Statics of Magnetic Fluid Drop with Compound Magnetic Core in a Wedge-Shaped Channel

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A behavior of magnetic fluid drop with compound magnetic core in a wedge-shaped channel was studied experimentally. The study examines influence of magnetic fluid properties, its volume and magnetic field on statics of the system compound magnet – magnetic fluid drop in wedge-shaped channel. The possibility to change the static conditions of such system by altering magnetic field of the core was observed

1. INTRODUCTION

A Permanent magnet covered with magnetic fluid drop is widely used in numerous magnetic fluid-based facilities. In particular, such drop could be used as an inertia mass of dampers and shock absorbers [1-4].

Appearance of volume magnetic force in non-uniform magnetic field results in levitation of magnets in the magnetic fluid placed in nonmagnetic container. The magnet is capable to be kept in the magnetic fluid at some distance from the walls of the container without a contact with them. Conditions of levitation and statics of magnetic bodies in magnetic fluids were elaborately described in [5, 6]. In [7] statics of magnetic fluid drop with permanent magnetic core in channels of the various forms was observed.

In this paper influence of magnetic field of compound magnetic core on statics of magnetic fluid drop in a wedge-shaped channel was studied experimentally.

2. COMPOUND SOURCE OF MAGNETIC FIELD

The compound magnetic core includes a permanent annular magnet and an electromagnet with a plunger. Here the plunger plays role of the magnetiziable insert. Material of the plunger meets conditions described above. The Electromagnet with the plunger is put in the hole of the annular magnet. Total field alteration is made by changing an amplitude of current which is applied to the electromagnet.

To evaluate a possible alteration of magnetic field magnetic induction was measured on the surface of the compound magnet for the different current intensity and direction.

Ferrite-barium annular magnet was chosen as a permanent source of magnetic field. Magnitude of magnetic field strength reached 90 kA/m on the surface of magnet. The magnet has the following geometrical parameters: outer diameter 36 mm, inner diameter (diameter of the hole) 18 mm, height 18 mm. Diameter of the electromagnet is 17, its height – 14 mm, number of turns – 822. Plunger material – steel 3, diameter – 6 mm, height – 15 mm.

Measurements were carried out at the geometrical centre of magnetic system and at the point which is equally-spaced from inner and outer edge of the annular magnet (Fig. 1).

Tesla meter was used to implement the measurements. After that magnetic field intensity was calculated. Fig. 2, illustrates results of calculations for the annular magnet (which is used as a part of compound magnet) and for the compound magnet for different current magnitude and direction at different points of measurement.

Fig. 2 shows that the plunger significantly strengthens magnetic field intensity in and around the hole of annular magnet. Current feed of electromagnet changes magnetic field intensity as well. The possible change of magnetic field intensity by means of the current was ± 27 kA/m at zero point O(0, 0) for the range of observed current value.
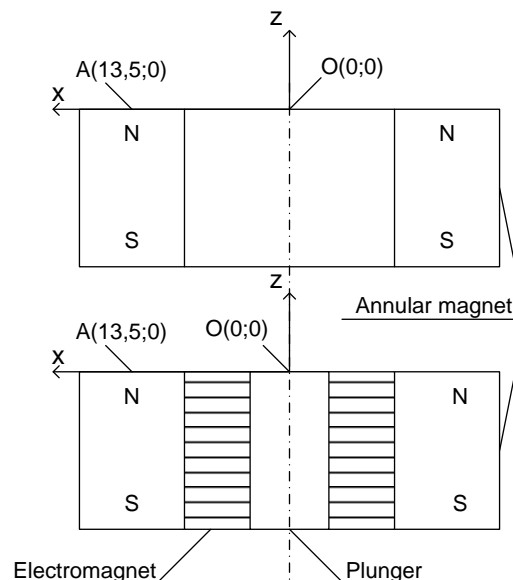

Fig. 1 – Geometry of measurements

Magnitude of the current was measured with an amperemeter. The measuring circuit was made in such way that when the current had positive direction, the intensity of magnetic field increased, on the contrary, negative direction of the current induced decrease of magnetic field intensity.
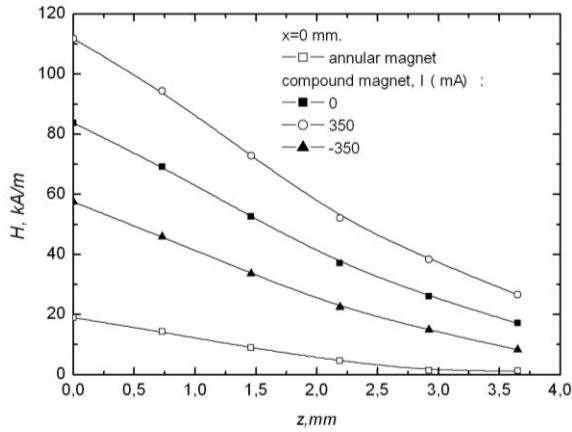
Fig. 2 – Magnetic field intensity of the annular magnet and the compound magnet for different magnitude and direction of the current fed to the compound magnet. Zero point is O (0, 0) measurements carried out along z axis

The plunger doesn't influence magnetic field intensity in zone between inner and outer boundary of annular magnet. As magnetic fluid tends to gather in zones with maximal field intensity, intensification of the field around the plunger will cause inleakage of the fluid to the area around the plunger. Decrease of magnetic field intensity will induce the opposite effect. In any of these cases free surface of magnetic fluid drop will undergo the change of its shape. As a result, elastic properties of the system magnet –magnetic fluid will change.

3. EXPERIMENTAL SETUP AND TECHNIQUE

Geometry of the experiment is shown in Fig. 3. The compound magnet covered with magnetic fluid drop 1 of certain volume V. This system is set in a wedge-shaped channel 2 with opening angle γ. The compound magnet consists of an annular permanent magnet 3, an electromagnet 4 and a plunger 5. When the channel is leaned to the horizontal plane on some angle α, the drop with the magnet shifts from the initial position x_0 to a narrower part of the channel under the action of gravity force. The shift is resisted by volume magnetic force. This force appears as a result of pressure redistribution in volume of the drop. This redistribution is induced by asymmetrical deformation of the drop. The volume magnetic force balances the component of gravity force and the drop rich some position x.
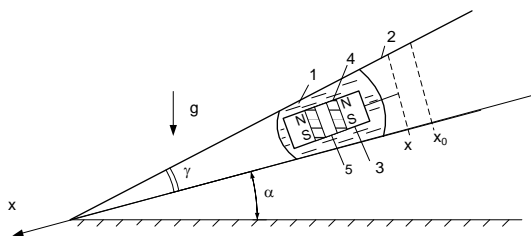

Fig. 3 – Geometry of the experiment

A wedge-shaped channel was formed by flat walls from plexiglass, which were located at an angle γ to each other. Non-magnetic thin wire (the pointer) was attached to the magnet to define its position in the channel. The initial point x_0 was defined as the point of

magnet in the narrowest possible part of the channel when volume magnetic force hasn't appeared yet and inclination angle $\alpha = 0$ (none of external forces act on the system along the channel). A point of maximal displacement of the magnet was determined as the point at which the magnet inside the drop directly contacted the walls of the channel.

The position of the pointer was measured accurate within 0.5 mm. Calculations of component of gravity force were based on the values of the inclination angle α. The inclination angle was measured accurate within 0.05 degree.

Magnetic fluids based on transformer oils with magnetic saturations $M_s = 23.1$ and 43.8 kA/m and magnetic fluid based on kerosene with magnetic saturation $M_s = 72.5$ kA/m were used in the experiment. Density of the fluids were 1180, 1400 and 1650 kg/m, respectively.

In the experiment the following parameters were variable: magnetic saturation of the fluid, volume of the drop, opening angle of the channel γ, magnitude and direction of electromagnet current. Magnitude and direction of the current were constant during particular measurement.

4. RESULTS

Dependencies of the magnet displacement on component of gravity force F_{mg} were gained. Fig. 4 represents results of measurements for magnetic fluids of different magnetic saturations Ms. Volume of the drop was $V = 10$ ml, opening angle of the channel – $\gamma = 2.5$ degree. Measurements were carried out for current intensities $I = 0$, 350 and $- 350$ mA. For each measurement zero point (0, 0) was defined as the initial magnet position when $I = 0$ mA.
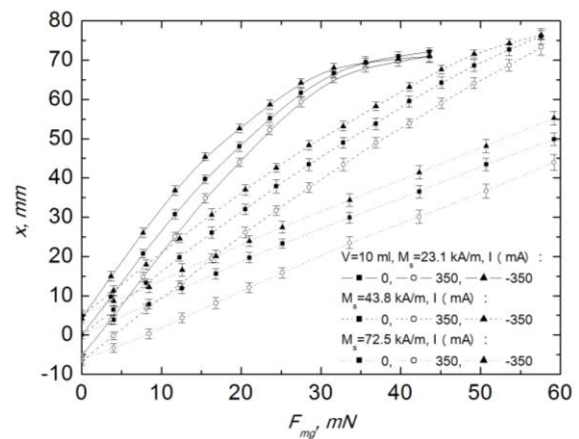

Fig. 4 – Displacement of the magnetic system as a function of component of gravity force. Volume of the drop $V = 10$ ml, opening angle $\gamma = 2.5$ degree

To analyse gained data a sensitivity of the drop was evaluated. The sensitivity increases with the decrease of magnetic saturation of the fluid. This is a result of volume magnetic force decrease the value of which depends on magnetic saturation of the fluid. Finite part of the function for the magnetic fluid with $Ms = 23.1$ kA/m is curvilinear. The cause of such behavior is the small distance between the magnet and walls of the channel.

Magnetic field intensity of the magnet experiences a nonlinear growth towards its surface. That results in nonlinear growth of volume magnetic force. A Function of the drop displacement is almost linear for fluids with $Ms = 43.8$ and 72.5 kA/m in observed range of the external force. This fact indicates that nonlinear growth of volume magnetic force significantly affects the displacement of the drop only if the gap between the magnet and walls is small enough. The mean sensitivity of the drop at the initial part of functions was 2.6, 1.6, 0.9 mm/mN for the fluids with $Ms = 23.1$, 43.8, 72.5 kA/m respectively.

Current feed enabled to vary the drop position while value of external acting force F_{mg} was constant. The shape of the drop changed as a result of field redistribution and led to the change of volume magnetic force. When the current had positive direction and the total magnetic field increased, the drop shifted to a wider part of the channel. Some volume of magnetic fluid flowed off from the annular magnet to the plunger. The volume of the fluid increased at the center of the compound system and decreased at its edges. As opposite, for negative current direction the drop shifted to narrower part of the channel and bigger volume of the fluid concentrated at the annular magnet. Thus, zones that are allocated between functions for $I = 350$ and $I = -350$ mA on Fig. 3.2 could be considered as possible control range of the drop displacement for certain value of external acting force. Decrease of magnetic saturation Ms didn't lead to a significant contraction of the control ranges which at the initial part of the functions were 10.9, 11.5, 11.9 mm for magnetic fluids with $Ms = 23.1$, 43.8, 72.5 kA/m respectively. Dividing control range of the drop displacement by value of sensitivity control range of volume magnetic force could be obtained. Control ranges of volume magnetic force at the initial part of functions were 4, 7, and 13 mN for above mentioned magnetic saturation respectively.

Fig. 5 represents dependences of the magnet displacement on component of gravity force F_{mg} for different volumes of the drop. Opening angle of the channel – $\gamma = 2.5$ degree, magnetic saturation of the fluid – $Ms = 43.8$ kA/m.
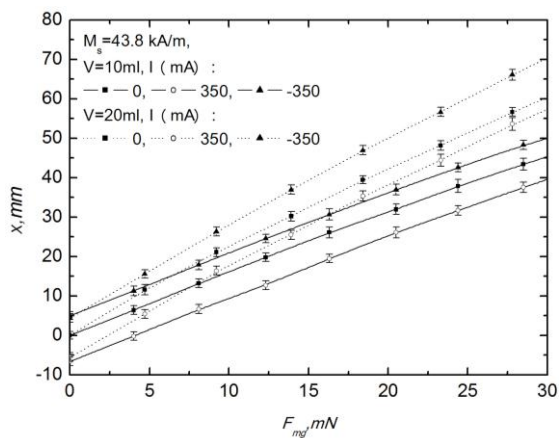

Fig. 5 – Displacement of the magnetic system as a function of component of gravity force. Volume of the drop $V = 10$ ml and 20 ml, opening angle $\gamma = 2.5$ degree, magnetic saturation $Ms = 43.8$ kA/m

The mean sensitivity of the drop at the initial part of functions was 1.6 and 2.2 mm/mN, control ranges of displacement at the initial part of functions were 11.5 and 10.6 mm, control ranges of volume magnetic force at the initial part of functions were 7 and 5 mN for volumes of the drop $V = 10$ ml and 20 ml respectively. The drop of bigger volume is more sensitive to external force and has more narrow control range. The distance between the surface of the magnet and the walls at the initial position increases with the increase of the fluid volume. Therefore contact zone between the fluid layer and walls locates in field of lesser intensity. That leads to a decrease of volume magnetic field which acts on the drop.

Fig. 6 represents dependences of the magnet displacement on component of gravity force F_{mg} for different opening angles of the channel. Volume of magnetic fluid – $V = 10$ ml, magnetic saturation of the fluid – $Ms = 43.8$ kA/m.
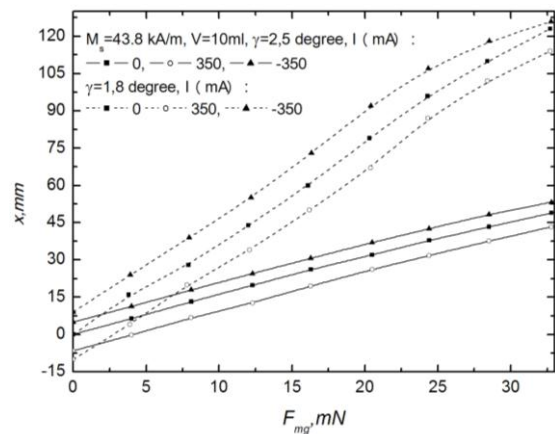

Fig. 6 – Displacement of the magnetic system as a function of component of gravity force. Volume of the drop $V = 10$ ml, magnetic saturation $Ms = 43.8$ kA/m, opening angles $\gamma = 2.5$ and 1.8 degree

The mean sensitivity of the drop at the initial part of functions was 1.6 and 3.8 mm/mN, control ranges of displacement at the initial part of functions were 11.5 and 20.4 mm, control ranges of volume magnetic force at the initial part of functions were 7 and 5 mN for opening angles of the channel $\gamma = 2.5$ and 1.8 degree respectively.

While the drop drifts to a narrower part of the channel, the distance between the magnet and walls diminishes to a lesser extent for smaller opening angle. That provokes lesser growth of volume magnetic force. The sensitivity of the drop increases due to lower rate of change of magnetic field intensity.

5. SUMMARY

The compound magnet enables to change the total intensity of its magnetic field and to vary the shape of free surface of magnetic fluid. Total field alteration is made by change of current amplitude which is applied on the electromagnet. Behavior of the drop in a wedge-shaped channel depends on the shape of the drop which is mainly determined by distribution of magnetic field around magnetic system and magnetic saturation of the fluid. The posi-

tion of the drop in the channel could be controlled by varying the shape of free surface of magnetic fluid. Sensitivity and control range of the displacement of the drop depends on several parameters. These parameters are magnetic saturation of the fluid, volume of the drop, opening angle of the channel. The drop of magnetic fluid with compound magnetic core could be applied as inertia mass of dampers and shock absorbers. Control of the elastisity of such system can improve effectiveness of magnetic fluid dampers.

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