

Short Communication

From the Dynamic Demagnetizing Factor to the Heat Capacity
of a Nanodispersed Magnetic Fluid

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A technique for the measurement of the dynamic demagnetizing factor, used for the description of magnetic fluid magnetization disturbance caused by a sonic wave has been offered. The formula for the calculation of heat capacity C_p of the synthesized magnetic colloids, which includes the parameter Nd has been obtained.

Keywords: Magnetic fluid, Acoustomagnetic effect, Langevin function, Magnetization curve, Demagnetizing field, Demagnetizing factor, Dynamic demagnetizing factor.

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1. INTRODUCTION

Specific effects, manifested in magnetizable fluids during the propagation of acoustic and electromagnetic waves have increasingly attracted the researchers' attention, as they open new ways of application of these unique nanodispersed systems in science and technology [1, 2].

If an acoustic wave propagates in a magnetic fluid (MF) as a result of the changes of magnetic nanoparticles concentration, disturbance of fluid magnetization and magnetizing intensity having opposite signs, take place. If there's no cancellation between them an acoustomagnetic effect (AME) – EMF induction in coil takes place. The model describing this effect is called concentration. [2].

If an isotropic magnetic is placed into an external magnetic field, the resultant field inside it depends only on the magnetic shape. In case of magnetization of irregular shaped bodies the demagnetizing field distribution in them is inhomogeneous, i.e. the field and its orientation change from point to point. In such cases it is difficult to estimate the demagnetizing factor. Strict and exact evaluation is possible only for homogeneously magnetized ellipsoid magnetics [3]. However, there are experimentally determined values for a round rod, shown in [3].

If a round tube is filled with MF, which magnetization is modulated by an acoustic wave, strict analytical solution obtaining the formula for demagnetizing factor calculation, called in this case dynamic, is impossible. Therefore new approaches to the problem based on the application of model theories [4] and experimental data are in need [5, 6]. In its turn, the experimental evaluation of the dynamic demagnetization factor Nd gives an opportunity to create a fundamentally new method of measuring of such an important thermal-physical parameter of a substance as the specific heat C_p .

Consequently, the aim of this paper is to develop methods of experimental determination of Nd and C_p parameters.

2. OBJECT OF RESEARCH

The sample under study, MF-3, is a magnetic colloid, a magnetite in kerosene, prepared by prolonged drying of the original sample MF2 [6]. The physical properties of MF3 are shown in Table 1 (ρ – density, n – concentration of solid phase, χ – initial magnetic susceptibility, M_s – saturation magnetization, c – speed of sound in the system “MF – glass tube”).

Table 1

Sample	ρ , kg/m	φ , %	χ	M_s , kA/m	c , m/s
MF-3	1934	25,6	9,73	90,73	811

The speed of sound in MF, filling the glass tube, was measured using an inhomogeneous magnetic field by means of the technique described in [7].

Magnetic properties χ and M_s are estimated according to the curves of magnetization $M(H)$, obtained by means of crossover study of the sample MF3 in Research and Educational Centre of the “SWSU – Institute of Continuous Media Mechanics, Ural branch of RAS”. Within the tolerance of measurement (5 %) the data of the ballistic method used in SWSU (squares) and the data reconstructed according to the dependence $\chi(H)$ used in ICMM, Ural branch of RAS (triangles), agreed. See Fig. 1.

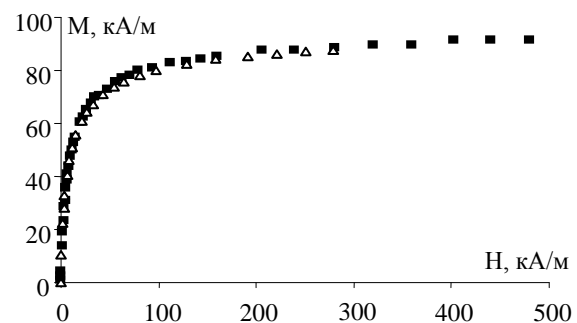


Fig. 1 – Curve of MF 3 magnetization

3. EXPERIMENTAL UNIT

The experimental unit, designed to study AME is described in detail in [8]. Its measuring block is schematically represented in Fig. 2

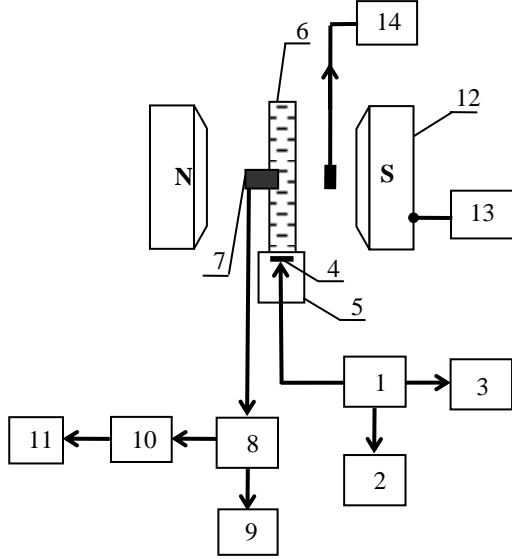


Fig. 2 – Experimental unit

The signal from acoustic generator 1 goes in parallel to cymometer 2, voltmeter 3 and piezoelectric plate 4, built in acoustic cell 5. Passing through the MF placed in glass tube 6, acoustic signal forms a standing wave. Variable EMF from the inductance coil 7, closely adjacent to the tube with a magnetic fluid goes to selective amplifier 8 then in parallel to oscilloscope 9 and to analog-digital converter 10 connected with computer 11. The magnetic field is generated by electromagnet 12 connected to power source 13. The value of magnetic induction is measured by teslameter 14, equipped with a Hall sensor. Signal acquisition and its primary processing is carried out by means of the program, developed in NI LabView.

4. EXPERIMENTAL DATA OF N_d

As is known, in a weak magnetic field in $H \rightarrow 0$ vicinity Langevin equation assumes the form of $L(\xi) = \xi/3$, which gives for βM (magnetization of MF, normalized saturation magnetization MS)

$$\beta_M = \frac{\xi}{3} = \frac{\mu_0 m^*}{3k_0 T} \cdot H$$

where μ_0 – magnetic constant, m^* – moment of magnet of MF particle, k_0 – Boltzmann's constant, T – absolute temperature.

For the field dependence of the relative amplitude of EMF induced by AME - $\beta(H)$ in weak fields the following formula has been obtained [8, 9]:

$$\beta_H = \mu_0 \frac{(1-k')}{3+k''} \frac{m^*}{k_0 T} \cdot H,$$

where $k' = qc^2 C_p^{-1}$, $k'' = N_d \mu_0 M_S m^* / k_0 T$, q – thermal expansion coefficient, C_p – specific heat at constant pressure, c – sound velocity in the system “MF – cylindrical shell”.

The relation β_M / β_H in approximation $H \rightarrow 0$ is:

$$\frac{\beta_M}{\beta_H} = \frac{1+k''/3}{1-k'} \quad (1)$$

The relation β_M / β_H doesn't depend on H, however, while experimental determining it is necessary to apply correction for the demagnetizing field taking into account the fact that the demagnetizing factor while determining $\beta_M(H)$ and $\beta_H(H)$ can be different.

The left-hand side of (1) can be conceived of as the relation of the slope of the initial parts of curves $\beta_M(H)$ and $\beta_H(H)$:

$$\frac{\beta_M(H)}{\beta_H(H)} = \frac{\text{tg } \beta_M}{\text{tg } \beta_H}$$

Taking into account the used values of $q = 0.66 \cdot 10^{-3} \text{ K}^{-1}$, $c = 811 \text{ m/s}$, $C_p = 1760 \text{ J/kg K}$, $N_d = 0,247$, $T = 303 \text{ K}$, we have $k' = 0,248$, $k'' = 9,48$ and respectively the equation (1) gives $\beta_M \approx 5,5 \beta_H$.

Taking into account the results of the experiment let's analyze the initial regions of the magnetization curve and field dependence of the relative amplitude of EMF induced by AME $\beta_M(H)$ in high-concentration sample MF3, shown in Fig. 3.

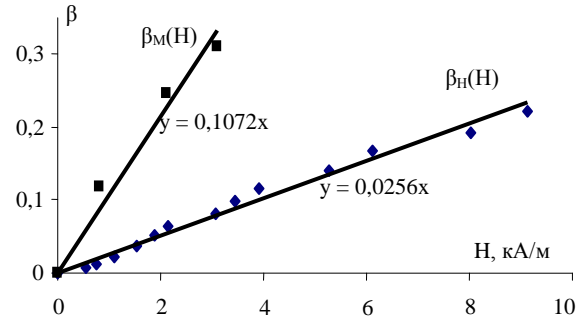


Fig. 3 – The initial parts (sections) $\beta_M(H)$ and $\beta_H(H)$

According to the data shown in Fig. 3 the relationship of the experimental values is $\beta_M \approx 4,3 \beta_H$. A difference between estimated data and experimental data is mostly determined by different numerous values m^* according to the results of magnetogranulometric and acoustogranulometric methods, which in its turn is connected with the inexactness of evaluation N_d , based on the model theory. However, the experiment and the calculation show that the initial part of the magnetization curve is steeper than the initial part of the field dependence of EMF of AME.

Let us rewrite expression (1) in the expanded form:

$$\frac{\text{tg } \beta_M}{\text{tg } \beta_H} = \frac{\mu_0 H m^*_{*1} (3 + N_d \mu_0 M_S m^*_{*2} / k_0 T) k_0 T}{3k_0 T \mu_0 (1 - qc^2 C_p^{-1}) m^*_{*2} H},$$

where m^*_{*1} and m^*_{*2} are magnetic moments, calculated according to the data of magnetogranulometric and acoustogranulometric methods respectively.

Setting $m^*_{*2} = m^*_{*1} = 10.7 \cdot 10^{-19} \text{ A/m}^2$, we can find $\text{tg } \beta_M / \text{tg } \beta_H = (3k_0 T + N_d \mu_0 M_S m^*_{*1}) / (3k_0 T (1 - qc^2 C_p^{-1}))$ whence after some elementary transformation it follows

that the expression for the dynamic demagnetizing factor evaluation N_d is:

$$N_d = 3k_0T \left[\frac{\text{tg} \beta_M}{\text{tg} \beta_H} \cdot (1 - qc^2 C_p^{-1}) - 1 \right] [\mu_0 m^* M_S]^{-1} \quad (2)$$

To evaluate N_d by formula (2) it is necessary to carry out comprehensive measurements of field dependence AME and the curve of magnetization of the studied sample of MF.

$\text{tg} \beta_M / \text{tg} \beta_H$ being a measured value is a part of formula (2). The measurement accuracy increases with the increase of MF magnetic phase concentration. That is the reason to use high-concentration samples of MF to get precise N_d measurements.

In accordance with the outlined technique a set of experiments have been performed provided data on the value of the demagnetizing factor for the frequencies 10-60 kHz. Graphically, the data presented in Fig. 4 in the form of points, reflecting the dependence of N_d on the parameter form $P = \lambda / 2d$.

It should be noted that by using a MF sample with the greatest possible concentration of magnetic nanoparticles as a reference sample in the evaluation formula (2), thermophysical parameters q and C_p , obtained by direct measurement should be used. The calculation of the values of these parameters according to mix formula [2] in this case can only provide an estimated (very approximate) value.

From the expression (2) by elementary transformations we obtain the formula for the specific heat of the magnetic colloid

$$C_p = qc^2 \left[1 - \frac{\text{tg} \beta_H}{\text{tg} \beta_M} (1 + N_d \mu_0 m^* M_S / 3k_0T) \right]^{-1} \quad (3)$$

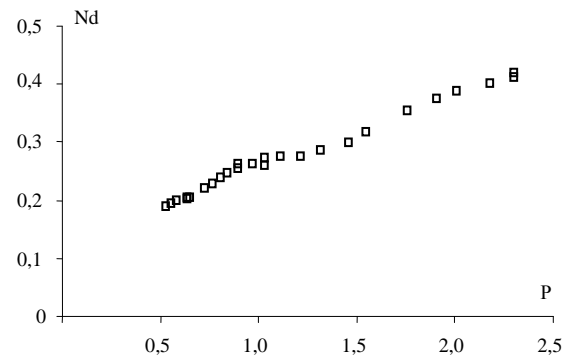


Fig. 4 – Dynamic demagnetizing factor

To calculate C_p it is necessary to make measurements of the values of the physical parameters given in formula (3): q , c , m^* , M_S , $\text{tg} \beta_M$, $\text{tg} \beta_H$. Note that the parameters included in this list, have as well an independent value in certification of the synthesized sample of a magnetic colloid.

Based on the proposed method preliminary (estimated) C_p measurements for five samples of MF prepared using various dispersive materials have been made. The obtained results are within 1070-1580 J/kg-K.

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