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About one Estimation of Physical Parameters of Magnetic Fluid Nanoparticles

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Abstract: The possibility of the estimation of magnetic moment and size of the magnetic nanoparticles of magnetic fluid by measuring results of acoustomagnetic effect field dependence in relative value in magnetic fields near to saturation is considered in this article. Three samples with various concentrations of a magnetic phase are obtained.

Key words: Magnetic fluid . acousto-magnetic effect . magnetic nanoparticles

INTRODUCTION

In the last years the materials with nanostructure have been paid much attention. Methods for the property analysis of such materials are improved. The possibility of the estimation of magnetic moment and size of the magnetic nanoparticles, dispersed into magnetic fluid, by measuring results of Acoustomagnetic Effect (AME) field dependence in relative value in high magnetic fields is considered in this article.

The AME essence consists of the electromagnetic waves emission of a column of a magnetized Magnetic Fluid (MF), when a sound wave propagate in it [1-3]. The voltage induced in contour is proportional to amplitude of the fluid magnetization fluctuations, caused mainly the concentration fluctuations of the disperse phase particles.

EXPERIMENTAL BASE

The scheme of the experimental unit is presented in Fig. 1. Vertically established glass tube with a flat bottom 1 is filled with a magnetic fluid. The sound fluctuations source is the piezoelectric plate 3, on which the ac voltage of the set frequency moves from the generator 4. The frequency is supervised by the frequency meter 5 and voltage by the voltmeter 6. The semicircle inductor 8, placed in immediate proximity to the external tube surface, is rigidly connected with the kinematic unit of the cathetometer 9. The voltage from the inductor enters on the broadband amplifier 10 from which exit moves on an oscilloscope 11 and external analog-to-digital converter NI USB-6251 BNC 12, connected to the laptop 13. The magnetic field source is the constant electromagnet FL-1 14 connected to the power supply 15. The magnetic induction value is defined by the tesla meter 16, supplied with the Hall probe 17. Thermostating is carried out by the thermostat 18. The program developed in NI LabView performs the filtration of the received signal; its decomposition in the spectrum for the control of radio noise level, the definition of the frequency and amplitude of AME, calculation of MF parameters' and the construction of the investigated dependences graphs.

THEORETICAL JUSTIFICATION

In small intervals of change of temperature T, magnetic intensity H and particles concentration n it is possible to present the equilibrium magnetization value of compressible MF M_e in the linear dependence form as follows:

$$M_e = M_0 + M_n \delta n + M_T \delta T + M_H \cdot \delta H \qquad (1)$$

where M_0 is magnetization,

$$M_n \equiv \left(\frac{\partial M}{\partial n}\right)_0, \; M_T \equiv \left(\frac{\partial M}{\partial T}\right)_0, \; M_H \equiv \left(\frac{\partial M}{\partial H}\right)_0$$

relate to the unperturbed medium.

Energy and continuity equations with reference to the plane sound wave, propagating in MF along an axis 0X, allow one to derive the following equations:

$$\delta T = q\, T\, \hat{c}^2 C_p^{-1} \rho^{-1} \delta\rho \qquad (2)$$

$$\frac{\delta n}{n} = -\frac{\partial u}{\partial x} \qquad (3)$$

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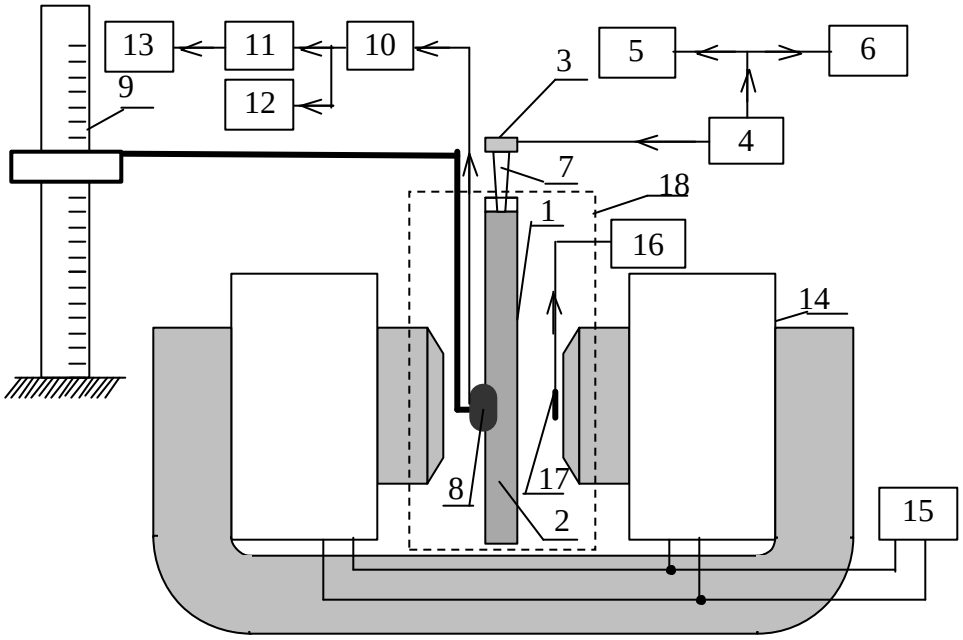

Fig. 1: The block-scheme of experimental unit

where $q \equiv -\rho^{-1}(\partial\rho/\partial T)$ is the thermal coefficient, ρ is the fluid density, c is the speed of sound waves propagation in MF without magnetic field; C_p is the specific heat capacity at the constant pressure and magnetic intensity and u is the displacement of the medium particles from the equilibrium position.

If the constant magnetic field is perpendicular to the sound beam with the limited lateral surface, the magnetization perturbation is accompanied by the demagnetizing field perturbation which in turn influences to the magnetization value. Therefore, expression for the equilibrium magnetization becomes [1, 3]

$$M_e = M_0 - (nM_n + \gamma_* M_T)\frac{\partial u}{\partial x} - N_d M_H \cdot \delta M \qquad (4)$$

where N_d is the dynamic demagnetizing, $\gamma_* = qTc^2C_p^{-1}$ and δM is the MF magnetization increment under the influence of adiabatic medium deformation in a sound wave.

The process of the equilibrium magnetic state ascertainment is described by the magnetization relaxation equation of the compressible MF [4]

$$\frac{\partial M}{\partial t} = -\tau_1^{-1}(M - M_e) - M\,\mathrm{div}\frac{\partial u}{\partial t}$$

where τ_1 is the relaxation time of magnetization component, parallel to the magnetic intensity vector.

The first term in the right part of the equation characterizes magnetization increment delay and the second term represents the instantaneous component of this increment. In case of a fluid magnetization perturbation by the flat sinusoidal acoustic wave the magnetization relaxation equation becomes

$$i\omega\tau_1\delta M = M_e - M - i\omega\tau_1 M\frac{\partial u}{\partial x} \qquad (5)$$

where ω is the circular oscillation frequency, $M = M_0 + \delta M$.

Solving system of Eqs. (1)-(5) and denoting $\tau \equiv \tau_1(1 + N_d M_H)^{-1}$, we find

$$\delta M = -\frac{(nM_n + \gamma_* M_T)/(1 + N_d M_H) + i\omega\tau M_0}{1 + i\omega\tau}\cdot\frac{\partial u}{\partial x} \qquad (6)$$

Allocating the valid part of expression (6), we receive the formula for the magnetization perturbation amplitude:

$$\Delta M = M_0\left[M_\beta + (\omega\tau)^2\right]\cdot\dot{u}_0\cdot\left(c\left[1 + (\omega\tau)^2\right]\right)^{-1}$$

where $\dot{u}_0$ is the oscillation speed amplitude and

$$M_\beta = (nM_n + \gamma_* M_T)\left[M_0(1 + N_d M_H)\right]^{-1}$$

Table 1:

Fluid	ρ, kg/m^3	φ, %	M_s, kA/m	v, Hz	$m_*\cdot10^{19}$, A·m^2	d, nm
MF1	1360	13,0	57,3	15035	1,6	8,7
MF2	1115	7,4	33,2	14869	1,2	8,0
MF3	882	2,1	9,7	14839	0,8	6,8

The process of MF magnetization is substantially determined by the two mechanisms of the ferroparticle magnet moment orientation along a magnetic field: Brownian rotation of the particles in the fluid matrix and the Néel mechanism of the thermal magnet moment fluctuations in the particle. From two magnetization relaxation mechanisms what is characterized by smaller time of the rotational diffusion is important. For magnetite particles with diameter d<10 nm, dispersed in kerosene, the Néel mechanism is characterized the smallest time of the rotational fluctuations, for which the thermal fluctuations time $\tau_n<10^{-9}$ sec. In the assigned experiment the sound oscillations frequency v≈15 kHz (Table 1) is used, therefore in expression for ΔM it is possible to accept $(\omega\tau)^2 \to 0$.

In the subsequent statement we will skip the index 0 in the designation of MF magnetization in the unperturbed state.

For magnetization perturbation amplitude it is possible to write

$$\Delta M = \frac{M\cdot M_\beta\cdot \dot{u}_0}{c}$$

In fields, close to MF magnetic saturation $M\to M_S$, $M_T\to 0$, $M_H\to 0$, $M_\beta \to M'_\beta$; therefore the peak magnetization increment

$$\Delta M_{max} = \frac{M_S\cdot M'_\beta\cdot \dot{u}_0}{c}$$

where M_S is the saturation magnetization.

If magnetization M is proportional to magnetic phase concentration of a n, i.e. M = Cn, that $M'_\beta = 1$ and

$$\Delta M_{max} = M_S\cdot \dot{u}_0/c$$

Relative magnetization amplitude increment

$$\beta'_\xi \equiv \frac{\Delta M}{\Delta M_{max}} = \frac{M+\gamma_* M_T}{M_S\left[1+N_d M_H\right]}$$

The amplitude induced EMF e_0 is proportional ΔM, therefore EMF amplitude expressed in the relative unities $e_0/e_{0max} = \beta_\xi$

According to the super paramagnetic theory β_ξ can be presented by the function of the parameter

$$\xi = (\mu_0 m_*/k_0 T)\cdot H$$

($\mu_0 = 4\pi\times10^{-7}$ H/m, $k_0 = 1{,}38\times10^{-23}$ JK^{-1}, m_* is the ferroparticle magnetic moment):

$$\beta_\xi = \frac{\beta'_\xi}{M_S} = \frac{L(\xi)+\gamma_*/M_S\cdot M_T}{1+N_d\cdot M_H} = \frac{(\mathrm{cth}\xi-\xi^{-1})-k'\cdot D(\xi)}{1+k'\cdot\xi^{-1}\cdot D(\xi)}$$

where L(ξ) is the Langevin function,

$$D(\xi) = \left(\xi^{-1}-\xi\,\mathrm{sh}^{-2}\xi\right),\ k' = qc^2C_p^{-1}$$

and

$$k' = N_d\mu_0 n m_*^2/k_0 T$$

The representation of the $\beta_\xi(\xi)$ function when $\xi\to\infty$ is as follows:

$$\beta_\xi = \frac{\left(1-\xi^{-1}\right)-k'\cdot\xi^{-1}}{1+k''\cdot\xi^{-2}} \approx 1-(1+k')\cdot\xi^{-1}$$

and the resulting formula can be expressed through H

$$\beta_H = 1-\frac{(1+k')k_0 T}{\mu_0 m_*}\cdot\frac{1}{H} \qquad (7)$$

Expression (7) shows that it is possible to obtain the value of magnetic parameter m_* from experimental dependence of the relative AME amplitude $\beta_H(H^{-1})$ by the formula

$$m_* = \frac{(1+k')k_0 T}{\mu_0}\cdot\left(\beta_H/H^{-1}\right)^{-1}$$

where (β_H/H^{-1}) is the slope of tangent line to curve (β_H/H^{-1}) when $H\to\infty$.

Further it is possible to calculate the diameter of a nanoparticle magnetic core d by known saturation magnetization of magnetite M_{S0} = 477.7 kA/m:

$$m_* = M_{S0}\cdot V_m = \frac{\pi}{6}\cdot M_{S0}\cdot d^3$$

whence $d = 0{,}016\cdot\sqrt[3]{m_*}$.

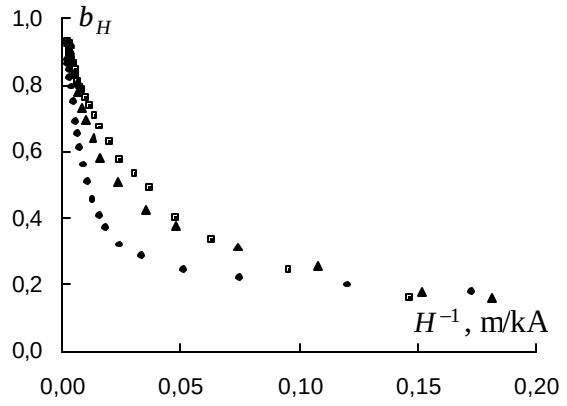

Fig. 2: The dependences (β_H/H^{-1}) ¦ - MF1, ? - MF2, ●- MF3

MEASUREMENT PROCEDURE AND RESULTS

The magnetic moment of nanoparticles is evaluated from AME field dependence in magnetic fields, near saturation (in the given experiment ? up to 400 kA/m). The AME amplitude is measured in the antinode of standing wave at tube part, placed in the area of the most uniform magnetic field.

The values m* are calculated by the experimental dates received in the relative unities, which allows supporting experimental conditions in an invariable state (measuring equipment adjustments, an arrangement of a receiver inductor, frequency and amplitude of sound oscillations). The intensity of magnetic fields, used in experiments, considerably exceeds saturation magnetization of explored MF samples, which allows neglecting the correction on degaussing field. The estimations show that the relative error of magnetic moment evaluation under the experimental conditions is 6,8%.

MF of one defined composition is examined in this work: colloidal solution of magnetite in hydrocarbon medium (kerosene) stabilized by oleic acid. Choice of this magnetic fluid type as an object to be examined is stipulated by its high homogeneity and stability for a long time. Samples MF nos. 1-3 are observed in this work. Sample no. 1 is gained by the chemical condensation method. Samples nos. 2 and 3 have been prepared by the dilution of the colloid no. 1. The measurements were made at 25°C.

The density of the MF sample is obtained by using glass pyknometer with the volume of 10 ml.

Solid phase volume concentration φ is obtained by the mixture formula:

$$\varphi = \frac{\rho - \rho_f}{\rho_s - \rho_f}$$

where $\rho = m_{mf}/V$ is the sample density, m_{mf} is its mass, V is the fluid volume in a pycnometer, ρ_S is the magnetite density (ρ_S=5200 kg/m^3) and ρ_f is the carrier fluid density (ρ_S=820 kg/m^3).

Saturation magnetization M_s and the initial magnetic susceptibility χ are obtained by the results of the magnetization curve measurement by ballistic method.

The dependences (β_H/H^{-1}) for MF nos. 1-3 are shown in Fig. 2. The limiting value of EMF amplitude induced in a measuring contour was found from dependence extrapolation (β_H/H^{-1}) at $H\rightarrow\infty$.

The physical parameters' of the investigated samples and data defined from the acoustogranulometric analysis are presented in Table 1.

DISCUSSION

The physical parameters' values of dispersed magnetic nanoparticles m* and d, obtained by the introduced method, are matched with the data received by other procedures, for example, on the basis of magnetization curve measurement [5]. As measurements of AME field dependence are performed in magnetic fields near to saturation, the numerical values m* and d presented in the table, seemingly, characterize fraction of the smallest magnetic nanoparticles in an observable disperse system.

The notable difference of the numerical values of parameters m* and d for the explored MF samples presented in Table 1 is noteworthy. In this respect it is possible to make following notes:

- The offered model is calculated for dilute MF in which dipole-dipole interaction of the magnetic particles is absent. From this viewpoint the nearest to the truth value m* and d can be the dates given for MF3.
- On increasing the upper limit of the intensity range in 1.5-2 times (that is in accordance with our plans), it is possible to expect some convergence of the specified parameters' values.
- The physical parameters' values of the magnetic nanoparticles received in given work have been estimated and also the conventional character as in MF there are the different sized particles and also their aggregates that are not taken into account by the offered model.

On further perfecting the acoustogranulometric procedure we see an improved calculated model by accounting ferroparticles distribution by the sizes, the presence of the aggregates in the initial sample and

comparison of acoustogranulometric results with the data obtained on the basis of power microscopy and wave methods [6].

It is probable to hope also, that the given method might allow obtaining the additional information about physical MF properties and structure.

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REFERENCES

1. Polunin, V.M., 2008. Acoustic Effects in Magnetic Fluids, Phyzmatlit, Moscow.
2. Polunin, V.M., I.A. Shabanova, S.S. Khotynyuk *et al*., 2010. Study of the kinetic and strength properties of magnetofluid membranes Magnetohydrodynamics, 3: 299-308.
3. Polunin, V.M., 1988. Electromagnetic effects caused by elastic deformation of the cylindrical sample of a magnetised fluid. Magnetohydrodynamics, 3: 300-307.
4. Pirozhkov, B.I. and M.I. Shliomis, 1977. A relaxation acoustical absorption in ferrosuspension. Mater. 9 all-USSR. Acoust. Conf. Section G, Science, Moscow, pp: 123-126.
5. Pshenichnikov, A.F., V.V. Mekhonoshin and A.V. Lebedev, 1996. Magnetodranulometric analysis of concentrated ferrocolloids. J. Magn. Magn. Mater., 161: 92-102.
6. Pshenichnikov, A.F. and A.A. Fedorenko, 2005. Chain-like aggregates in magnetic fluids. J. Magn. Magn. Mater., 292: 332-344.