THE EXPERIMENTAL STUDY OF THE MOTION OF ELONGATED BODIES WITH MAGNETIZABLE MATERIAL IN ROTATING MAGNETIC FIELD

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Abstract: The rotation and translational motion of a fixed volume made of a magnetizable material in a uniform applied rotating magnetic field are examined experimentally. We consider two magnetizable materials: a magnetic fluid and a magnetizable polymer.

1. Introduction

In [1] experimentally investigated the translational motion of magnetic fluid drop, wetting the smooth horizontal substrate, in a rotating magnetic field. Drop moving towards the solid rolling or in the opposite direction depending on the properties of the surrounding liquid. In this paper, we investigate experimentally the rolling drop of magnetic fluid, not wetting the substrate, along a rough bottom of the vessel.

In [2] theoretically and experimentally the motion of an elongated cylindrical body with a magnetizable polymer in a traveling magnetic field is considered. In this paper, we investigate experimentally the ellipsoid made of magnetizable polymer in a rotating magnetic field.

1. Experimental setup

Uniform applied magnetic field H_∞ is generated by two pairs of Helmholtz coils (a pair of coils with a common axis, the distance between the coils is equal to the coil radius; magnetic field on the axis of the coils is uniform).

Current in the coils is controlled by a software package LabView. The relationship between the current in the coils and the magnetic field on the axis was found by the Hall sensor. Field amplitude can reach 29.4 kA/m, field frequency varies from zero to 50 Hz.
Body (drop) with magnetizable material was placed in a rectangular vessel made of plexiglass (L = 7.5 cm, δ = 0.3 cm, h = 2 cm) and was immersed in a viscous non-magnetic liquid (water, glycerol, a mixture of glycerol and water). The cell was placed in a rotating homogeneous field.

Properties of the MF and polymer used in the experiment are shown in the table, see Tab. 1. Also the mixture of glycerol (ρ = 1261 kg/m^3, μ = 5.94 kg/sm) and water was used in the experiments.

Table 1. Properties of magnetizable materials.

Material	Density ρ, $10^3\cdot$kg/m^3	Saturation magnetization M_s, kA/m	Initial susceptibility χ_0	Volume V, mm^3
MF	1.21	31.8	1.89	14.2
Polymer	3.6	394	4.39	12.4

2. Behavior of the MF drop immersed in a nonmagnetic fluid in a rotating magnetic field

In the experiments the drop made of highly magnetizable MF EFH1 based on kerosene with ferrite particles was placed in the rectangular vessel made of plexiglass ($L = 7.5$ cm , $\delta = 0.3$ cm , $h = 2$ cm), filled with a mixture of glycerol and water in equal proportions by volume. The vessel was placed in a rotating homogeneous magnetic field of Helmholtz coils. The MF drop extends along the field. The drop rotation and translational motion along the bottom was observed for some magnetic field amplitudes and frequencies. The nonmonotonic dependence with one maximum of the average speed U of the drop translational motion on the frequency ω of the magnetic field was found. Average speed U is calculated as the ratio of a distance of 3 cm and a time in which the drop passes this distance. For some field values and frequencies, the drop has an ellipsoidal shape (see Fig. 1 a.) and moves toward solid rolling. Also, there are field values and frequencies in which the drop has a curved shape (see Fig. 1 b.) and moves toward the side opposite to the solid rolling.

Figure 1: The MF drop shape a. $H_\infty = 7.95$ kA/m, $\omega = 2.5$ Hz; b. $H_\infty = 7.95$ kA/m, $\omega = 5.25$ Hz; c. Separation of the MF drop $H_\infty = 9.94$ kA/m, $\omega = 4$ Hz..

When $H_\infty < 5.96$ kA/m the MF drop does not move, just oscillates and remains in the same place. When $H_\infty = 5.96$ kA/m drop has an ellipsoidal shape and rolls along the bottom of the vessel in the direction of solid rolling. Dependence of the average speed U on the field frequency ω is not monotonic and has a single maximum, see Fig. 2, point line. For some value of ω (ω=8.75 Hz for H_∞=5.96 kA/m), the MF drop stops and does not move with further increasing of the field frequency.

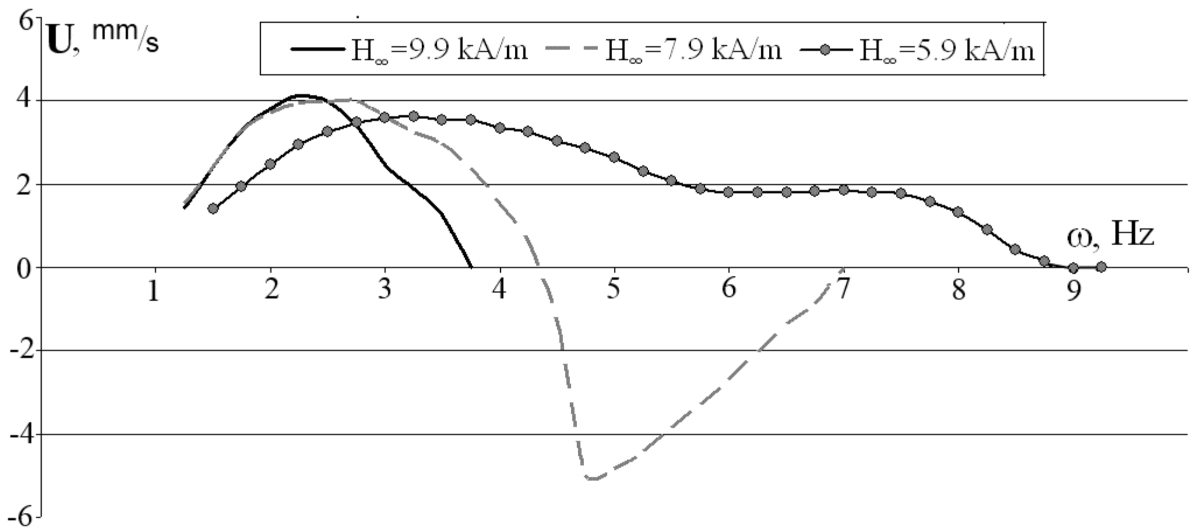

Figure 2: Dependence of the MF drop average speed U on the field frequency ω for different amplitudes H_∞.

In the larger field amplitude H_∞= 7.95 kA/m for the low frequencies ω the MF drop moves similarly to the case H_∞ = 5.96 kA/m. However, after the stop with further increasing of frequency ω the MF drop gets a curved shape and begins to move in the opposite direction to the solid rolling (see Fig. 2, dash line). At the same time drop continues to rotate in the direction of the field rotation.

In fields H_∞ = 9.94 kA/m the effect of the translational motion in the opposite direction to the solid rolling is not obtained. For H_∞ = 9.94 kA/m before the MF drop stops it's motion is similarly to the case H_∞ = 5.96 kA/m (see Fig. 2, solid line). After the stop with further increasing of frequency ω the MF drop is divided into smaller droplets, see Fig. 1. c. Each of the smaller droplets rolls in the direction of solid rolling.

When the amplitude of the applied field H_∞ increases the frequency at which the drop has the maximum average speed U, and the frequency at which the drop stops, decrease (see Fig. 2). The value of the maximum of the average speed U weakly depends on the amplitude of the applied field H_∞.

3. Behavior of magnetizable polymer in a rotating magnetic field

The behavior of the ellipsoid of magnetizable polymer in a nonmagnetic environment in a rotating homogeneous magnetic field was investigated. In experiments it was used the ellipsoidal body made of visco-elastic polymer with nickel micro-sized particles. Polymer's long axis orients along the field vector $\boldsymbol{H}_\infty$. Body rotates in the same direction as the field, and thus rolls along the bottom of the vessel.

We investigated the average speed U of the polymer body on frequency ω of the magnetic field for different field amplitudes H_∞, elongation of ellipsoid and various environments. The nonmonotonic dependence of the average speed U on ω with one maximum was received. At low frequencies ω, the frequency of the body rotation is equal to the field frequency ω, and speed U= $\omega \cdot L_p$ (L_p - circumference of the ellipsoid). At the higher frequencies ω the speed U decreases due to body inertia, and then for some value of ω the polymer stops (see Fig. 3, a.). The average speed U and frequency range, in which the body moves, reduces with decreasing of the ellipsoid elongation and field amplitude H_∞, also with increasing of the environment viscosity (see Fig. 3).

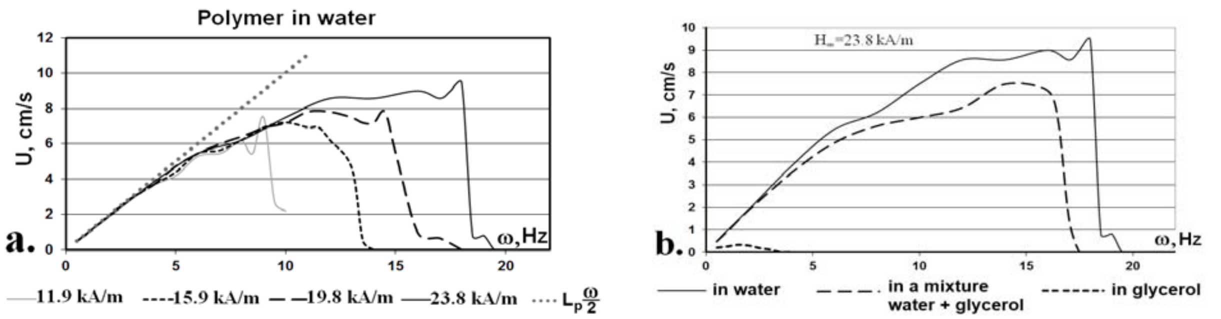

Figure 3: Dependence of the polymer average speed U on the field frequency ω a. For different field amplitudes H_∞; b. For different environments, H_∞=23.87 kA/m.

4. Comparison of droplets and polymer

A comparison of the behavior of the MF drop and ellipsoidal body with magnetizable polymer in rotating magnetic fields was done. It was shown that even at low field frequencies ω the drop speed differs significantly from the polymer speed (see Fig. 4). Thus, even at relatively slow speeds drop motion is not similar to the solid body motion, as it is initiated by the hydrodynamic flow.

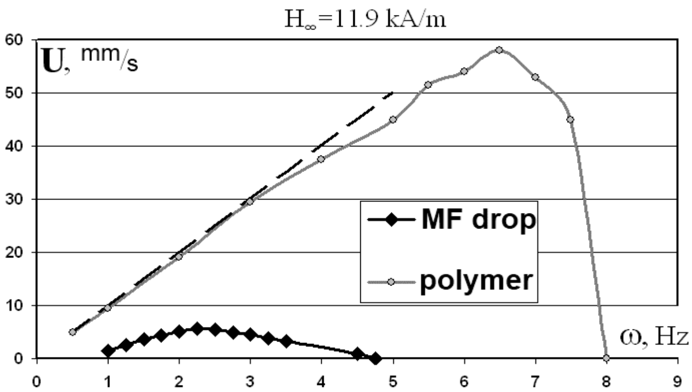

Figure 4: Dependence of the average speed U of the MF drop and the magnetizable polymer on the field frequency ω for H_∞ = 11.93 kA/m.

5. Conclusion

The magnetic fluid drop movements in a nonmagnetic environment near the bottom of the vessel in a rotating magnetic field were investigated experimentally. The drop rotation and translational motion are observed. The nonmonotonic dependence of the average velocity of the frequency of the applied magnetic field was found. For some field values and frequencies, the drop has an ellipsoidal form and moves toward solid rolling. Also, it was obtained field values and frequencies in which the drop has a curved shape and moves in the opposite direction.

The movements of ellipsoidal body with magnetizable polymer were investigated experimentally. The rotation in the direction of the field rotation and the translational motion toward solid rolling are observed. The nonmonotonic dependence of the average velocity on the frequency of the applied magnetic field was found.

The results of this work can be used to create micro robots made of magnetizable materials.

6. Acknowledgements.

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7. References

[1] Zakinyan A., Nechaeva O., Dikansky Yu.: Motion of a deformable drop of magnetic fluid on a solid surface in a rotating magnetic field. Experimental Thermal and Fluid Science, 39 (2012), 265–268.

[2] Kalmykov S. A., Naletova V. A., Turkov V. A. Motion of a Slender Body Made of Magnetizable Composite in a Traveling Magnetic Field. Fluid Dynamics, 48, No. 1 (2013), 4–13.