

Application of the magnetic fluid as a detector for changing the magnetic field

D Zyatkov^{1,2}, A Yurchenko^{1,2}, V Yurchenko^{2,3}, V Balashov^{2,3}

¹National Research Tomsk Polytechnic University, Tomsk, Russia

²National Research Tomsk State University, Tomsk, Russia

³Research Institute of Semiconductor Devices Tomsk, Russia

E-mail: zyatkov.88@mail.ru

Abstract. In article the possibility of use of magnetic fluid as a sensitive element for fixing of change of induction of magnetic field in space is considered. Importance of solvable tasks is connected with search of the perspective magnetic substances susceptible to weak magnetic field. The results of a study of the capacitive method for fixing the change in the magnetic field on the basis of a ferromagnetic liquid are presented. The formation of chain structures in the ferrofluid from magnetic particles under the influence of the applied magnetic field leads to a change in the capacitance of the plate condenser. This task has important practical value for development of a magnetosensitive sensor of change of magnetic field.

1. Introduction

Magnetic fluids are artificially formed and specially structured media with unique electrical and magnetic properties. Such properties should be understood as special values of the physical parameters of the medium: dielectric ϵ and magnetic μ permeabilities, spatial structurization, depending on the size and shape of magnetic and dielectric particles, the possibility of controlling the parameters of the medium as a result of external influences. The high mobility of magnetic particles in the fluid ensures their strong sensitivity to low magnetic fields and gives a significant advantage in comparison with solid-state analogs [1, 2].

Now the increased interest in the magnetic and magnetodielectric fluids (MF) shown from theorists and experimenters is caused by the fact that these substances have properties which are in many respects unique and difficult predicted. The uniqueness of these properties and the possibility of practical use in various industries contribute to the development of fundamental research on their study and practical application in complex technical problems. For example, using MF developed technologies for cleaning water surfaces from oil products in case of accidents and catastrophes; MF allowed to create dampers and shock absorbers with controlled rigidity; MF became the basis for creating acceleration, tilt, level sensors; on the basis of the magnetic fluid, magnetic-fluid bearings, suspensions and bearings have been created; at present, physicists from the Michigan University of Technology have developed a new type of engine for small space vehicles. They resemble ionic engines, but the working substance in them is an ionic magnetic fluid. Thus, the use of a magnetic fluid expands, there are new areas of their application [3–8].

Usually, magnetic fluids investigate in strong magnetic fields ($B = 10^{-3} - 10^3$ T). The study of structuring mechanism of magnetic particles in the fluid matrix under the influence of a weak magnetic field ($B = 10^{-6} - 10^{-9}$ T) and creation of model of composition magnetic substance for a sensitive element of the capacitive sensor of magnetic fields have a considerable scientific interest.



The importance of current task is connected with search of the perspective magnetic substances susceptible to weak magnetic field [9,10,12].

2. Object of experimental studies

In experimental studies the magnetic fluid on the basis of a polimetilfenilsiloksan (PFMS-4) containing particles of carbonyl iron dispersion of 3 microns was applied. Concentration of particles of iron in PFMS-4 doesn't exceed 10% and 40%. Preparation of magnetic fluid was carried out by mechanical and ultrasonic agitation.

The next step was to located suspension on a ceramic plate with a structure of condenser. The condenser is made of gold. A photo of the capacitor is shown in Figure 1.

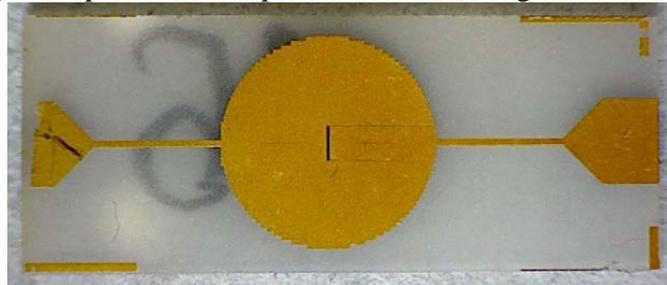


Figure 1. Capacitor on a ceramic plate.

The scheme of the capacitor is shown in Figure 2.

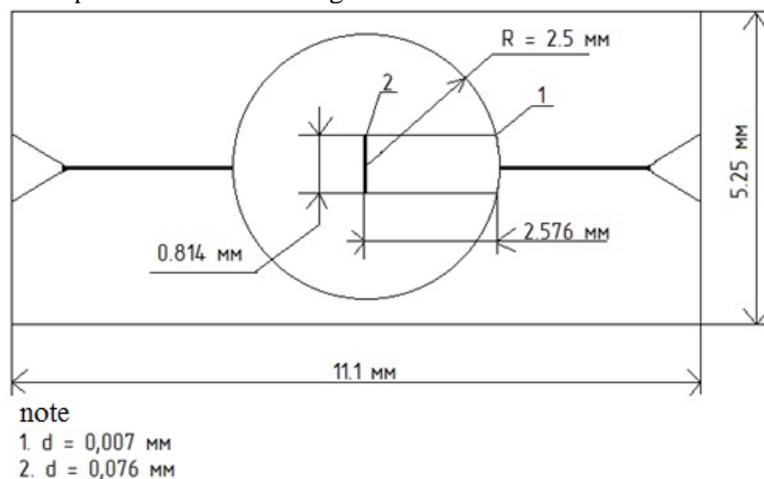


Figure 2. Scheme of the condenser.

The thickness of the a ceramic plate is equal to 470 microns. The thickness of gold plating is equal to 6.21 μm.

Solid particles in a magnetic fluid experience the action of gravity and Archimedes force. Gravity in the case of spherical particles is equal to:

$$F_g = -\frac{4}{3}\pi r^3 \rho_p g$$

Archimedes force in case of spherical particles is equal:

$$F_{Arch} = \frac{4}{3}\pi r^3 \rho_f g$$

where r – particle radius, ρ_p and ρ_f – density of a particle and fluid respectively.

Under the action of sedimentation force, the particles acquire velocity. This velocity leads to the appearance of a frictional force which is directed opposite to the velocity of the particles in the fluid medium. For spherical particles friction force can be calculated according to the Stokes law:

$$F_{fr} = -6\pi r \eta v$$

where η – the dynamic viscosity of the fluid, \mathbf{v} – the velocity of the particle. Thus, the total force acting on particles in a magnetic fluid is equal to:

$$F = -\frac{4}{3}\pi r^3 \rho_p g + \frac{4}{3}\pi r^3 \rho_f g - 6\pi r \eta v$$

The equation of motion (settling) of particles along the z axis is written as:

$$\begin{cases} M\ddot{z} = -\frac{4}{3}\pi r^3 \rho_p g + \frac{4}{3}\pi r^3 \rho_f g - 6\pi r \eta \dot{z}; \\ z(0) = z_0; \\ \left. \frac{dz}{dt} \right|_{t=0} = v_0. \end{cases}$$

Solving this equation, we obtain:

$$\begin{aligned} z(t) &= z_0 + \left(v_0 - \frac{\alpha}{\beta}\right)t + \frac{\alpha}{\beta^2}(1 - e^{-\beta t}); \\ v(t) &= v_0 - \frac{\alpha}{\beta}(1 - e^{-\beta t}). \end{aligned} \tag{1}$$

where $\alpha = g(1 - \rho_{ж}/\rho_{ч})$, $\beta = 6\eta\pi r/M$

A magnetic fluid consisting of carbonyl iron particles and PFMS-4 was placed in a cylindrical vessel 0.5 cm high. Figures 3 and 4 show the graphs $z(t)$ and $v(t)$ constructed according to formula 1 for a magnetic fluid in a cylindrical vessel. The radius of the carbonyl iron particle is equal to 2 μm , the density of the PFMS -4 is equal to 1.1 g/cm^3 , the density of the particles is equal to 7.5 g/cm^3 , the dynamic viscosity of the fluid is equal to 6.6 $\text{g}/(\text{s} * \text{cm})$.

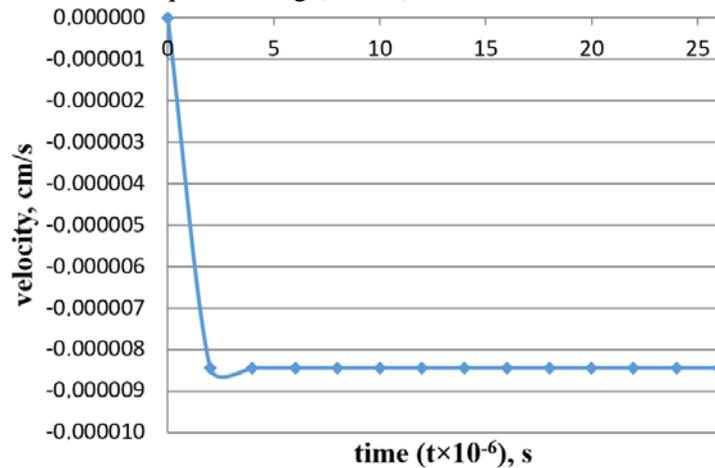


Figure 3. Graph of the dependence of the velocity of motion of particles on time.

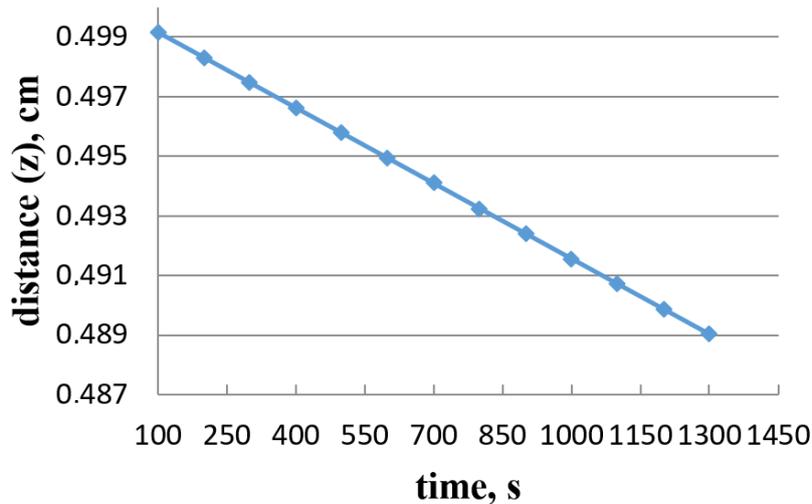


Figure 4. The plot of the distance the passable by particles along the z axis from time.

At the initial moment of time, because of the low settling velocity, the resistance of the fluid is small, and the particles move at an accelerated rate. With further increase in velocity, the frictional force becomes equal to the force of sedimentation. It can be seen from graph 3 that the particle velocity during a time of the order of 10^{-6} s is established and move with a constant speed. It can be seen from graph 4 it is visible that the position of the particle along the z axis changes by 0.001 cm in 100 s. It should be noted that in the preparation of a magnetic fluid, a stabilizing agent (surfactant) was not used. The absence of surfactants leads to the sedimentation of particles and the stratification of the magnetic fluid over time. Several minutes were spent for performance of measurements. It allows to consider magnetic liquid as steady system and to neglect influence of sedimentation of particles in the course of measurement of change of magnetic field.

3. Method and result of experimental study

Each atom of magnetic substance produces a tiny magnet or magnetic dipole, so total magnetization of substance is achieved when all the single atomic magnets are built into a certain order. In this way, the presence of the magnetic moments leads to their orientation longer axis along direction of field. Due to their interaction, they can uniting be combined chain aggregates under effect of the magnetic field (Figure 5) [11].

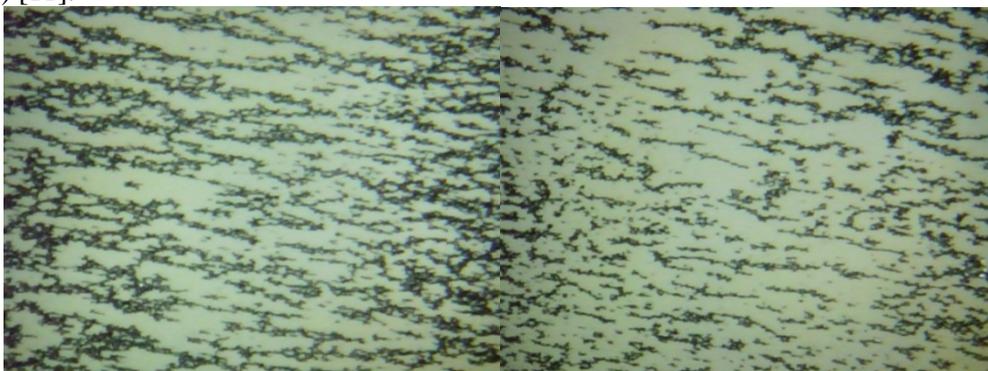


Figure 5. The formation of chain aggregates of carbonyl iron.

It is assumed that the formation of chain structures can lead to significant changes in the magnetic and other properties of ferrofluids which influence on change of capacity of the condenser filled with magnetic liquid. The capacitance measurement was carried out on an E7-12 device. To study the effect

of a magnetic fluid on the electrical parameters of a cell, it was subjected to an external magnetic field. Figure 6 shows the scheme of the experiment.

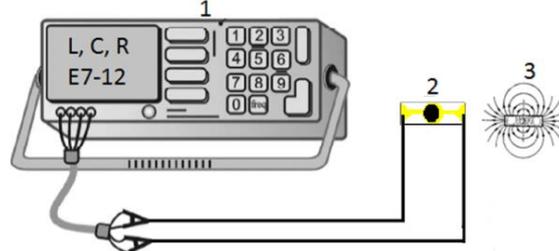


Figure 6. Experimental setup for studying the effect of a magnetic field on a magnetic fluid in a capacitor, where 1 is a meter of L, C, R type E7-12; 2 – a condenser on a ceramic plate with a magnetic fluid; 3– the magnet.

The magnetic field was created by a permanent magnet. To determine the strength of the magnetic field (magnetic induction) of the magnet acting on the measuring cell, a microteslameter MT-10 was used.

The coordinates of the position of the magnet are (x: y: z): (i: 0: 0); (-i: 0: 0); (0: i: 0); (0: -i: 0); (0: 0: i), where i = 20, 15, 10, 5 mm (the distance from the magnet to the sensor). The distance was measured on millimeter paper.

Before the experiment by influence of the magnet field on the electrical parameters of the cell with the magnetic fluid, we have measured induction of magnetic field in the place of an experiment. The magnetic field induction was 84 μ T. Then a cell with a magnetic fluid of carbonyl iron was placed at the site of the experiment. The magnetic field of the magnet was applied to the measuring cell in five directions ((i: 0: 0); (-i: 0: 0); (0: i: 0); (0: -i: 0); (0: 0: i)). In Table 1 values of relative change of capacity the condenser with magnetic fluid depending on concentration of particles in magnetic fluid and induction of magnetic field are given.

Table 1. Relative change of capacity from the position of the magnet in space

| | The concentration of particles in a magnetic fluid, 10 % | | | | The concentration of particles in a magnetic fluid, 40 % | | | |
|--|--|-------|-------|-------|--|-------|-------|-------|
| Capacitance of a capacitor with a magnetic fluid without the action of a magnetic field, pF | 0.993 | | | | 1.118 | | | |
| Distance from magnet to sensor (mm) | 20 | 15 | 10 | 5 | 20 | 10 | 5 | |
| The magnetic field strength of a magnet, (μ T) | 35.9 | 50 | 65.5 | 105 | 35.9 | 65.5 | 105 | |
| Location of the magnet relative to the condenser with magnetic fluid | (i:0:0) | 0.993 | 0.993 | 0.995 | 0.998 | 1.118 | 1.150 | 1.15 |
| | (-i:0:0) | 0.993 | 0.993 | 0.996 | 1.005 | 1.118 | 1.135 | 1.142 |
| | (0:i:0) | 0.993 | 0.993 | 0.996 | 1.001 | 1.118 | 1.150 | 1.170 |
| | (0:-i:0) | 0.993 | 0.994 | 0.999 | 1.002 | 1.118 | 1.135 | 1.167 |
| | (0:0:i) | 0.993 | 0.994 | 1.001 | 1.008 | 1.118 | 1.138 | 1.180 |
| The relative change in capacitance (Δ C.%) under the influence of the magnetic field of the magnet | 0 | 0.04 | 0.44 | 0.98 | 0 | 2.1 | 3.9 | |

4. Conclusion

Thus, the results of the studies showed the possibility of detecting the change in the magnetic field produced by the magnet. The change in capacitance of a capacitor with a magnetic fluid is caused by the structurization processes proceeding in them. Table 1 shows that the sensor element based on the capacitor plate reacts to the magnetic field in all directions. In this case, the orientation sensitivity of the sensor element is practically independent of the position of the magnet in space. However It should be noted that there is a shortcoming, namely after influence by magnetic field on solution of a ferromagnetic, iron particles adopt the chaotic provision not at once. Because of this, further measurement accuracy suffers. For increase of sensitivity to weak magnetic field it is necessary to use particles of an anisotropic form with high magnetic permeability [9,13]. In order that energy of an attraction between particles didn't exceed energy of the chaotic movement, it is necessary to add to ferromagnetic liquid the substances consisting of polar organic molecules which create on a surface of disperse particles of the adsorption-solvate layers. This will also preserve the stability of the magnetic fluid and the particles will not settle in the gravity field, so that the magnetic fluid can retain its properties for a long time.

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