The Capacitive Magnetic Field Sensor

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Abstract. The results of a study of sensitive element magnetic field sensor are represented in this paper. The sensor is based on the change of the capacitance with an active dielectric (ferrofluid) due to the magnitude of magnetic field. To prepare the ferrofluid magnetic particles are used, which have a followingdispersion equal to 50 < Ø ≤ 56, 45 < Ø ≤ 50, 40 < Ø ≤ 45 and Ø ≤ 40micron of nanocrystalline alloy of brand 5BDSR. The dependence of the sensitivity of the capacitive element from the ferrofluid with different dispersion of magnetic particles is considered. The threshold of sensitivity and sensitivity of a measuring cell with ferrofluid by a magnetic field was determined. The experimental graphs of capacitance change of the magnitude of magnetic field are presented.

1.Introduction

Naturally occurring liquidsweakly interact with the magnetic field. However, the ability to control fluid by a magnetic field is attractive in quite a number of technical problems. To solve these problems magnetic fluid was invented in 1960. Magnetic fluids or ferrofluids are colloidal suspensionsof magnetic particles dispersed stably in a carrier liquid. The properties of the magnetic fluid are determined by the size magnetic particles, property of this particle, surface-active substance and carrier liquid. Parameters of ferrofluid depend on the composition of magnetic liquid.Magnetization of magnetic liquid on a magnetic fielddepends on the chemical composition of the substance and its structure. Magnetic liquids thanks to itsthe properties are perspective materials and they have different application in various areas of measurement technology [1, 2].

These fluids have very unusual physical phenomena, sometimes a unique combination of strong magnetic properties and fluidity.

Generally, magnetic fluid consist of magnetic particles of size 10 nm [2].

Existence of a uniform suspension of small particles in magnetic fluid without settling occur with magnetic particles of size 10 nm.In this case, the thermal motion is sufficient to maintain the particles in suspension [2, 3].

However, with increase of the particles size sedimentation stability due to adhesion particles is violated because they have big magnetic moments.

However, sedimentation stability is violated due to increase of the particles size. It takes place because of agglomeration of particles at the expense of the big magnetic moment. Also separation of particles occur in its gravitational force field due to difference of densities solid and fluid phases.

In order to avoid agglomeration of particles and to prevent subsidence (sedimentation) by gravitational force field due to integration of particles (formation of lumps), it is necessary to stabilize particles in the liquid carrier [4].

Surface – active substances which are adsorbed on a surface of particles, forming a thin covering with a thickness 3–4 nm are used for this purpose. The covering is enough in order to particles aren't approached each other within short distance, when the forces of interaction between particles which lead to aggregation of particles, will dominate [5, 6].

Chain aggregates due to interaction of particles are formed [7]. Average number of particles in chain aggregates is determined by the parameter of the its magnetic-dipole interaction and concentration of the magnetic fluid. In a weak field the chain aggregates due to thermal fluctuations has a “vermiform” appearance.The formation of chain aggregates is capable of leading to considerable changes of magnetic and other properties of ferrofluids which are appeared in capacity change of the condenser [8, 9].

Thus, the our researchis the creation of a capacitive sensor with ferrofluid for fixation and control of weak magnetic fields.

2. Object and methods of experimental research

Magnetic fluids in experimental investigations are used. Thesemagnetic fluids consist of a polimetilfenilsiloksan (PFMS-4) which have a following dispersions of magnetic particles: 50 < Ø ≤ 56, 45 < Ø ≤ 50, 40 < Ø ≤ 45 and Ø ≤ 40microns. These magnetic particles were obtained by grinding of ribbonnanocrystalline alloy in an agate mortar and siftingits through 56, 50, 45 and 40 micron sieve.The concentration of magnetic powder in PFMS-4 was 15 volume percent.

Measuring cell had the form of a dielectric cylindricity vessel which made from the insulation material and 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) between the plates is placed. Figure 1 shows the experimental setup layout.

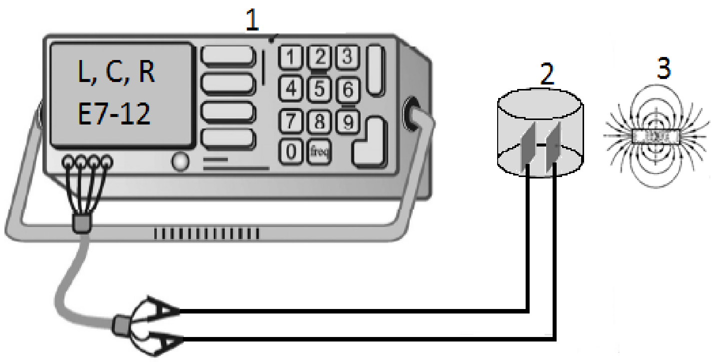

Figure 1. Experimental setup to study the magnetic fluid, where 1 – measuring device, 2 – electrical measuring cell filled with magnetic fluid, 3 – magnet.

The capacity of plane condenser consisting of two parallel plates (figure1) is determined from the formula:

$$C = \frac{\varepsilon\varepsilon_0 s}{d}$$

where*s* – the area of electrodes, *d* – the distance between electrodes, ε_0 – dielectric constant, ε – the dielectric permeability of the medium filling the space between the plates.

The capacity change of measuring 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 1

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MHz.It should be noted that the value of the experimental measuring electrical field of cell was weak enough and didn't have effect on the structural state of the emulsion in a measuring cell, that is, the structure of emulsion is formed only under applied external magnetic field. To study the effect of magnetic fluid on the electrical parameters of the measuring cell it was exposed toan external magnetic field. The measurements were made under magnetic field which is oriented parallel and perpendicular of the orientation of the measuring electrical field. The magnetic field was created by a permanent magnet.

It is should be noted that surface-active substance was not used, because the measurements were taken a couple of minutes, therefore, the magnetic fluid can be considered as a stable system and the sedimentation of particles is neglected.

3. The results of experimental studies

To determine greatest sensitivity of magnetic particles on dispersion from magnetic field, the measuring cell filled the study magnetic fluid which has different dispersion of particles was exposed to action of the external magnetic field created by a permanent magnet.The action of a magnetic field leads to the capacity change of a measuring cell due to reorganization and structuring suspension (figure 2 and figure 3).

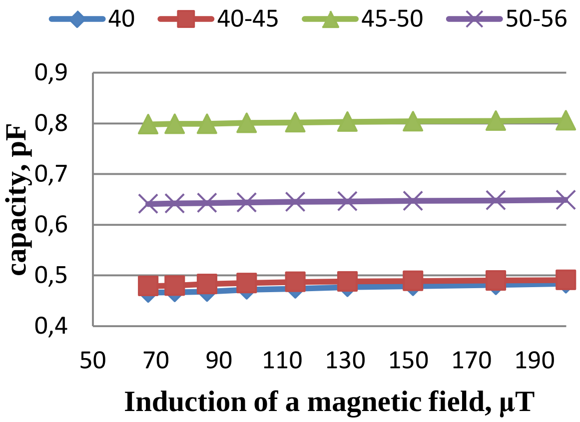


Figure 2. The capacity change of a measuring cellin the perpendicular orientations of the external magnetic and measuring electrical fields.

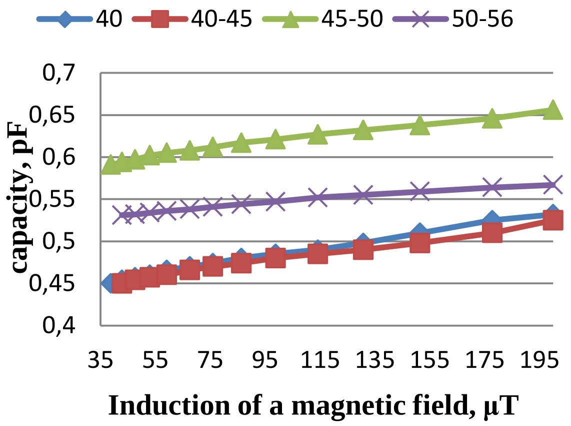


Figure 3. The capacity change of a measuring cellin the parallelorientations of the external magnetic and measuring electrical fields.

In that way, the capacity change is equated with the change of mutual positioning of particles in the fluid. The mutual ordering of particle distribution are sited along the magnetic field vector. Figure 4 and figure 5 shows the dependence of the relative capacity change of a measuring cell with magnetic particles of different dispersions: 50< Ø ≤ 56, 45< Ø ≤ 50, 40 < Ø ≤ 45 and Ø ≤ 40 micron from the magnitude of the magnetic field in the various mutual orientations of the magnetic and electric fields.

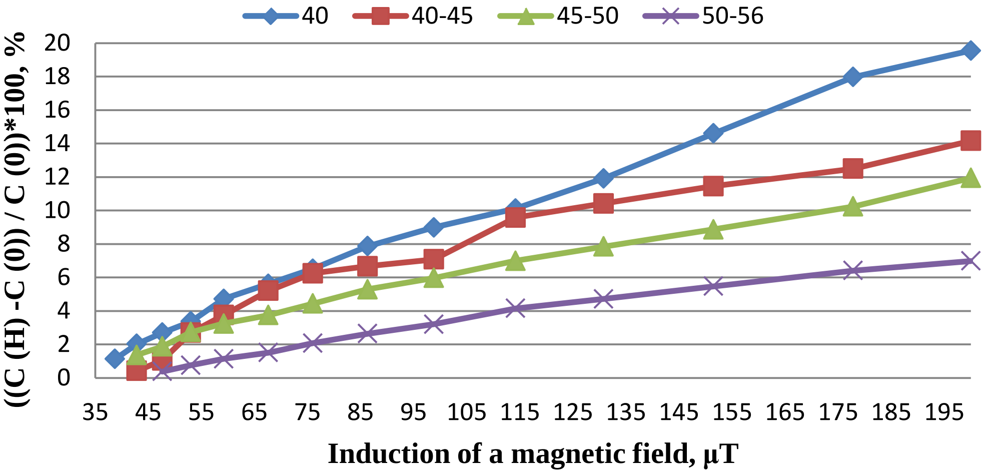


Figure 4. The relative capacity changein the parallelorientations of the external magnetic and measuring electrical fields.

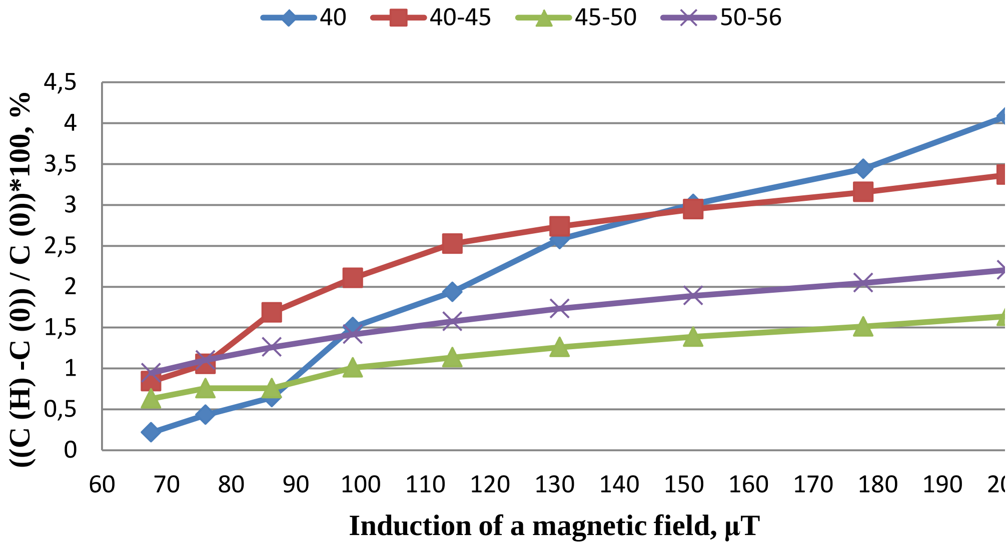


Figure 5. The relative capacity changein the perpendicular orientations of the external magnetic and measuring electrical fields.

The relative capacity change is defined from the formula:

$$\Delta C = \frac{C(H) - C(0)}{C(0)} * 100\%$$

where *C(H)*is the capacity of measuring cell in dependence from the magnetic field, *C(0)* – the capacity of measuring cell in case absence magnetic field.

Figure 4 shows a consistent decrease of the sensitivity threshold of a measuring cell with the magnetic fluid by decreasing the size of the magnetic particles. The threshold of sensitivity (figure 4) for particles which have a size of dispersion less 40 microns is equal to 38.7 µT. Given the linear dependence, we can assume, that further decrease of particle size will be reduced threshold of sensitivity to the magnetic field in case accounting of linear dependence.

The threshold of sensitivity is the lower-range value of the magnetic field magnitude, which generated appearance output signal.

Figure 6 the sensitivity (S) of a measuring cell with the magnetic fluid depending on the dispersity of the particles in a carrier liquid is presented.

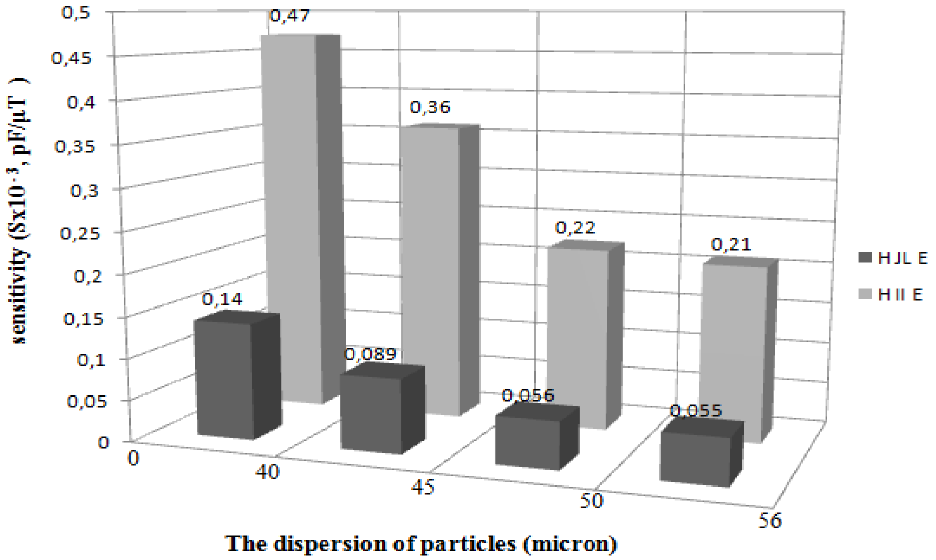
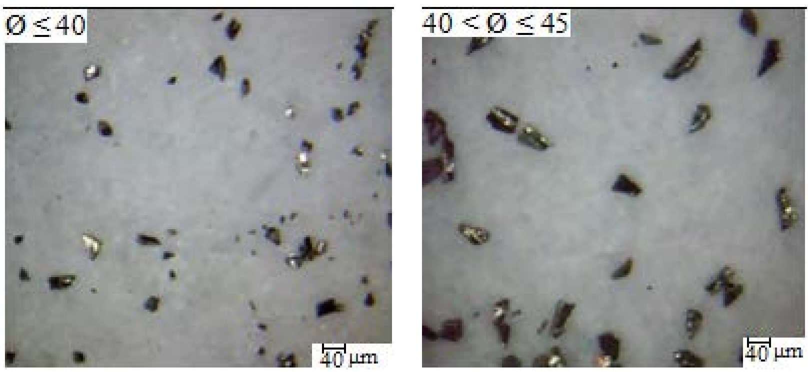
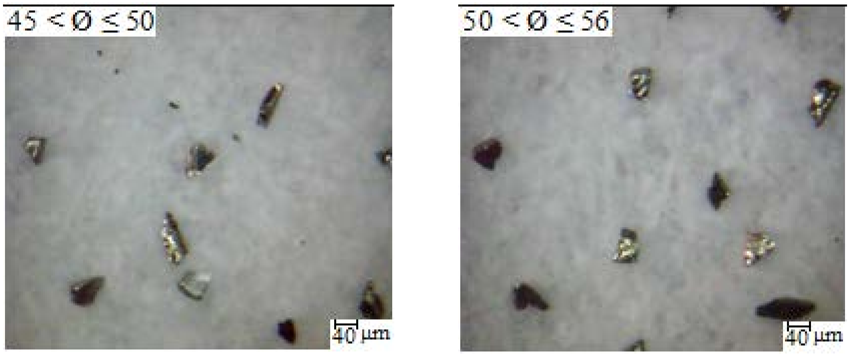


Figure 6. The sensitivity of a measuring cell with the magnetic fluid depending on the dispersity of the particles.

Figure 7 shows a photograph of the particles of dispersity:50 < Ø ≤ 56, 45 < Ø ≤ 50, 40 < Ø ≤ 45 and Ø ≤ 40 micron.



a) b)



c) d)

Figure 7. The dispersion of particles: Ø ≤ 40 (a), 40 < Ø ≤ 45 (b), 45 < Ø ≤ 50 (c) and 50 < Ø ≤ 56 (d) micron.

Figure 7 shows that the particles have extended (in the form of "needles") or flat (in the form of "disks") forms and according to [10] they are easier to magnetic texturing, i.e. the ordering of the directions of the magnetic axes of the particles.

4. Conclusion

According to the results of experimental research it can be concluded that magnetic particles move in the liquid matrix orientating across the field by changing the physical characteristics of the matrix. Figure 4 shows a consistent decrease of the sensitivity threshold due to decreasing the size of the magnetic particles. The detection limit of the magnetic field by a measuring cell with the magnetic fluid in the parallel orientation of the external magnetic and measuring electrical fields is equal to 38.7 µT when use a dispersion of particles less 40 microns. The sensitivity of the measuring cell to the magnetic field is 0.47 fF/µTby the parallelorientations of the external magnetic and measuring electrical fields and 0.14 fF/µT by the perpendicular orientations of the external magnetic and measuring electrical fields.

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