Commentary

Research Status and Development Trend of Magnetic Fluid Acceleration Sensors

***Abstract*—**As a new type of accelerometer, in recent years, the magnetic liquid acceleration sensor has attracted widespread attention worldwide, and related research results have also continued to emerge. This article mainly introduces the theoretical basis and general structure of the magnetic liquid acceleration sensor, and according to the difference of inertial mass, briefly describes the research progress of the magnetic liquid acceleration sensor by national and foreign scholars in recent years and some in existing problems. Finally, suggestions and prospects for the future development trend of the magnetic liquid acceleration sensor are given.

***Keywords*—**magnetic liquid; acceleration sensor; status quo; inertial mass

I. Introduction

Magnetic liquid, also known as ferromagnetic fluid, is to disperse strong magnetic solid particles (usually ferrite, metal, alloy, etc. with a diameter of less than 10nm in the base carrier fluid (usually water) under the action of surfactants (usually Kerosene, synthetic oil, etc., and the stable colloidal solution formed is shown in Figure 1. This new type of nanomaterial has both the fluidity of liquid and the magnetism of solid magnetic materials[1]. And many other solid magnetic materials and liquids do not have special properties. Since the first successful preparation in the 1960s, it has provided researchers with new functional materials and scientific and technological directions.

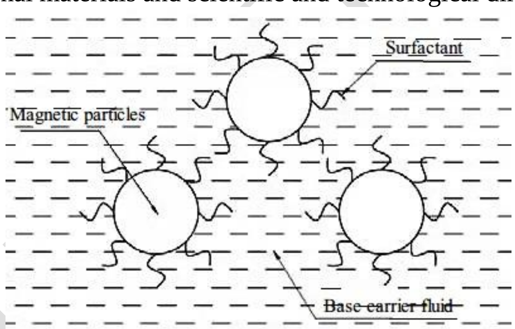


Figure 1: Composition of magnetic fluid

With the in-depth research on magnetic fluids, the research on the basic theory, physical and chemical properties, manufacturing process, and development and application of this new type of material has developed into a new subject category. At present, scientific research scholars from various countries have applied magnetic fluids in many fields such as mechanical sealing, lubrication, shock absorption, sensing, biomedicine, and so on. In the future, this new type of material will also have more advantages in the fields of acoustics, optics, and thermodynamics. For broad application prospects.

Initially, researchers sensitively discovered that some unique performance parameters of magnetic fluids can be used to apply them to sensors. First in the 1980s, the famous American ATA Application Technology Company developed high-precision magnetic fluid sensors for modal analysis of large machines and various vibration detection in aircraft wind tunnel tests[2]. In the following thirty years, in addition to the United States, scholars from Russia, Japan, Romania and other countries have done a lot of work on new types of magnetic fluid sensors, and many related technical results have emerged. The domestic research on magnetic liquid sensors started relatively late, but fruitful research has been carried out in the past ten years, and some significant patent results have been obtained, especially for the research on magnetic liquid acceleration sensors.

Because the application field of magnetic liquid acceleration sensor is very wide, especially in the field of national defense and military, there is still a great demand. At present, the research on the magnetic liquid acceleration sensor is gradually becoming complete and mature. From basic principles to structural design and then to experiment[3], a relatively systematic theory has been gradually formed. This article analyzes the theoretical basis and structure of the magnetic liquid acceleration sensor, and according to the difference of inertial mass, respectively introduces the research situation of various types of magnetic liquid acceleration sensor, in the hope that it can play a role in attracting ideas.

II. Principle and Structure

A. Theoretical basis

Compared with other materials, as a new type of functional material, magnetic fluid has many excellent characteristics suitable for sensor structure. Such as colloidal medium suspension, elastic stability, inertial body, proportional damping, magnetic liquid buoyancy servo loop[4] and so on.

For the magnetic liquid acceleration sensor, the theoretical basis of its design is the first-order and second-order buoyancy principles. According to the common sense of suspension, in general, liquids suspend objects with a smaller specific gravity than themselves, but magnetic liquids have their own unique properties. The principle of first-order buoyancy of magnetic liquids[5,6] shows that magnetic liquids can suspend non-magnetic bodies immersed in them and whose specific gravity is greater than itself. The additional condition is only the presence of an external magnetic field. The principle of second-order buoyancy of the magnetic liquid[7] is simpler, because the permanent magnet generates a magnetic field around itself, so there is no need for additional conditions for an external magnetic field. The magnetic liquid can suspend the permanent magnet that is immersed in it and has a larger specific gravity than itself. stand up.

B. General structure

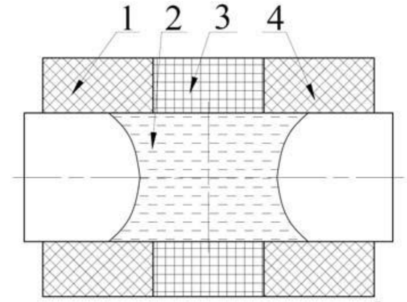
The magnetic liquid acceleration sensor is usually composed of an inertial mass body (also called a magnetic core), an elastic element that generates a restoring force, an attenuation damper[3], and a non-magnetic shell that can be magnetically shielded. The magnetic core can generally be permanent magnets, magnetic liquids or non-magnetic materials; elastic elements are generally the magnetic field force generated by the inductance coil, the magnetic buoyancy force of the magnetic liquid or the repulsive force between the permanent magnets; the electromagnetic damping and magnetism of the inductance coil. The viscous damping of liquid and water, air and other media constitute the damping part of the sensor; finally, there are inductors, capacitors or Hall elements as displacement detection units.

According to the difference of inertial mass[8] in the structural design, this paper briefly describes the representative magnetic liquid acceleration sensor designed by scholars at home and abroad, and analyzes its basic composition, compares its difference in the measurement principle of acceleration, and tries to summarize the general method of designing magnetic fluid acceleration sensors.

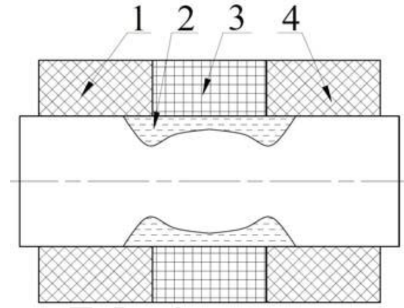
III. VARIOUS INERTIAL MASS MAGNETIC LIQUID ACCELERATION SENSORS

A. Acceleration sensor with inertial mass as magnetic liquid

Figure 2 shows a magnetic liquid acceleration sensor proposed by Romanian scholar M.I.Piso[9]. 1 and 3 are induction coils, 2 is a permanent magnet, and 4 is a magnetic liquid. The ring-shaped permanent magnet in the middle generates a magnetic field to provide restoring force. Keep the magnetic liquid in the center of the container. The detection principle of the device is that two induction coils are used to detect the displacement change of the magnetic liquid, thereby realizing the measurement of acceleration. As shown in Figure 2, the difference between (a) and (b) design lies in the volume of magnetic fluid used. When more magnetic liquid is placed in the glass tube, the glass tube can be separated from the middle to form a sealing effect; when more magnetic liquid is placed, although there is no seal, the magnetic liquid will not be exposed to air during the movement. The pressure is obstructed, so the sensitivity of the sensor can be greatly improved, so as to be suitable for the measurement with higher sensitivity requirements.



(a) With more magnetic liquid



(b) With less magnetic liquid

Figure 2: Sensor with permanent magnet providing restoring force

In addition to using permanent magnets to generate a magnetic field, coils can also be used to generate a magnetic field, which is further used to confine the magnetic liquid. This is the design of Italian scholar Salvatore Baglio[10] and others. As shown in Figure 3, 1 and 2 are induction coils, 3 is the excitation coil, 4 is the magnetic liquid, and 5 is the glass tube. The induction coil and the excitation coil are wound on top of each other. Only a small amount of magnetic liquid is placed in the glass tube, and the remaining space is filled with deionized water. The excitation coil wound on the outermost circle is used to replace the permanent magnet in Figure 2, and the purpose is also to generate a magnetic field to provide a restoring force to keep the magnetic liquid in the center. When there is an external axial acceleration stimulus, the magnetic fluid will move along the glass tube, and then the inductance of the two induction coils will change, and the displacement signal of the detected magnetic fluid will be converted into an electrical signal for output, thereby realizing acceleration measurement.

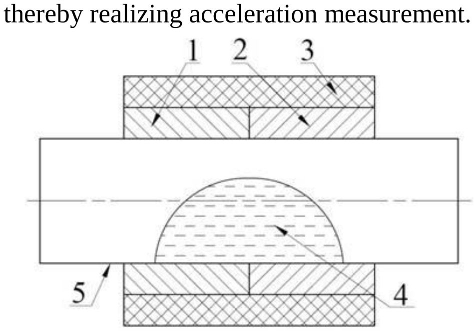
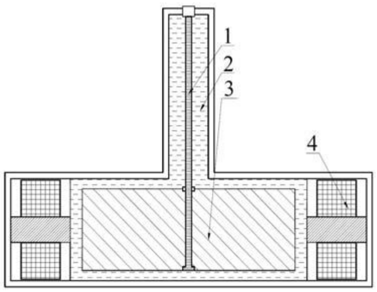


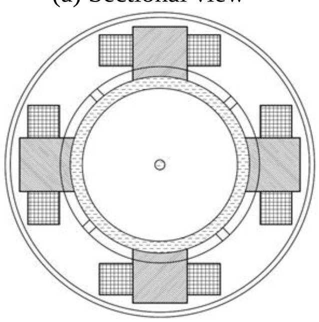
Figure 3: Magnetic fluid acceleration sensor

B. Acceleration sensor whose inertial mass is a non-magnetic substance

Figure 4 is a two-dimensional magnetic liquid acceleration sensor based on passive suspension of non-magnetic materials[11-13]. As shown in the figure, 1 is an elastic rod, 2 is a magnetic liquid, 3 is a non-magnetic inertial mass, and 4 is an electromagnet. First, the inertial mass is connected to the shell through an elastic rod, and four electromagnets evenly distributed outside the container are used to generate a magnetic field, so that the inertial mass is at the center of the container. The detection principle of the device is that four electrodes are evenly arranged outside the container. When the inertial mass is displaced, the capacitance between the inertial mass and the electrodes will change, and the change in capacitance is used to measure acceleration.



(a) Sectional view



(b) Sectional view

Figure 4: Two-dimensional magnetic liquid acceleration sensor

C. Inertial mass is an acceleration sensor containing permanent magnet material

Not only can the magnetic liquid act as a restoring force, the repulsive force between the magnetic poles of the permanent magnet with the same name can also act as a restoring force. Figure 5 is a new type of magnetic liquid acceleration sensor designed by Li Qiang[14] that uses the repulsive force between permanent magnets as the restoring force. 6 is a magnetic liquid, and its measurement principle is similar to the previous ones. The inertial mass of the device is composed of two parts: the permanent magnet and the magnetic liquid adsorbed on its two ends. By suspending in the magnetic liquid, the permanent magnet can greatly reduce the friction with the inner wall of the container.

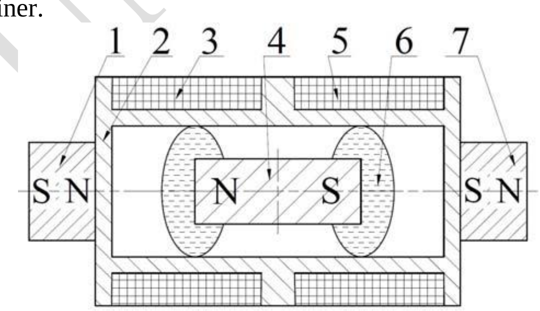


Figure 5: A new type of magnetic liquid acceleration sensor

Figure 6 is a magnetic liquid acceleration sensor proposed by Zhang Xining[15] and others with a spring force in its restoring force. As shown in the figure, 1 is a Hall element, 2 is a housing, 3 is a spring, 4 is a permanent magnet, and 5 is a magnetic liquid. The innovation of this setup is that the Hall element is used to replace the original induction coil to detect the position of the permanent magnet. The permanent magnet as an inertial mass is connected to the top of the housing by a spring. The restoring force of the permanent magnet consists of two parts: the suspension force of the magnetic liquid and the elastic force of the spring, which act together. Because of the innovative use of springs to connect with the inertial mass, the device has a 256% wider usable frequency compared to other sensors.

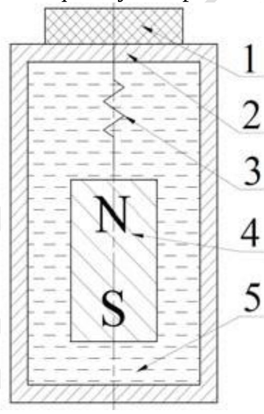


Figure 6: Magnetic liquid acceleration sensor with spring

IV. Existing Problems and Development Direction

A. Currently existing problems

According to the above research summary of domestic and foreign magnetic fluid acceleration sensors, we can find that current scientific researchers generally only pay attention to the design improvement of the sensor's own mechanical structure to achieve better sensitivity and accuracy. For the development of a sensor, its importance is indeed self-evident, but it ignores the application to actual products.

Looking at the research status of magnetic liquid acceleration sensors at home and abroad in recent years, although the volume of the internal mechanical structure of the acceleration sensor has been designed to be small and conforms to the actual product application, once the necessary wire for signal transmission is connected, and Peripheral circuits such as filter circuits, signal amplifier circuits, and rectifier circuits will become very large and bloated, which is not suitable for actual products[16]. In addition, the manufacture of a single acceleration sensor requires more magnetic liquid, which is relatively expensive compared to traditional sensors, and it is difficult to promote and apply in a large range, which is also the current research deficiencies. Finally, there are few reports on magnetic liquid acceleration sensor products that are completely packaged and suitable for industrial measurement at home and abroad.

B. Future direction

Looking forward to the future, combined with the current situation that the magnetic liquid acceleration sensor has high sensitivity, accuracy, and good dynamic and static performance, the following suggestions are made to future scientific researchers: improve and redesign the structure, and continue to reduce The amount of magnetic fluid used is to achieve the purpose of further reducing the cost of the sensor[17]; when designing the peripheral circuit, the overall circuit design and the mechanical structure of the sensor are integrated into consideration, and package it and reduce the volume of the whole sensor, so as to achieve the purpose of practical application in more fields. In this way, it is believed that the magnetic liquid acceleration sensor will have a very broad application prospect.

V. CONCLUSION

This article first briefly describes the composition of the magnetic fluid, as well as its special physical and chemical properties, and the main application scenarios at present: mechanical seals and lubrication, shock absorbers, sensors and many other fields. The development of sensors is advancing with the times[18]. Sensors in different periods will continue to use various newly developed functional materials to empower the development of sensors in the hope of achieving higher development. Therefore, the research on magnetic fluid sensors is a very important direction for the application of magnetic fluids, and it is also very consistent with the research and utilization of new materials for sensors. With the application of magnetic fluid, a new type of nano-functional material, acceleration sensors can develop in the direction of having better sensitivity, accuracy, larger measurement range, and better dynamic and static performance.

The theoretical basis and general structure of the magnetic liquid acceleration sensor are further introduced, and some representative magnetic liquid acceleration sensors designed by scholars at home and abroad in the recent period are described in detail. The basic structure and measurement principle of the magnetic liquid acceleration sensor are compared and analyzed to facilitate Make a detailed understanding of the development status of liquid acceleration sensors. Finally, it analyzes its current deficiencies, looks forward to the future development direction, and hopes to provide help to future researchers.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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