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Research Status and Development Trend of Magnetic Fluid Micro-differential Pressure Sensor

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As a nano-scale composite functional material, the basic structure of the new magnetic fluid is to uniformly disperse the magnetic solid particles adsorbed with surfactants into the base liquid, thus forming a stable colloid system with high dispersion. Magnetic fluid can exist stably for a long time even under the action of gravity field, magnetic field and electric field without precipitation and separation. This kind of magnetic fluid has both magnetic and liquid fluidity under the action of magnetic field, so it has great potential for the application of magnetic fluid in the field of sensors. This paper mainly analyzes the research achievements of magnetic fluid in the neighborhood of micro-differential pressure sensor at home and abroad in recent years, and introduces the working principle and latest research progress of magnetic fluid sensor. Thus, making use of the special properties of magnetic fluid, it is applied to some problems in the field of micro-pressure difference sensor and the research direction of magnetic fluid micro-pressure difference sensor in the future.

Keywords: Magnetic liquid; micro pressure difference; materials performance; sensor.

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1. INTRODUCTION

In the 21 century. We were brought to the information age and ushered in the revolution of sensor, communication and computer technology. These are now widely used in various fields that we are familiar with. For example, the (Falcon Heavy) carrier rocket launched by Mr. Musk SpaceX two years ago, especially in the most difficult launch phase, requires a large number of sensor technology to feedback the delivery system in real time; To keep in touch with ground personnel at all times using communication technology; And to make timely data processing and adjustment through computer technology. There is also China's deep-sea probe Endeavour, which also relies heavily on sensors, communications and computers to make it dive to a depth of

less than 10000 meters. Even all kinds of detection and control appliances in family life are inseparable from the application and development of sensors. Nowadays, on the basis of superconducting materials, optical fibers and other new materials, the application of nano-material technology to the field of sensors has become a hot issue of international research. As a new type of nano-functional material, magnetic fluid has many characteristics needed by sensors, so it attracts more and more researchers to study and explore it.

Micro-pressure difference (micro-pressure difference in the range of ±60kPa) is one of the commonly used physical parameters in the field of modern engineering. The piezoresistive, quartz crystal and capacitive sensors in the traditional micro-pressure difference sensors have great limitations and poor detection accuracy in engineering [1]. If the fluidity and magnetism of magnetic fluid are applied to the technical research of micro-differential pressure sensor, will it improve the shortcomings of conventional micro-differential pressure sensor, the development of magnetic fluid micro-differential pressure sensor with better performance is of great research significance. This paper mainly summarizes the achievements and latest progress of magnetic fluid micro-differential pressure sensor, and analyzes the working principle of all kinds of magnetic fluid micro-differential pressure sensor and its application in different fields. this paper describes the structural characteristics, advantages and disadvantages of each type of micro-differential pressure sensor, and puts forward the deficiency of the application and research of magnetic fluid in the field of micro-differential pressure sensor and the prospect of the development direction of magnetic fluid micro-differential pressure sensor in the future.

2. MAGNETIC FLUID

2.1 Brief Introduction of Magnetic Fluid

Magnetic fluid, as its name implies, literally means that it contains magnetic particles (below 10nm), flowing base liquid (which can be water, engine oil, kerosene, phosphodiester, synthetic oil, etc.), and surfactants, which are mixed into stable colloidal solutions that do not precipitate and accumulate because of the gravity or magnetic force of the magnetic particles themselves [2]. Among them, the tiny nano-sized magnetic particles are encapsulated by interfacial active agents, so that they are uniformly dispersed in the carrier solution. In many fields such as machinery, sealing, sensor, lubrication and chemical industry, magnetic fluid, as a kind of nano-material with both solid magnetism and liquid fluidity, naturally has a very wide application prospect. As shown in Fig. 1. The magnetic fluid is mainly composed of: 1 Magnetic particles, 2 Surfactant, 3 Base carrier liquid.

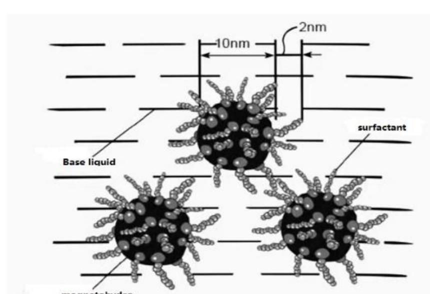

Fig. 1. Schematic diagram of magnetic liquid structure

2.2 Development and Research Status of Magnetic Fluid

The concept of magnetic fluid was boldly put forward by Gowan Knight in 1778. It was not until the 1960s that American researchers successfully prepared a stable magnetic fluid using oleic acid as surfactant, successfully applied the magnetic fluid to the sealing of some positions of spaceships and spacesuits, and applied for the first patent for the preparation of magnetic fluid with practical application in the world. Almost at the same time, in 1964, American researchers J.Neuringer and R.E.Rosensweig made great progress in the study of magnetic fluid thermodynamics and hydrodynamics, and published Ferrohydrodynamics articles, which laid the foundation of magnetic fluid dynamics [3]. In the 1980s, the book was published and systematized the theory of magnetic fluid into an independent discipline [4].

The first International Conference on Magnetic Liquids, held since 1977, promoted the research on magnetic liquids and their application technologies. After several international conferences, the research on magnetic liquids has been divided into many different disciplines [5]. For example, using the inherent characteristics of magnetic fluid itself to seal, lubricate and shock absorption in the field of machinery; Using the motion characteristics of magnetic fluid, it is applied to metering valve, flow regulating valve, compressor, medical contrast agent and so on; In addition, the superparamagnetic and electromagnetic response characteristics of magnetic fluid are applied to the field of sensors, such as acceleration sensor, magnetic fluid vibration sensor, micro differential pressure sensor, inclination and level sensor, in fig. 2 (a b c d).

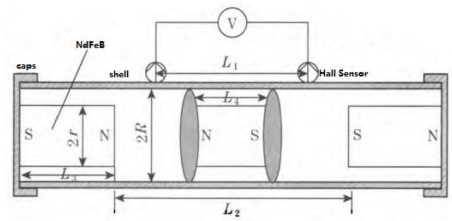

Fig. 2a. Magnetic liquid inertial sensor

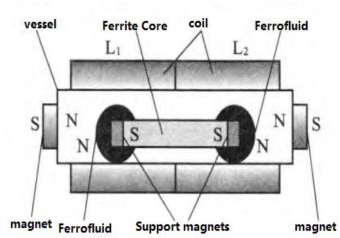

Fig. 2b. Magnetic liquid tilt sensor

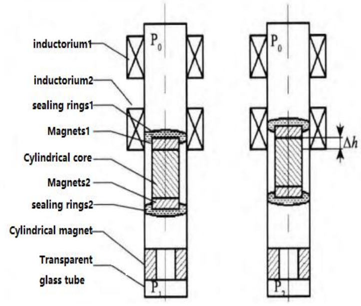

Fig. 2c. Magnetic liquid microdifferential pressure sensor

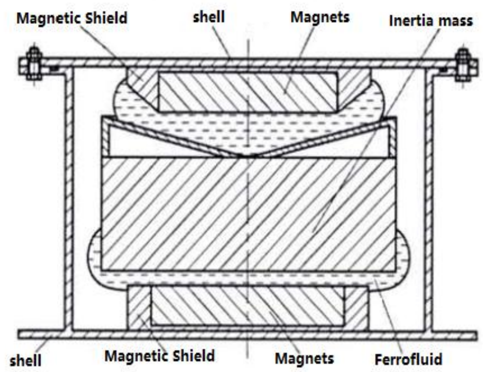

Fig. 2d. Magnetic liquid shock absorber

3. MAGNETIC FLUID MICRO-PRESSURE DIFFERENCE SENSOR

Sensor technology,computer technology and communication technology are the three pillar fields of modern information technology, among which developed countries, mainly led by the United States and Japan, have been competing for commanding heights in these three technological fields [6]. Now all kinds of sensors are used in a variety of ways, and the selection of sensor materials is endless. The key point of the cha-cha sensor technology is the selection of the sensor material itself. as a new type of nano-material, magnetic fluid has been applied in various fields. With the rapid application and development of sensor technology, if combined with new magnetic fluid materials and making use of the magnetic function advantages of magnetic fluid itself, it will certainly make the sensor technology leap to a new level.

3.1 Development of Magnetic Fluid Micro-differential Pressure Sensor

The design principle of magnetic fluid sensor is based on electromagnetic induction, using magnetic fluid, a nano-material with both solid magnetic and liquid flow characteristics, as a sensitive medium. At present, there are many kinds of sensors made by using the special properties of magnetic fluid. According to the different detection forms, it can be divided into magnetic fluid acceleration sensor, magnetic fluid micro-pressure difference sensor, magnetic fluid tilt sensor and so on. At present, the accuracy and stability of the widely used micro-pressure difference sensor in micro-pressure difference measurement need to be improved. From the analysis of the principle of material characteristics, the magnetic fluid micro-pressure difference sensor can not only improve the measurement sensitivity and stability, but also make up for the shortcomings of the conventional micro-pressure difference sensor and improve the performance of the traditional sensor. in order to achieve the goal of simple structure and low cost. The concept of combining magnetic fluid with sensor was put forward by American scholar R E Renswei in 1969 when he tried to use magnetic fluid as the magnetic core of accelerometer [7]. Since then, a series of studies conducted by many researchers have failed to fully combine the two. From 1985-1989, the publication of international papers on magnetic fluid reached its peak.

3.2 Research Status of Magnetic Fluid Micro-differential Pressure Sensor Abroad

In 1992, Romanian researchers led by N C Popa carried out research on the application of magnetic liquid to micro-differential pressure sensor based on magnetic liquid acceleration sensor [8].After continuous exploration and research, keen scholars boldly proposed to take the U-shaped glass tube as the carrier of magnetic liquid, through the change of pressure at both ends of the glass tube, the magnetic liquid in the U-shaped glass tube will move up and fall, resulting in the height difference of liquid level. The height difference of the magnetic liquid will cause the completely symmetrical inductance coils at both ends of the U-shaped tube to generate different electrical signals to represent small pressure changes, as shown. Figure 3. Firstly, uniform, symmetrical and equal turns coils are wound at both ends of the U-shaped tube. When the pressure of the two arms of the

U-shaped tube is different, the pressure difference will be generated. At this time, the height difference of the liquid level of the magnetic liquid will lead to the change of the initial inductance at both ends. The inductance coil wound around the glass tube is used to sense the fluctuation of the volume of magnetic liquid to generate induction coefficient, which is converted into electrical signal to feedback real-time detection and measurement of micro-differential pressure [9].

Roger N.Hastings et al. put forward a magnetic liquid vascular pressure sensing device in 2011, as shown in fig 4, which is mainly characterized by small volume and high precision. Often used in medical equipment, it is intuitive to monitor blood pressure changes in real time in cardiovascular and cerebrovascular surgery, which is of great significance for medical treatment. The main structure of the magnetic fluid pressure sensor is as follows: the magnetic sensitive element is fixed inside the sensor, the permanent magnet absorbs magnetic fluid and is separated from the sensitive element by a certain distance, and a certain amount of compressible fluid is sealed between the magnetic sensitive element and the permanent magnet to ensure that the permanent magnet can freely slide axially in the tube [10].

3.3 Research Status of Magnetic Liquid Micro-pressure Difference Sensor in China

After 2000, the research on magnetic fluid sensors began gradually in China, but compared with Romania, the United States and Japan, there is still a big gap in the research on magnetic fluid micro-pressure difference sensors. Since 2013, the team of Beijing Jiaotong University and Tsinghua University Magnetic Liquid Laboratory headed by Li Decai has made continuous research and experiments on the application of magnetic liquid in the field of micro-pressure difference sensors, and successfully prepared magnetic liquid micro-pressure difference sensors with different materials [11]. The following is a brief introduction of several relatively novel and typical magnetofluid micro-pressure difference sensors.

In 2014, the Magnetic fluid Laboratory of Beijing Jiaotong University initially developed and manufactured a magnetic fluid micro-pressure difference sensor that uses mutual inductance reaction to measure, a new type of mutual inductance magnetic fluid micro-pressure difference sensor [12]. The working principle of the device is as follows: the excitation coil is wound in the middle of the glass tube, and then two induction coils are distributed on the left and right sides of the coil; once the pressure difference effect occurs when the mutual inductive magnetic fluid micro-pressure difference sensor is working, the left and right induction coils will also detect the change of the iron core and send out inductance signals. Compared with the mutual inductance micro-differential pressure sensor, the improvement of its structure and working principle has many advantages, such as smaller structure volume, zero residual and low voltage, so the detection accuracy is greatly improved. A self-confirming magnetic fluid micro-differential pressure sensor written by Li Decai and others of Tsinghua University in 2016. Figure 5: the focus of this device is in the internal central position: a composite core composed of an iron core (6), a first cylindrical permanent magnet (5-1) and a second cylindrical permanent magnet (5-2). In this way, the working state of the magnetic fluid micro-pressure difference sensor can be monitored in real time, and the requirements of improving measurement accuracy and safety in production can be achieved.

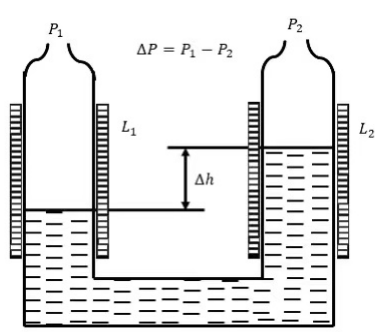

Fig. 3. U-tube magnetic fluid micro-pressure difference sensor

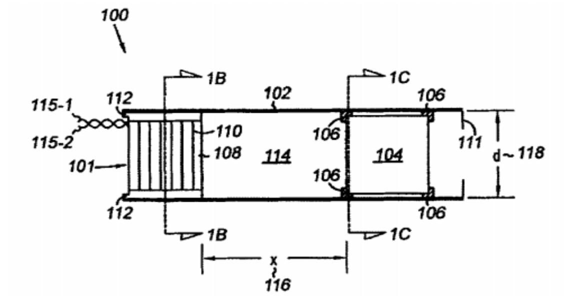

Fig. 4. Magnetic fluid vascular pressure sensor

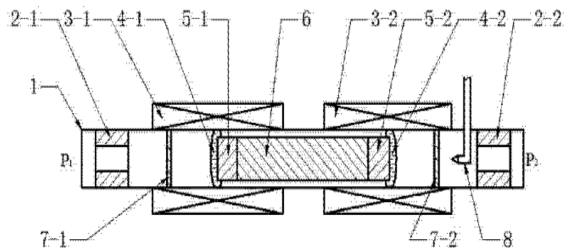

Fig. 5. A self-confirming Magnetic fluid Micro-differential pressure Sensor

Transparent glass tube (1), The first cylindrical hollow permanent magnet (2-1), Second cylindrical hollow permanent magnet (2-2), Primary induction coil (3-1) Second induction coil (3-2), The first magnetic liquid ring (4-1), Second magnetic liquid ring (4-2), First cylindrical permanent magnet (5-1), Second cylindrical permanent magnet (5-2), The iron core (6) The first limiter (7-1) Second limiter (7-2) Infrared range sensor (8), subtracter (9)

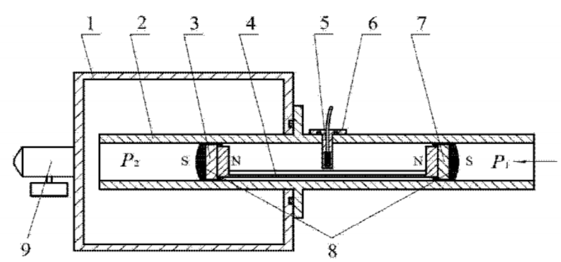

Fig. 6. A New Type of Hall Magnetic fluid Micro-differential pressure Sensor

Based on the study of mutual inductance and self-confirmation, the researchers found that the detection elements used in both are inductance coils. Yao Jie's team proposed in the magnetic fluid laboratory that a new type of Hall-type magnetic fluid micro-pressure difference sensor [14] is redesigned and improved in structure, with a linear Hall sensor as the detection element. The magnetic sensitive sensing circuit composed of Hall element inputs the magnetic induction intensity through the movement of the permanent magnet, and then outputs a digital voltage signal through circuit feedback [15]. Figure 6. Hall type magnetic fluid micro-pressure difference sensor has the advantages of high resolution, small volume, long life and low cost of research and development compared with the previous magnetic fluid micro-pressure difference sensor. it can be used in hospital clean room or drug production workshop and other occasions with strict pressure requirements.

According to the current research data at home and abroad, the research of magnetic fluid micro-pressure difference sensor is still in the early stage of experiment in China, especially the development of micro-pressure difference sensor. High sensitivity, high linearity, high repeatability, low zero drift and low hysteresis are required [17]. We should expand the research mainstream of magnetic fluid in the field of micro-differential pressure sensor as soon as possible, and improve the practical application of magnetic fluid micro-differential pressure sensor.

SUMMARY AND PROSPECT OF MAGNETIC LIQUID DIFFERENTIAL PRESSURE SENSOR.

3.4 Summary and Deficiency

In this paper, firstly, the research on magnetic liquid by researchers at home and abroad is summarized, and it is found that magnetic liquid is a kind of nano-functional material with various mixed characteristics. Then, the preparation methods, advantages and disadvantages of its own structure and application places of magnetic liquid are described. This paper analyzes the current theoretical research status of micro-pressure differential sensor and the progress of actual product research and development, and details the structure, working principle, existing shortcomings, sustainable development and research direction of several new achievements developed by domestic and foreign researchers in the field of micro-pressure differential sensor. According to the research status of magnetic fluid differential pressure sensor at home and abroad and the latest product application status. At present, the magnetic liquid micro-pressure difference sensor is large in volume, poor in detection linearity, large in quantity of magnetic liquid and high in cost, and the relative permeability of magnetic liquid is only slightly larger than that of air, so the inductance change caused by the change of liquid level height is small, and the output voltage signal is not obvious.

Future development and research direction

Magnetic micro-pressure differential sensor technology has a very wide application prospect, and the future research direction should closely follow the development direction of modern technology. Combined with the current research status of the latest products, aiming at the next research direction, the following three suggestions are put forward:

The optimization technology of magnetic fluid micro-pressure difference sensor and the improvement of tube internal structure are studied, such as using better processing technology to improve the measurement accuracy of magnetic fluid micro-pressure difference sensor.

4. CONCLUSION

In the research of magnetic fluid micro-pressure difference sensor, the packaging of magnetic fluid is also an important standard to determine its practicability. From the research of magnetic fluid micro-pressure difference sensor itself, it requires high sensitivity, high linearity, high repeatability, low zero drift and low hysteresis.

The research of magnetic fluid micro-pressure difference sensor should also keep up with the latest development trend, and make the product miniaturized to a relatively small size to meet the working requirements of micro-machinery.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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