IOP Conf. Series: Journal of Physics: Conf. Series **881** (2017) 012037 doi:10.1088/1742-6596/881/1/012037

Detection of the change of a magnetic field in the environment by magnetic fluid

D Zyatkov[1], A Yurchenko[1, 2] and V Yurchenko[3]

[1] National Research Tomsk Polytechnic University, Tomsk, Russia
[2] National Research Tomsk State University, Tomsk, Russia
[3] Research Institute of Semiconductor Devices, Tomsk, Russia

E-mail: zyatkov.88@mail.ru

Abstract. The experimental results of the magnetic field sensor based on various materials are presented. In article the possibility of use of magnetic fluid as a sensitive element of the magnetic field sensor is considered. The importance of current tasks deals with the search of the perspective magnetic substances susceptible to weak magnetic field. The operation principle of the sensor is based on change in the capacity of the condenser with magnetic active medium caused by the magnetic field. The complex organization of magnetic particles into chain aggregates was considered. The principle of measuring the condenser capacity is described. The experimental results are promising for future application.

1. Introduction

Ferromagnetic fluids are colloidal suspensions of magnetic particles stably dispersed in a carrier liquid. Such fluids are able to interact with the magnetic field. The properties of the magnetic fluid are determined by the size of magnetic particles, their properties, surface-active substance and carrier liquid. Generally, the magnetic fluid consists of 10 nm magnetic particles. These particles are coated with a surface-active substance and the liquid carrier can be polar or nonpolar [1].
Magnitude magnetic susceptibility of the magnetic fluid increases with the size of magnetic particles and their concentration. However, as the particle size increases, the sedimentation stability due to adhesion particles is violated because they have big magnetic moments.

The magnetization of the magnetic fluid depends on the volume concentration of the magnetic particles, the magnetic moment of the particles, the applied magnetic field and the energy of thermal motion [2]. These ferromagnetic fluids have attracted research interest because of a combinations of factors: they have good fluidity, they actively respond to an external magnetic field, and their physical properties we can control by external fields [3].

The magnetic properties of the particles are determined by many factors, such as: chemical composition, type of a crystal lattice and degree of its deficiency, the size and a form of particles, composition and structure of the particles, the interaction of particles with a liquid carrier and the neighboring particles [4]. Changing these parameters, you can change the magnetic properties of magnetic fluids. Article [2] said that the extended (in the form of “needles”) particles or flat (in the form of “disks”) particles easily give in to magnetic texturing (ordering of the directions of the magnetic axes of the particles). Furthermore, non-spherical particles have an additional source of magnetic anisotropy (shape anisotropy) [2]. In an external magnetic field, particles form the chains extended along a vector of this field. The processes of association and aggregation of particles in external magnetic fields are central to the physics of magnetic colloids and also they determine magnetic, optical, acoustic, and other rheological properties of magnetic fluid. The change of the magnetic properties of magnetic fluid due to the formation of aggregates is considered in [5, 6, 7] with different points of view.

The research of microstructuring processes of magnetic suspensions in weak magnetic fields with application of particles of different dispersion and high magnetic permeability is poorly studied. The relevance of a research can be caused by the practical application of its results for creation of sensors of weak magnetic fields.

Usually, magnetic fluids investigate in strong magnetic fields ($B = 10^{-3} – 10^{3}$ T). The study of structuring mechanism of magnetic particles in the liquid matrix under the influence of a weak magnetic field ($B = 10^{-6} – 10^{-9}$ T) and creation of model of omposition 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. Therefore, the research of influence of magnetic particles of different shapes and dimensions, which are a part of magnetic fluids, on the formation of chain-like structures under the magnetic field is an urgent task [8-10].

2. Experiment

In experimental research it was used the magnetic fluid, which is based on the polymethylphenylsiloxane. Magnetic fluid have following dispersions of magnetic particles: 1. iron nanoparticles (dimension is 100 nm); 2. carbonyl iron particles which have particle 2 – 5 micron; 3. particles of a nanocrystalline alloy that have a size 5-40 micron; particles of a nanocrystalline alloy that have a size 50-56 micron. The concentration of magnetic powder in PFMS-4 is not above 15 volume percent. It should be noted that during process of preparation of magnetic liquid the stabilizing agents (surfactant) aren't applied. It led to a sidementation of particles of magnetic powder and stratification of magnetic liquid over time. By reason of rapidity of performance of measurements (less than a minute), it allows one to consider magnetic fluid as a stable system in the process of measurement and the influence of the sedimentation of particles on its properties is neglected.

The next step was to put suspension in measuring cell from dielectric insulation material and having form of cylindrical vessel provided with two plane-parallel plates with flexible leads. The distance between the plates is equal to 3 mm and them area is equal to 10 mm2. Active dielectric (magnetic fluid) is placed between the plates. Figure 1 shows the scheme of measuring cell and measuring scheme.

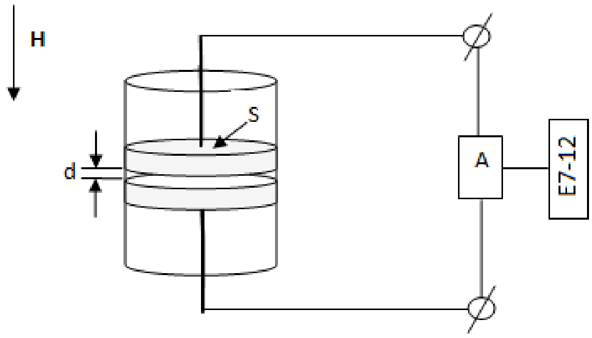

Figure 1. The scheme of measuring cell and measuring scheme:
A - contact device (adapter) of meter E7-12.

Capacity of the measuring cells was measured with the help of digital L, C, R meter type E7-12 with adapter to reduce the influence of parasitic parameters (Figure 2).

Figure 2. Digital L, C, R meter type E7-12 and magnet for the experiment:
1–E7-12, 2–adapter, 3- magnet.

Measuring cell with fine-dispersed magnetic particles is installed in the adapter slots (2). In order to create a magnetic field used permanent magnet (3) (Figure 2). To determine force of magnetic field (magnetic induction) of the magnet which acts on the measuring cell, microteslameter MT-10 is used.

3. Result and discussion

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 μT. Cell of the magnetic fluid with nanoparticles of iron which have dispersion 100 nanometers and then cell of carbonyl iron of dispersion 2-3 μm and then cell of particles of a nanocrystalline alloy of dispersion 5-40 and 50-56 μm were set.

The threshold of detection of induction of the magnetic field created by a magnet and change of capacity of the condenser under the influence of this field is shown in table 1

Table 1. Threshold of detection and change of container of the condenser with different magnetic fluid.

The induction of magnetic field created by a magnet, B (μT)	Capacitance of a capacitor with a magnetic fluid, C (pF)				
	The magnetic fluid consists of carbonyl iron and glycerin	The magnetic fluid consists of carbonyl iron and PFMS	The magnetic fluid consists of nanoiron and PFMS	The magnetic fluid consists of particles of a nanocrystalline alloy of dispersion 5-40 μm and PFMS	The magnetic fluid consists of particles of a nanocrystalline alloy of dispersion 50-56 μm and PFMS
0	4.985	0.451	0.626	0.445	0.478
38	-	-	-	0.449	-
42	-	-	-	0.453	-
47	-	-	-	0.456	-
53	-	-	-	0.465	-
59	-	-	-	0.466	-
67	4.995	-	-	0.469	0.486
76	5.000	-	-	0.473	0.488
86	5.006	-	-	0.479	0.492
98	5.010	-	-	0.485	0.496
114	5.014	-	-	0.49	0.499
130	5.021	0.453	-	0.496	0.505

As shown in table 1, the threshold of detection of the magnetic field created by a magnet has next value, for carbonyl iron in PFMS is equal to 130 μT, for carbonyl iron in glycerin is equal to 67 μT, for particles of a nanocrystalline alloy of size 5-40 micron is equal to 38 μT, for particles of a nanocrystalline alloy of size 50-56 micron is equal to 67 μT.

Each atom of magnetic substance produces a very small magnet or magnetic dipole, so maximum of magnetization of substance is achieved when all the single atomic magnets are built into a certain order. Magnetization in a ferromagnetic is created by the spin magnetic moments. The presence of the magnetic moments leads to the emergence of the rotating moment, which acts on randomly located particle with respect to the magnetic field direction. In this way, the presence of the magnetic moments leads to their orientation along on direction of vector of field . As a result of their interaction, they can be combined to form of chain-like aggregates (Figure 3).

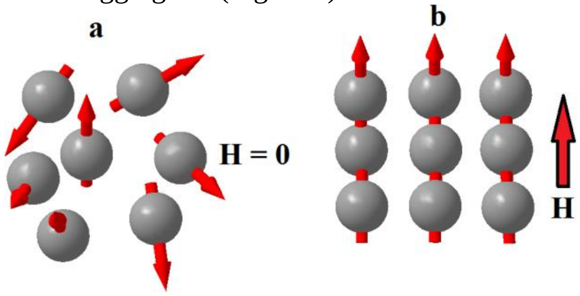

Figure 3. Dependence of orientation of magnetic particles on the direction of magnetic field where a – the magnetic particles without a magnetic field, b – the formation of chain aggregates by the influence of the magnetic field.

In a case absence of magnetic field, the magnetic moment of a particle seeks to be oriented in the direction of one of axes of the easiest magnetization of magnetic field of space, to provide a minimum of the total magnetic anisotropy energy. When creating a magnetic field by magnet , magnetic force μ_0 $(m\nabla)\, H$ and the moment $\mu_0\, [m \times H]$ act on the particle in the space. In consequence of particle start to moving. A uniform magnetic field orients the magnetic moments. Local equilibrium occurs when the magnetic moment m is parallel to the effective field H_{eff}, which is composed of an external magnetic field H and the field of anisotropy particles H_a. The inhomogeneous magnetic field draws the solid particles in the region of a strong field, causing it to move in the direction of the magnetic field gradient.

4. Conclusion

The experiment apparently shows that sensitivity of magnetic fluid with particles of a nanocrystalline alloy of size 5-40 micron to low magnetic field is higher than in other cases. Under the influence of the magnetic field on the capacitive sensor element with the magnetic fluid, the particles aggregate in chain aggregates due to interaction of the magnetic moments. Such structure formation leads to the change of the electrical properties of ferromagnetic fluids, including changes in dielectric permeability. As a result, the capacity of the condenser with a ferromagnetic fluid changes. According to the results of the experimental study we can draw a conclusion that capacitive cells with ferromagnetic fluid are responsive to an change external magnetic field due to orientation of magnetic particles and their interaction.

References

[1] Taketomi S and Chikazumi S 1988 *Magnetic Fluids-principle and Application* (Tokio: Nokkan Kogyo Shinbun)
[2] Gubin S P, Koksharov Y A, Homutov G B and Yurkov G Y 2005 *Russ. chem. rev*. **74(6)** 541-74 (in Russian)
[3] Zubarev A Yu and lskakov L Yu 1995 *JETP* **80(5)**

[4] Baranov D A and Gubin S P 2009 *RENSIT* **1(1-2)** 129-147

[5] Liao W H and Krueger D A 1979 *Journal of Colloid and Interface Science* **70(3)** 564-76

[6] Jordan P C 1973 *Molecular Physics* **25(4)** 961-73

[7] Bogardus E H, Krueger D A and Thompson D 1978 *J. Appl. Phys.* **49(6)** 3422-9

[8] Zyatkov D O, Yurchenko A V, Balashov V B and Yurchenko V I 2016 *Journal of Physics: Conference Series* **671** 012065

[9] Dolgih (Ivanova) A, Martemyanov V 2013 *International Siberian Conference on Control and Communications SIBCON 2013* 6693632

[10] Zyatkov D O, Kozubova M A, Yurchenko A V, Balashov V B and Yurchenko V I 2016 *Technology of radio communication* **2(29)** 92-100 (in Russian)