Capacitive Sensor of Weak Magnetic Field on the Basis of Feromagnetic Fluid with Micro- and Nanoscale Particles

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Abstract— 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 results of a research of the capacitive sensor of magnetic field with ferromagnetic fluid are presented. Formation of chained structures from magnetic particles in ferrofluid by the influence of the magnetic field leads to change of magnetic properties of ferrofluid. The sensor is based on the change of the capacitance with an active dielectric (ferrofluid) on the magnitude of magnetic field.

1. INTRODUCTION

Magnetic fluid is a colloidal suspension of ferromagnetic particles in the carrier liquid (kerosene, water, mineral and silicone oils, etc.). Magnetic properties of ferromagnetic fluids are caused by the substance of a solid magnetic component which can reach 25 volume percent. The magnetic permeability of ferromagnetic fluids is higher than at homogeneous paramagnetic fluids, and its value can reach several tens [1, 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 [5] 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) [5]. 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 [6–11] 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 ($B = 10^{-3}$–$10^{3}\,\mathrm{T}$. The study of structuring mechanism of magnetic particles in the liquid matrix under the influence of a weak magnetic field ($B = 10^{-6}$–$10^{-9}\,\mathrm{T}$ 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. 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.

2. MODEL OF INFLUENCE OF MAGNETIC FIELD

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 of semimajor axis on direction of field (in case of particles have anisotropic shape). As a result of their interaction, they can be combined to form of chain-like aggregates (Fig. 1) [3].

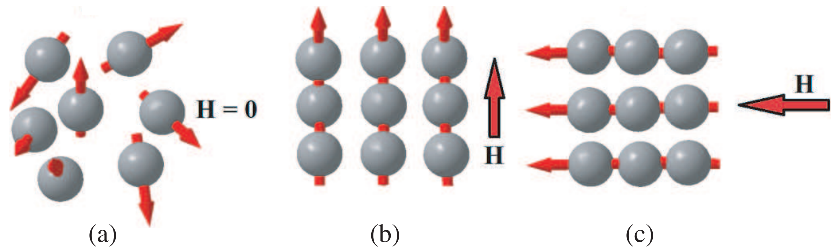

Figure 1: Dependence of orientation of magnetic particles on the direction of magnetic field where (a) — the magnetic particles without a magnetic field, (b), (c) — the formation of chain aggregates by the influence of the magnetic field.

It is supposed, that the formation of chain-like structures can lead to considerable changes of magnetic and other properties of ferrofluids which show up as change of capacity of the condenser filled with magnetic liquid [12–14].

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 $\mu_0(m\nabla)H$ 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 [14–17].

3. OBJECT AND METHOD OF EXPERIMENTAL RESEARCH

Magnetic fluid has been used in experimental investigations. It consists of a polimetilfenilsiloksan (PFMS-4) which have following dispersions of magnetic particles: 1. iron nanoparticles (dimension is 100 nm); 2. carbonyl iron nanoparticles which have particle 2 — 5 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 mm^2. Active dielectric (magnetic fluid) is placed between the plates. Figure 2 shows the measuring cell with a magnetic fluid.

The capacity change of the cell was measured by digital L, C, R meter type E7-12 with an adapter which reduces of influence of stray parameters on the frequency of the measuring signal of

Figure 2: The measuring cell with a magnetic fluid.

1 MHz. To study the influence of the magnetic fluid on the electrical parameters of the cell, external magnetic field was affected on the cell. The measurements of cell capacity were made under the influence of the magnetic field which was parallel and perpendicular to measuring electric field. Figure 3 shows the experimental setup.

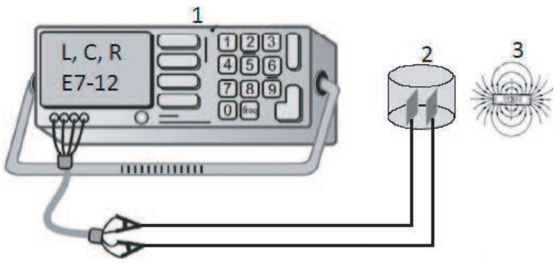

Figure 3: Experimental installation of research of the magnetic field influence on the magnetic fluid in the condenser, where 1 — meter L, C, R type E7-12; 2 — the measuring cell filled by the studied liquid; 3 — magnet.

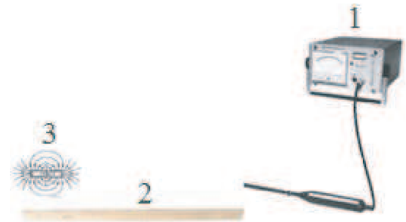

Figure 4: The scheme of measurement of induction of magnetic field of a magnet from distance to a microteslameter, where 1 — microteslameter MT-10; 2 — measuring ruler; 3 — magnet.

The magnetic field was created by a permanent magnet. To determine force of magnetic field (magnetic induction) of the magnet which act on the measuring cell, microteslameter MT-10 is used. To this indication, microteslameter MT-10 was established on zero. Magnet shifted along a measuring ruler, and on the basis it we can determine distance between a magnet and a microteslameter, consequently it allows us to find force of field of the magnet which acts on microteslameter (Figure 4).

The Figure 5 shows a graph of dependence of magnetic field force (magnetic induction) of a magnet from distance to the sensor of a microteslametr.

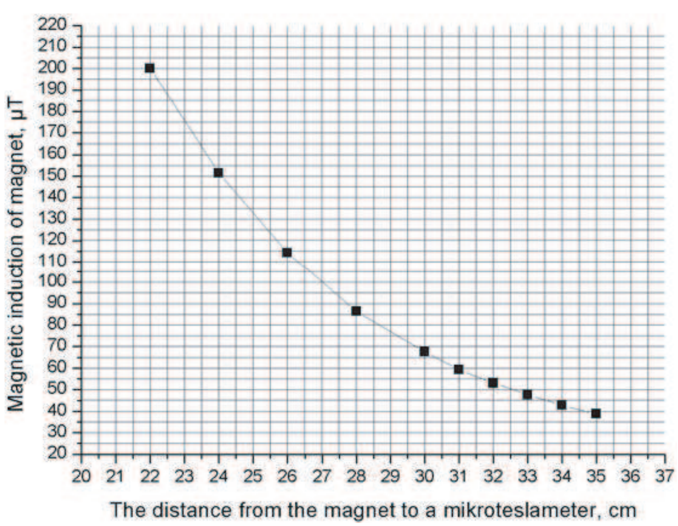

Figure 5: The dependence of the induction of magnetic field of a magnet from distance.

Measurement of magnetic field induction, created by the magnet, was carried out on the distance up to 22 cm, because the range of measurement of magnetic field induction of microteslametr is ±200 μT.

4. RESULTS OF RESEARCHES

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 were set. Action by field of a magnet on a measuring cell was carried out in two directions: 1. parallel to measuring electric field of a cell; 2. perpendicular to the measuring electric field of a cell. The figure 6 shows the dependence of the cell capacity with the magnetic fluid of nanoparticles of iron and of carbonyl iron on the distance between cell and magnet. It should be noted that in the case magnet shifted parallel to electric field of a cell.

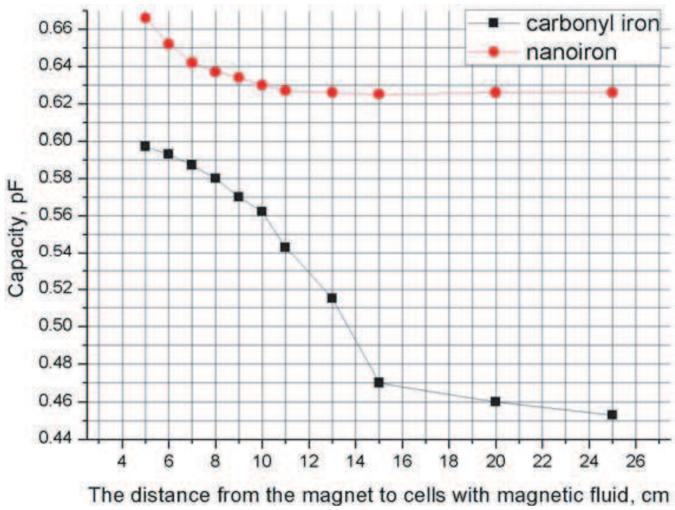

Figure 6: The dependence of the cell capacity with magnetic fluid on distance between a cell and a magnet, where induction of field of a magnet is directed parallel to measuring electric field of a cell.

The Figure 7 shows the dependence of the cell capacity with a magnetic fluid of iron nanoparticles and of carbonyl iron on the distance between cell and magnet. It is noted that in the case magnet shifted perpendicular to electric field of a cell.

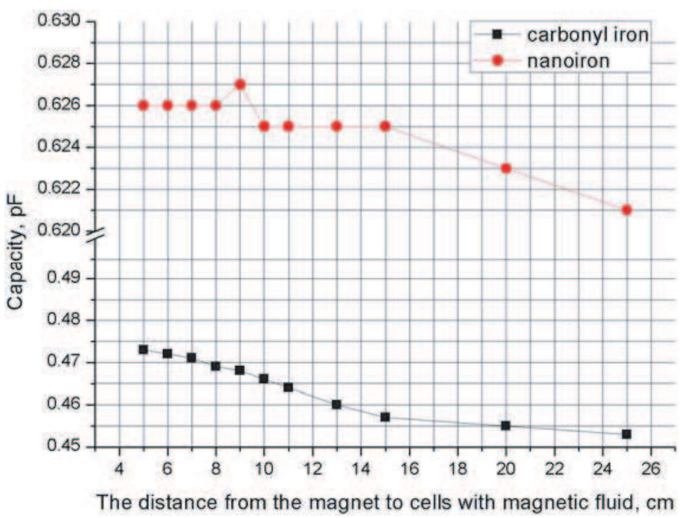

Figure 7: The dependence of the cell capacity with magnetic fluid on distance between a cell and a magnet, where induction of field of a magnet is directed perpendicular to measuring electric field of a cell.

As shown in Figures 6 and 7, the most sensitivity to the magnetic field has a carbonyl iron in PFMS-4, when the magnetic field is directed parallel to the electric field of a cell. To increase in sensitivity we use magnetic fluid with carbonyl iron in glycerin, which has a viscosity less than at PFMS-4. The field of a magnet is directed parallel to measuring electric field of the cell (Figure 8).

As shown in Figure 8, the threshold of detection of the magnetic field created by a magnet has decreased from 130 μT to 70 μT (Figure 5), due to reduction of viscosity of the liquid carrier, which increased the mobility of the magnetic particles.

To larger sensitivity it is necessary to use particles of an anisotropic form (in the form of needles or disks) with high magnetic permeability of particles [13].

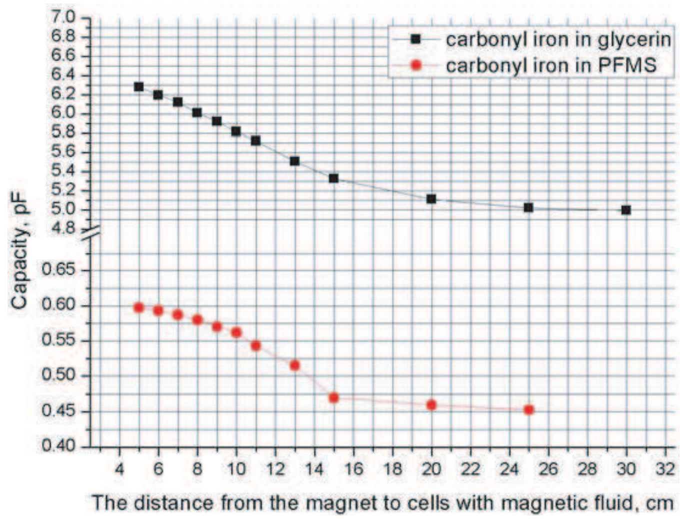

Figure 8: The dependence of the cell capacity with different liquid carriers on distance between a cell and a magnet, where induction of magnetic field of a magnet is directed parallel to measuring electric field of a cell.

5. CONCLUSION

Thus, results of the conducted researches lead to the conclusion about the possibility of detecting a weak magnetic field created by a magnet. Change of capacity condenser with magnetic fluid is caused by the structurization processes, the sizes of particles in liquid carriers and different viscosity. Varying such parameters as the size and the configuration of particles, the liquid carrier, magnetic permeability of particles we can increase the sensitivity of the capacitive sensor with the magnetic fluid to the magnetic field.

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