Study on Supermagnetism and Buoyancy Principle of Magnetic Fluid

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Keywords: Magnetic fluid, Supermagnetism, Buoyancy principle.

Abstract. Magnetic fluid is a new nanometer functional material with both magnetism and fluidity, which is also a green material for many polluting engineering fields. The supermagnetism of magnetic fluid was studied and the magnetic curve of magnetic fluid was measured. The first-order buoyancy principle was introduced and the buoyancy force was deduced. It was concluded that with the increasing of the current, the first-order buoyancy force of magnetic fluid increases. As the height of the object increases, the first-order magnetic buoyancy decreases slowly, and the moving object tend to move to the cup wall during the nonmagnetic object rising. The second-order principle of magnetic fluid was studied, and it was concluded that with the dimension of magnet increasing, the second-order buoyancy forces increases.

Introduction

Magnetic fluid (MF) is a kind of new functional material composed of magnetic particles suspending in the base fluid, stabilizer and base fluid. Magnetic fluid has the fluidity of liquid as well as the magnetism of solid ferromagnetic materials[1], and it possesses some unique properties other materials do not possess. Fig.1 shows the performance of magnetic fluid under magnetic field. It has been applied in many fields especially in aerospace, instrument and machinery, with a very broad engineering application prospect.

![Figure 1. Performance of Magnetic fluid under Magnetic field.](image)

Relatively high permeability, fluidity and electromagnetic response of magnetic fluid have determined its application in measuring devices. Theory and application researches on magnetic fluid have been conducted in many countries like USA, China, Romania, and France, etc. [2-6]. Currently, the sensors with magnetic fluid as core are not matured in China. It introduces and analyzes the working principles and applications of various magnetic fluid sensors.

Properties of Magnetic Fluid

Because of electromagnetic response property, magnetic fluid can be controlled by magnetic field, and it will be kept in any position, and moreover, its viscosity will change with the change of external magnetic field. It is a kind of new material with special performance combining the magnetism and fluidity of liquid, and can be applied in machinery, electron, ship, aerospace, telemetering, instrument,
print, medical treatment, and many other fields. Such sensing and detection technology mainly uses the superparamagnetism and first-order and second-order buoyancy principles of magnetic fluid.

**Superparamagnetism**

Superparamagnetism refers to that, the ferromagnetic materials in single domain structure when their grains are smaller than critical dimensions show paramagnetism when temperature is lower than Curie temperature and higher than block temperature, however, their paramagnetic susceptibility is far higher than that of ordinary paramagnetic materials under the effect of external magnetic field, and this is called as superparamagnetism.

Superparamagnetism has two most important characteristics: first, if a figure is plotted with magnetization intensity M as Y-axis and H/T as X-axis (H is the magnetic field intensity applied, and T is absolute temperature), then magnetizing curve is measured under different temperatures in the temperature range when single domain particle aggregation shows superparamagnetism, these magnetizing curves are certainly coincident. Second, no hysteresis will appear, that is, the remanence and coercivity of aggregation both will be zero.

![Magnetic Curve of Magnetic fluid.](image)

With the density of magnetic fluid increasing, the magnetism and saturation magnetization of magnetic fluid increases.

**First-Order Buoyancy Principle**

First-order buoyancy principle refers to that magnetic fluid under the effect of magnetic field is able to suspend the nonmagnetic substances with a higher specific gravity than magnetic fluid.

Where, \( \rho_0 \) is the density of magnetic fluid, \( v \) is the current velocity of the fluid, \( z \) is the relevant height at one point in magnetic fluid, \( g \) is the gravitational acceleration, \( p \) is the pressure at a certain height, \( \mu_0 \) is the magnetic permeability of vacuum, \( M \) is the magnetization of magnetic fluid, \( H \) is the magnetic field intensity.

Magnetic fluid is an isotropic magnetic medium, so

\[
M = \chi H
\]

where, \( \chi \) is magnetic susceptibility of magnetic fluid\(^7\).

When the magnetic field intensity is weak, the magnetic fluid is not saturated, and \( \chi \) is constant. When the magnetic field intensity is strong, the magnetic fluid is saturated, the magnetization of magnetic fluid at this time \( M = M_s \), where \( M_s \) is the saturated magnetization of magnetic fluid.

The applied magnetic field intensity is less than that of the magnetic fluid. \( \rho_s \) is apparent density of magnetic fluid with an external magnetic field\(^8\). The apparent density of magnetic fluid could be expressed as

\[
\rho_s = \rho_0 + \mu_0 \chi H \frac{\partial H}{\partial z} / g
\]
When an external magnetic field is applied, the buoyancy of non-magnetic objects with a volume of \( V \) in magnetic fluid is obtained.

\[
F_s = \rho_s g V = \rho_0 g V + \mu_0 V \chi H \frac{\partial H}{\partial z}
\]

If the external magnetic field intensity applied is less than the saturated magnetization of magnetic fluid, the first-order buoyancy is

\[
f = \mu_0 V \chi H \frac{\partial H}{\partial z}
\]

If the external magnetic field intensity applied reaches the saturated magnetization of magnetic fluid, the first-order buoyancy is

\[
f = \mu_0 V M_s \frac{\partial H}{\partial z}
\]

So, the first order magnetic buoyancy of a nonmagnetic object in a ferromagnetic liquid is related to the magnetic susceptibility and saturation magnetization of the magnetic fluid, as well as the magnetic field intensity and magnetic gradient of the applied magnetic field\(^9\).

Fig.3 is the first-order buoyancy force of a magnetic fluid, whose density is 1.1 g/cm\(^3\), saturated magnetization is 67 mT, magnetic susceptibility is 0.08. The magnetic field generated by different currents such as 0A, 0.2A, 0.4A, 0.6A, 0.8A, 1.0A.

![Figure 3. First-order Buoyancy of a Magnetic fluid.](image)

From Fig.3, we could conclude that with the increasing of the height of nonmagnetic objective, the first-order buoyancy force increases. With the increasing of the current, the magnetic field intensity increases, then the first-order buoyancy force of magnetic fluid increases.

As the height of the object increases, the magnetic field gradient tends to zero. At this time, the first-order buoyancy of the magnetic fluid is mainly influenced by the magnetic field intensity. The first-order magnetic buoyancy decreases slowly, and the first-order magnetic buoyancy at the test cup wall is the smallest. So the moving object tend to move to the cup wall during the nonmagnetic object rising.

**Second-Order Buoyancy Principle**

Second-order buoyancy principle refers to that magnetic fluid is able to suspend the permanent magnet with a higher specific gravity soaked in the magnetic fluid\(^{10-11}\). The second-order buoyancy force exerted on the magnet object decreases, as the distance of the object moving along the cylindrical vessel axis increases.

Fig.4 shows that at different height of the object, the second-order buoyancy forces exerted on the magnet object decrease with the moving distance along the axis of vessel increasing.
And, experiment results show that with the dimension of magnet increasing, the second-order buoyancy forces increases.

Conclusion
The properties such as supermagnetism, first-order buoyancy principle and second-order principle were studied. It was concluded that the remanence and coercivity of magnetic fluid both are zero. It could float up both nonmagnetic object and magnetic object. We could control the parameters of magnetic fluid and magnetic field to apply its engineering application. Also, because of its high magnetic permeability, green environmental protection, it would be more and more broadly prospectively developed and be applied in more engineering fields.

Acknowledgement
This project is supported by Beijing Municipal Commission of Education Technology Plan Project (KM201910858005) and Beijing Polytechnic Science and Technology Project (2018Z002-029-KXZ).

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