so the inductance change caused by the position of the liquid level is small, which makes the output voltage signal not obvious enough.

In this paper, an innovative vertical magnetic fluid pressure sensor is presented. Then a theoretical analysis of the sensing methodology is performed, along with experiments on the laboratory-scale prototype of the vertical magnetic fluid pressure

* Corresponding author. Tel.: +86 13651206606; fax: +86 01051684006.
E-mail address: dcli@bjtu.edu.cn (D. Li).

http://dx.doi.org/10.1016/j.sna.2015.03.007
0924-4247/

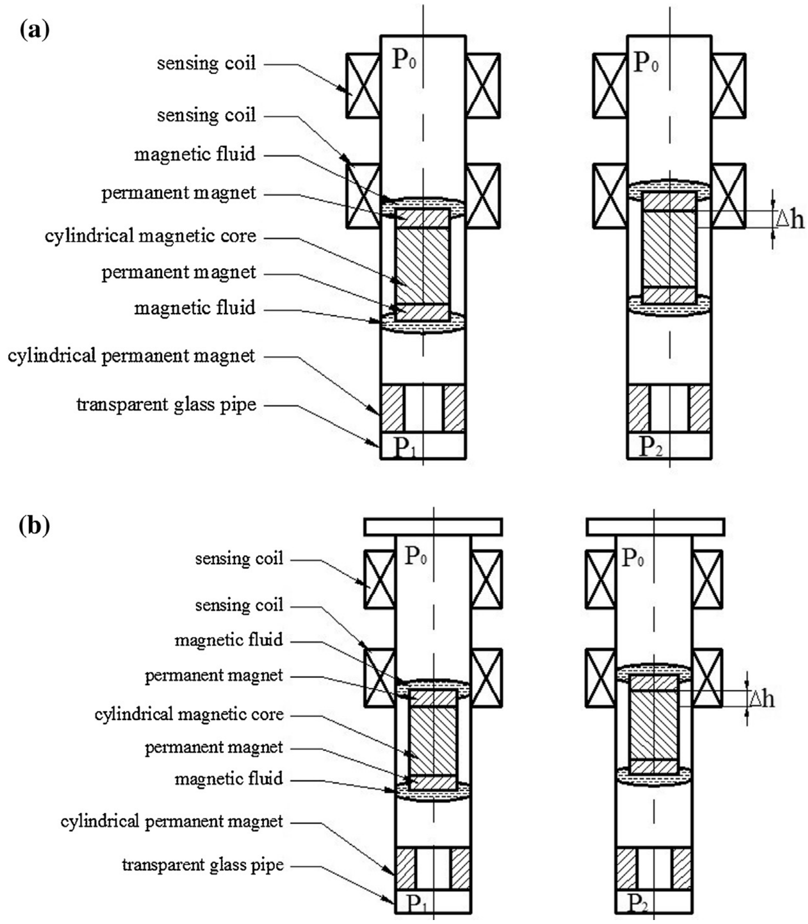

Fig. 1. The schematic diagram of the vertical magnetic fluid pressure difference sensor. (a) Open type and (b) enclosed type.

difference sensor. The open type magnetic fluid pressure sensor shows the satisfactory linearity and high reliability, and the enclosed type exhibits the characteristics of wide-range and low-cost. The measuring range of the enclosed type sensor is ten times than the open type sensor.

2. The structure of the vertical magnetic fluid pressure difference sensor

The structure of the vertical magnetic pressure sensor is presented in Fig. 1(a) stands for the open type sensor, and (b) stands for the enclosed type sensor. The structures of the two types are identical except the top ends of the pipes, just as shown in Fig. 1. There is a through-hole on the axis of the cylindrical permanent magnet, which is used to provide magnetic force to suspend the compound magnetic core in the glass pipe. The external diameter of the cylindrical permanent magnet is equal to the inner diameter of the glass pipe. The magnetic fluid adheres at the two permanent magnets, thus ensuring sustaining and sliding the compound magnetic core along to the recipient and sealing. The material of the cylindrical magnetic core is 1Cr13 with high permeability, which constitutes the compound magnetic core together with the permanent magnets. The number of windings, size and inductance of the two sensing coils are identical. The two sensing coils are connected to a bridge circuit to output signal as a sensing strategy.

At the initial state, the position of the compound magnetic core is shown in the left part of Fig. 1(a) and (b). The upper surface of the magnetic core is parallel with the lower surface of the sensing coil. The intensity pressure of the two sides of the compound magnetic core is equal. Because the inductances of coils satisfy $L_1 = L_2$, the output signal of the bridge circuit is zero unless we take the magnetic fluid and the permanent magnet into account. When the lower pressure increases, the compound magnetic core will move upward, and then the magnetic core will enter into the sensing coil. Because of the high permeability of the magnetic core, just as what is shown in the right part of Fig. 1(a) and (b), the inductance of the under coil increases, and then the balance of the bridge circuit is broken, which will lead to the output voltage signal ΔU. The output voltage increases with the height Δh.

The compound magnetic core is shown in Fig. 2, which is consist of magnetic core 1Cr13 in the middle and the permanent magnets on both ends. The magnetic fluid is absorbed on the magnets. Two identical induction coils wind on the glass pipe, and the compound magnetic core suspends in the glass pipe with the action of the permanent magnet ring. Then the final magnetic fluid pressure sensor is presented in Fig. 3.

Then we connect the final model with appropriate circuit to form the integral experiment table of the sensor, which is shown in Fig. 4. The signal generator is used to provide alternating current for the sensing coils. The linear power source is used to provide direct current for the measuring circuit. The voltmeter is used to show the output voltage signal. The tube standing is used to fix the sensor and ensure it is vertical. The pressure is exerted through a rubber pipe. The measuring and amplifying circuit is used to process the output voltage signal. Both of the pressure gages are used to standardize.