The influence of the viscosity on the oscillations of the element of magnetic fluid in the magnetic field

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Abstract. The article describes a study of the viscoelastic parameters of the system based on a element of magnetic fluid bounded by the surface of a horizontal plexiglass tube located in the field of an electromagnet. A element of magnetic fluid makes damped oscillations. A mechanism is proposed for interpreting the experimental results to determine the dependence of the viscosity of a magnetic fluid on the magnetic field strength.

1 Introduction

Due to the ability to control the physical parameters, first of all, viscosity and fluidity, using an external magnetic field, magnetic fluids (MF) are widely used in various devices for vibration damping, control of friction characteristics, in shock absorbers and dampers. Of particular interest is the study of the dependence of the viscosity of the MF on the strength of an external magnetic field. In most studies, the research of the dependence of viscosity on the magnitude of the magnetic field was based on the Brookfield rotary rheometers, in which the shaft, disk or cone rotates in the liquid under study [1–4]. Various ferrofluids under shear flow were investigated in [5]. Experiments have shown that an increase in the magnetic field strength leads to an increase in the viscosity of the liquid, the so-called «magneto-viscous effect». However, in most of the MF-based damping devices, the active element, most often the cylinder, makes oscillatory movements, therefore, it is of particular interest to study the dependence of the viscosity of the MF on the external magnetic field strength in such systems.

2 Physical and chemical properties of magnetic fluid, experimental setup and measurement technique

Two samples of magnetic fluid MF-1 and MF-2 are investigated in the work. The samples ore based on finely dispersed magnetite which is stabilized by a surfactant – oleic acid. In the sample MF-1, kerosene was used as a dispersive medium – a carrier liquid; in the sample MF-2, undecane was carrier liquid. The objects of the research were synthesized in

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the Fundamental Scientific Research Laboratory of Applied Ferrohydrodynamics of ISPEU. The density of samples ρ = 1245 kg/m^3 and ρ = 1227 kg/m^3, their saturation magnetization M_s = 39.5 kA/m and M_s = 40.4 kA/m. The shear viscosity η for MF-1 and MF-2 is 34.8 mPa·s and 30.4 mPa·s at the shear rate (79,2 1/s) in the experiment presented in the next paragraph.

The block diagram of the experimental setup for measuring the oscillation frequency of the MF element ν is shown in Figure 1.

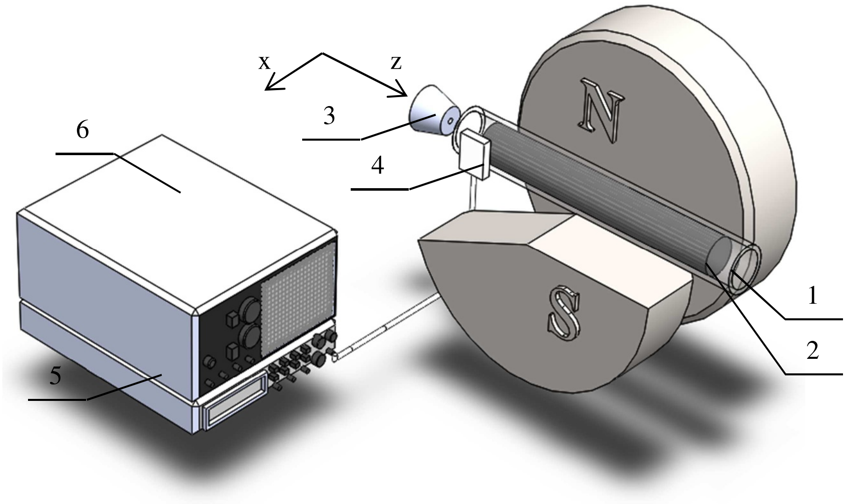

Fig. 1. Block diagram of the experimental setup.

We used a laboratory FL-1 electromagnet with a pole diameter of 100 mm. The design of the electromagnet FL-1 and technical data are described in [6]. A transparent tube 1 with an internal diameter d = 12 mm, made of plexiglass, is placed between the pole pieces. The axis of the tube passes horizontally through the center of the interpolar gap parallel to the surface of the pole pieces. When the magnetic field strength is ≥ 100 kA / m, the tube is filled with magnetic fluid 2, which is captured by the field and hangs in it. The piston 3 is used to excite vibrations. In the gap between the tube and the pole tip at the level of the free surface of the element MF installed vibration indicator - inductor 4. The inductor has 5000 turns, wound with a copper wire with a diameter of 0.071 mm, on the frame of Plexiglas. The signal from the oscillation indicator is fed to a Selective Nanovoltmeter type 237 5 amplifier. After amplification, the signal is transmitted to the GwInstek GOS-72074 6 oscilloscope, and then to a computer (not shown in the figure) for further processing.

Elastic vibrations of the magnetic fluid were excited by pulling out the rubber stopper from the free end of the tube. During the experiment, a tube with a hole was used to excite oscillations, which was opened during the process of screwing it into the tube, then the hole was sealed and the tube was pulled out of the tube, thus exciting the magnetic fluid. The oscillogram of the received oscillations was recorded using a digital oscilloscope.

3 The theory and experiment results

Expression (17) in [7] can be rewritten as:

$$\pi^3 \nu^2 \rho b d^2 + bd\sqrt{\pi^7 \nu^3 \eta \rho} = \mu_0 \frac{\pi d^2}{2}\left(M_x \frac{\partial H_x}{\partial z}\right)_{z=b/2}, \qquad (1)$$

where μ_0 is the magnetic constant, M_x and $\partial H_x/\partial z$ are the magnetization and the gradient of the magnetic field strength at the location of the base of the MF element, respectively.

In the left part of (1), the first term represents the dynamic coefficient of elasticity, $k_{d\omega}$, the second term is the correction for the motion of a viscous fluid $|\delta_\eta|$, and the right part is the coefficient of ponderomotive elasticity, k_p, obtained in [8].

The coefficient of ponderomotive elasticity k_p is due to the interaction of the MF with a non-uniform magnetic field [9-10]. In the works [11,12], an amendment to the coefficient of elasticity is obtained, associated with the flow of a viscous fluid:

$$\delta_\eta = -h_f d\sqrt{\pi^7 \nu^3 \eta\rho} \tag{2}$$

However, the formula obtained for δ_η gives an estimate "from above" (the maximum value after the expiration of a quarter of a period). The coefficient of viscous elasticity k_η represents the "average half-period" harmonic function of the maximum value, i.e. $k_\eta = 2\delta_\eta / \pi$. Therefore:

$$k_\eta = -\frac{2}{\pi} h_f d\sqrt{\pi^7 \nu^3 \eta\rho} \tag{3}$$

In addition, it was previously assumed that the viscosity of the MF does not depend on the magnetic field strength. Assuming this dependence, make the replacement of η by η_H. Then the expression (1) takes the form:

$$\pi^3 \nu^2 \rho b d^2 + 2bd\sqrt{\pi^5 \nu^3 \eta_H \rho} = \mu_0 \frac{\pi d^2}{2}\left(M_x \frac{\partial H_x}{\partial z}\right)_{z=b/2}, \tag{5}$$

From where, taking into account the effective part of the shifting surface of the element and making the transition $M_S \rightarrow M_x$, using the graph of the magnetization curve in part of the dependence of M_x on $1/H$, we obtain:

$$\eta_H = \frac{1}{\nu^3}\left[\frac{\mu_0 d \cdot M_x}{4b\pi\sqrt{\pi\rho}} \cdot (\partial H_x / \partial z)_{z=b/2} - \frac{\sqrt{\pi\rho} \cdot d_{ef}^2 \nu^2}{2d}\right]^2 \tag{6}$$

Using formula (6), we obtain an estimate of the dependence on the magnetic field strength, the results of which are presented in Figure 2.

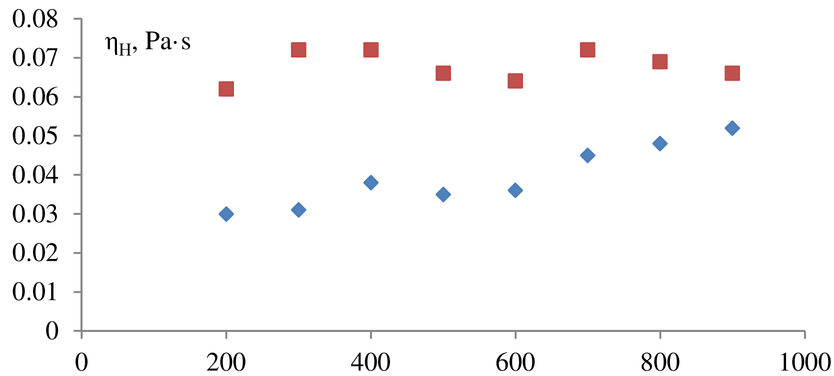

Fig. 2. The dependence shear viscosity for MF-1 (blue rhombuses) and MF-2 (red squares) on the magnetic field strength.

The results obtained are preliminary in nature and require the continuation of experimental and theoretical studies, primarily in the methodological aspect. First, the reduced and subtracted in brackets of the formula (6) is much larger than the resulting difference, which requires upgrading the installation to more accurately determine the parameters. Secondly, the calculations do not take into account the transient thin layer of the passage of a viscous wave. It is assumed that the entire MF element is involved in the oscillatory motion.

To refine the estimate of viscosity, we will need to expand the applicability of the relations obtained, for example, by increasing the magnetic field gradient, which allows us to obtain a higher frequency of oscillations of the MF element.

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References

1. S. Odenbach, T. Rylewicz, M. Heyen JMMM **201**, 198 (1999)
2. L.M. Pop, S. Odenbach, A. Wiedenmann, N. Matoussevitch, H. Bonnemann JMMM **289**, 303 (2005)
3. J. Nowak, D. Wolf, S. Odenbach JMMM **354**, 98-104 (2014)
4. F.R. Arantes, S. Odenbach JMMM **390**, 91-95. (2015)
5. L.M. Pop, S. Odenbach // J. Phys. Condens **20**, 20 (2008)
6. Chechernikov V.I. Magnetic measurements (MSU, 1969)
7. V. Polunin, P. Ryapolov, V. Platonov Akust. Phys. **63,** 371-379 (2017)
8. V. Polunin, P. Ryapolov, V. Platonov, A. Kuzko Akust. Phys. **62**, 302-307 (2016)
9. S. Odenbach, (Ed.) *Colloidal Magnetic Fluids: Basics, Development and Application of Ferrofluids* (Lect. Notes Phys, Springer, 2009).
10. V. Polunin, A. Storozhenko, P. Ryapolov *Mechanics of liquid nano- and microdispersed magnetic media* (CRC Press, CISP, 2017).
11. V. Polunin *Acoustics of nanodispersed magnetic fluids* (CRC Press, CISP, 2015)
12. V. Polunin, M. Boev, M. Min Tan, G. Karpova, L. Roslyakova Akust. Phys. **59**, 63–69 (2013)