

# Summary of Research on Magnetic Fluid and Its Inclination Sensor

**Abstract**—Magnetic fluid is a multifunctional new fluid material. Because of its combination of magnetism and fluidity, it has an irreplaceable role in many occasions. The application of magnetic fluid in the sensor field is not yet mature, but with the continuous attempts of researchers, the huge potential of magnetic fluid in this field has been explored. This article briefly introduces the magnetic fluid, and then discusses the preparation method of the magnetic fluid and the application scenarios of the magnetic fluid. The principle of the magnetic fluid inclination sensor is introduced emphatically, and the magnetic fluid inclination sensor is classified according to the different restriction methods of the magnetic fluid. Pointed out the gap between the research directions of magnetic fluid inclination sensors at home and abroad, as well as the problems existing in research and development, and prospects for future innovation in this field.

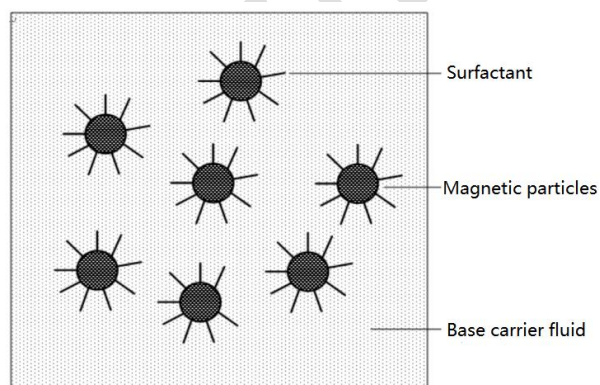
**Keywords**—magnetic fluid, sensor, inclination, application, summary.

## I. INTRODUCTION

### A. Introduction to magnetic fluids

Magnetic fluids, some called ferromagnetic fluids, and some called magnetic fluids, are mixed colloidal solutions with high stability. It is formed by nano-level ferromagnetic particles or ferrimagnetic particles uniformly distributed in the base carrier liquid. Even under the action of a magnetic field and a gravitational field, the original physical and chemical properties can be guaranteed, and precipitation and decomposition will not occur, so it has strong practicability [1]. The composition of the magnetic fluid is shown in Figure 1. The surfactant can make the magnetic particles uniformly dispersed in the base carrier liquid. The colloidal solution not only has the magnetic properties of solid magnetic materials and the fluidity of liquids, but also has many properties that ordinary solid phase and liquid phase materials do not have. Since the early 1960s, NASA has successfully applied magnetic fluids in the sealing of spacecraft's movable and transitional chambers. With the reduction of production costs and the disclosure of related technologies, it has gradually begun to turn to civilian use. People have begun to study a series of related topics such as the basic theoretical equations, physical properties, and technological processes of magnetic fluids. The research results

show a blowout growth, and the applications are gradually increasing [2]. At present, the research scope of magnetic fluids is relatively good, but the depth is insufficient. It should be that the theory and practice of magnetic fluids are more closely combined.



**Figure 1:** Composition of magnetic fluid

### B. Preparation of magnetic fluid

There are many methods for the preparation of magnetic fluids, such as: co-precipitation method, pulverization method, anion exchange resin method, hydrogen reduction method, and electrodeposition method. Gowan Knight[3] first tried to disperse iron filings in the base carrier liquid. Although the mixture obtained by this method settled after a period of time, the iron filings settled, but this method of operation has brought enlightenment to everyone. Taking shape. To improve the stability of the magnetic fluid, it is necessary to prepare finer magnetic particles. The co-precipitation method can solve this demand: the iron ion compound and the ferrous ion compound are mixed and reacted, and the magnetic  $\text{Fe}_3\text{O}_4$  solid particles produced can meet the requirements of the nanometer level. According to the obtained magnetic particles, different base carrier liquids and manufacturing processes can be used to obtain magnetic fluids with different properties. In this way, the magnetic fluids can be mechanized and automatically produced, which is more economical and practical in application.

### C. Magnetic fluid application

The earliest magnetic fluid was used in space to seal the movable joints of spacesuits in a weightless environment and to achieve the function of weightless liquid transportation in spacecraft. With the development of magnetic fluid-related technologies, magnetic fluids have gradually been widely used in various fields from confidential military applications and

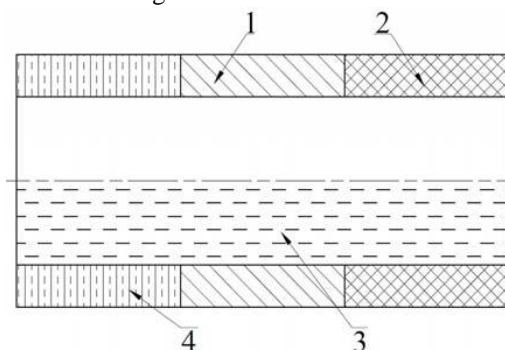
turned to civilian use. Here are some of the most promising applications of magnetic fluids: (1) The application of magnetic fluids in the field of sealing, and the application of magnetic fluids on seals is the most mature and extensive [4]. According to the different magnetic fluid seals of the sealed medium, there are mainly three types: the magnetic fluid is used to form an O-ring with a pressure difference under the action of an external magnetic field to achieve vacuum, gas and liquid sealing. It is worth noting that magnetic fluids have reached a very high level in sealing vacuum and gas technology, while sealing liquids have not yet achieved good practical applications. The reason is that the magnetic fluid is in direct contact with the liquid to be sealed, and when the speed reaches a certain speed, the contact surface of the magnetic fluid and the sealed medium transitions, causing the seal to fail. Therefore, how to ensure the stability of the liquid-liquid contact surface is a key and difficult problem in the research of magnetic fluid sealing liquid technology. (2) The application of magnetic fluid in the field of lubrication. Magnetic fluid is used as a new type of lubricant. The lubricant can be fixed on the part that needs lubrication by means of magnetic field control to achieve precise lubrication. In addition to the advantages of traditional lubrication, the advantages of sealing and dust-proofing can also be added. At the same time, the magnetic fluid is used as a lubricant without loss, and there is no need to supply the system to replenish the lubricant, which can achieve long-life lubrication. (3) The application of magnetic fluid in damping and vibration reduction. The viscosity of magnetic fluid can be controlled by the strength of an external magnetic field. According to the mechanism of controllable viscosity, the optimal performance of damping and shock absorption can be achieved. Magnetic fluid damper is a relatively mature application in this field, and has been put into use in industries such as stepper motors and servo motors. How to design the magnetic fluid shock absorber with the best parameter matching is a hot issue in this field. (4) The application of magnetic fluid in biomedicine. Magnetic fluid is not only widely used in the field of engineering, but its unique properties make it emerge in the field of biomedicine. Magnetic fluids are currently used in medical methods such as targeted drug delivery, treatment of vascular embolism, and magnetic injections. However, current medical treatment is all individual experiments, and it has not completely replaced the more mature traditional therapies. (5) The application of magnetic fluid in the sensor, the application of magnetic fluid in the sensor direction is a hot research field of magnetic fluid [5]. Magnetic fluid sensors can measure inertial signals such as acceleration and speed, as well as electrical signals such as current and magnetic field strength. Magnetic fluid sensors have been used for practical purposes, such as mountain slope measurement, automobile acceleration measurement, and so on. At present, there is not much research on the application of magnetic fluid sensors, and the application range is not wide enough. Most of them are customized magnetic fluid sensors under special working conditions. How to make the magnetic fluid sensor a mature product, reduce its size, and be able to

mass-produce and put it into widespread use is an urgent problem in this field.

## II. MAGNETIC FLUID INCLINATION SENSOR

### A. Working principle

The structure diagram of the magnetic fluid tilt angle sensor is shown in Figure 1. The coil is evenly wound on both ends of the cylindrical non-magnetic shell. The initial method is to use only the magnetic fluid injected into the container as the inertial mass of the sensor. The coils at both ends are connected in reverse series to detect the induced signal and output an induced electromotive force difference  $\Delta u$ . When the inclination angle of the magnetic fluid inclination sensor is 0 (the position is horizontal), the magnetic fluid is uniformly distributed, and the output  $\Delta u=0$ . When the magnetic fluid inclination sensor no longer maintains the horizontal position, the magnetic fluid flows, the induced electromotive force generated by the inductive coils at both ends is not equal, and the output pressure difference  $\Delta u$ . For each different tilt angle, a different pressure difference  $\Delta u$  is generated, and the value of the tilt angle can be obtained by measuring the magnitude of  $\Delta u$ . Subsequent magnetic fluid inclination sensors have different appearances and structures, but they are all evolved on the basis of Figure 2. The basic working principle is the same, but the structure, shape and parameters are different, for example: changing the overall non-magnetic container The shape, the number of turns of the coil and the winding method are different, and other electronic components such as Hall elements are used instead of the coil to collect the induction signal.



**Figure 2:** Magnetic fluid tilt sensor structure

1-excitation coil, 2,4-induction coil, 3-magnetic fluid

### B. Types of magnetic fluid inclination sensor

According to the different limited force field of the magnetic fluid, the magnetic fluid inclination sensor can be divided into the following types.

Gravity field limits the inclination sensor of magnetic fluid: The magnetic fluid is injected into the cylindrical plexiglass tube, and the injection volume is half of the volume of the plexiglass tube to make the sensor obtain the highest sensitivity, as shown in Figure 3 [6]. When the sensor is tilted, the magnetic fluid flows to a lower place. At this time, the

volume of the magnetic fluid wrapped by the coils wound at both ends changes, causing the two sets of coils to have different inductances and produce an electromotive force difference. The induced electromotive force difference of the two sets of coils is proportional to the inclination angle of the sensor. It basically conforms to the linear relationship.

This kind of magnetic fluid sensor has a simple structure and is very sensitive to angle changes. The disadvantage is that it will affect the measurement results when it is affected by vibration, and the angle measurement range is small; the magnetic fluid inclination sensor proposed by T.Medvegy [7] et al. is shown in Figure 4. The principle is the same as that of the linear magnetic fluid inclination sensor, and better linearity can be obtained by adopting a ring-shaped housing. And the resolution can be further improved by increasing the ratio of the length and radius of the glass tube, but the larger sensor volume is not conducive to the integration and development of the sensor; The first two magnetic fluid inclination sensors cannot directly measure the inclination angle of three-dimensional space. To solve this problem, Guo Bing [8] and others designed a magnetic fluid omnidirectional inclination sensor. As shown in Figure 5, the use of a TMR sensor instead of a coil makes the structure more streamlined, and the structure effectively expands the range of inclination to  $10^{\circ} \sim 170^{\circ}$ .

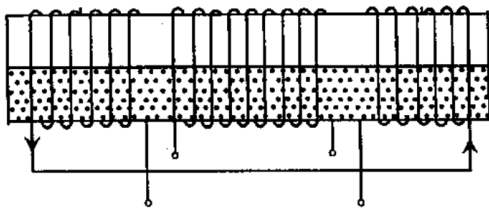


Figure 3: Plexiglass tube filled with half of the magnetic field

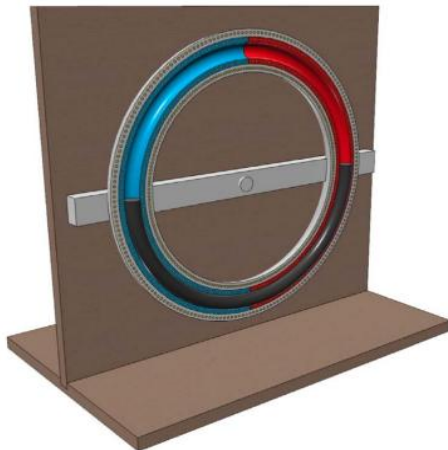


Figure 4: Annular magnetic liquid sensor

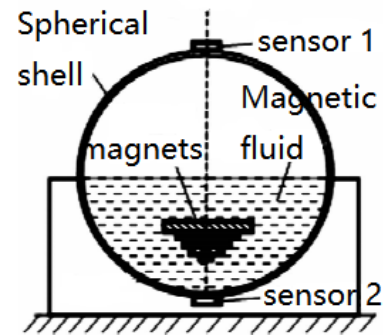


Figure 5: Annular magnetic liquid sensor

Magnetic field limit magnetic fluid tilt sensor: Put the permanent magnet in a cylindrical container and then inject a certain amount of magnetic fluid. The magnetic fluid will be adsorbed on the two magnetic poles of the permanent magnet with the strongest magnetism. The magnetic fluid will hold the permanent magnet up under the action of the magnetic field of the permanent magnet, which is the second-order levitation characteristic of the magnetic fluid. The two ends of the cylindrical shell are respectively fixed with permanent magnets, which are opposite to the magnetic poles of the permanent magnets in the container, and provide a restoring force to the magnetic core. When the sensor is tilted, the magnetic core shifts, and the coils wound on both ends of the housing will generate induced electromotive force. The principle is the same as that of the above-mentioned inclination sensors that restrict the magnetic fluid by the gravity field, and different inclination angles correspond to different induced electromotive forces. This structure uses the magnetic field generated by the permanent magnet to confine the magnetic fluid, which can provide higher reliability than gravity confinement, and can generate stronger signals for dynamic measurement. The tilt sensor that relies on gravity to limit the magnetic fluid is limited to static applications, and its overall structure is shown in Figure 6 [9]. Su Shuqiang innovatively designed a new type of magnetic fluid tilt sensor structure based on this structure, as shown in Figure 7. After the improvement, a stronger signal can be obtained to make the measurement more accurate, and the weight of the entire sensor is also reduced.

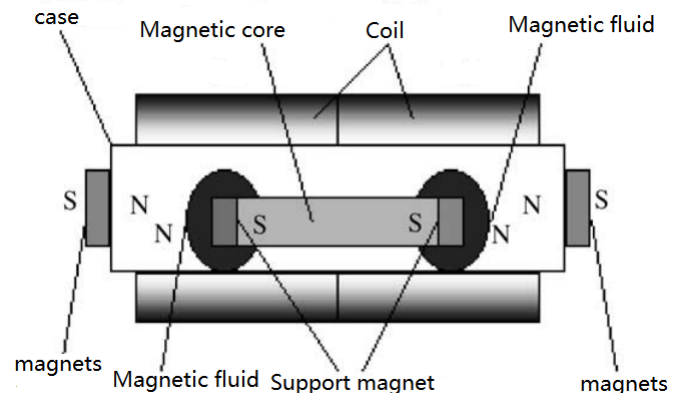
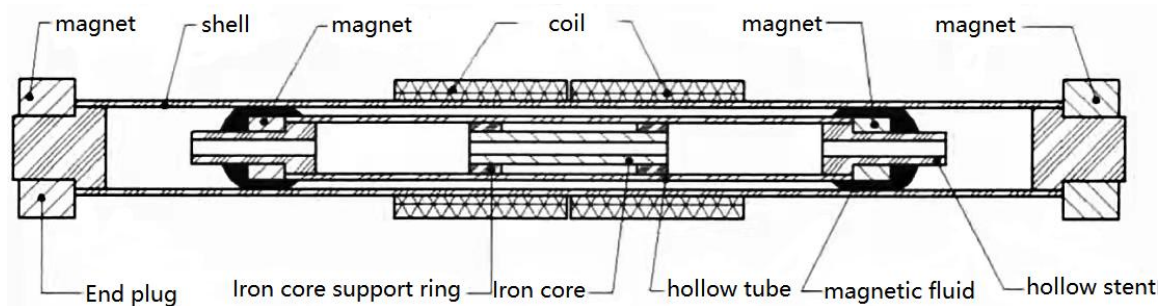
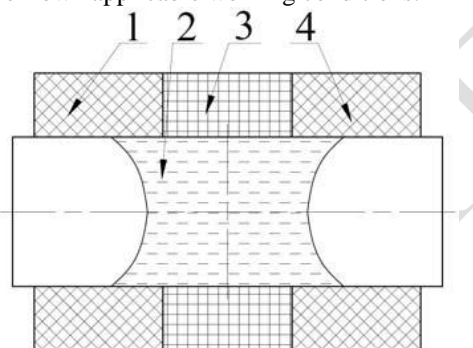


Figure 6: Magnetic liquid inclination sensor



**Figure 7:**New type of magnetic liquid inclination sensor

Gravity field and magnetic field jointly limit the inclination sensor of magnetic fluid: M.I. Piso [10] proposed a magnetic fluid inclination sensor structure as shown in Figure 8, using a ring-shaped permanent magnet sleeved at the center of the container, two induction coils at both ends of the container, and an appropriate amount of magnetic fluid is injected into the container. The magnetic field generated by the ring-shaped permanent magnet can confine the magnetic fluid and provide it with a restoring force, so that the magnetic fluid can return to the center position when the container is kept horizontal, and the induction coil is used to detect the displacement change of the magnetic fluid due to gravity, thereby realizing the inclination measurement. In short, these three types of magnetic fluid inclination sensors all have different advantages and have their own applicable working conditions.



**Figure 8:**Magnetic liquid inclination sensor  
1,4-induction coil, 2-magnetic liquid, 3-ring permanent magnet

### III. SUMMARY AND OUTLOOK

This article first briefly introduces the composition of the magnetic fluid, the preparation method of the magnetic fluid, and the application status in various fields, focusing on the working principle and classification method of the magnetic fluid inclination sensor. Let readers have an understanding of the field of magnetic fluid sensors, it can be seen that magnetic fluid sensors developed earlier in foreign countries, and domestic research is generally an application innovation on the original structure. At present, there is no relatively mature and commonly used magnetic fluid inclination sensor product. It is necessary to further improve the performance parameters of the magnetic fluid inclination sensor, and to reduce the volume of

the magnetic fluid inclination sensor to make it a precision device. With the advent of the 5G era, the application field of sensors will continue to expand. In order to shorten the gap in the field of magnetic fluids at home and abroad, there are two issues that need to be resolved: one is to in-depth study the basic theory of magnetic fluids, and the other is to accelerate the commercialization of magnetic fluid sensors so that the characteristics of magnetic fluids can be fully utilized and have an irreplaceable role.

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