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Modelling of magnetic fluid support

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Abstract

One kind of elastic magnetic fluid support representing the magnetic fluid drop with permanent magnet inside is investigated experimentally and numerically. The dependencies between the magneto static force in support and the geometrical parameters and properties of the magnet and the magnetic fluid are established.

Keywords: Magnetic fluid; Magnetic field; Magnetostatic force; Support

1. Introduction

An interesting and promising application of magnetic fluids is their use as an elastic support in a damping device [1]. These devices operate due to magnetostatic force existing in magnetic fluids under the influence of a nonuniform magnetic field. In some types of this application, a magnetic fluid drop with a permanent magnet inside is the working element [2]. It can work due to a magnetic fluid drop in a magnetic field behaving as an elastic material. Thus, the drop can both play the role of spring and damper in the support. One kind of this support is considered in this paper. It consists of a long nonmagnetic cylinder with permanent magnet on the end (Fig. 1). Magnetic fluid covers the magnet and creates the elastic support for the plate, which is placed on it. The supporting force depends on the distance between plate and magnet. It increases when the distance decreases. The set of these supports can provide suspension of the plate with long sizes.

2. Theory

Geometry and state of the problem are presented in Fig. 1. The problem is considered as axial symmetric. The permanent cylindrical magnet is situated on a nonmagnetic infinite core. The magnet is covered by drop of magnetic fluid. From the standpoint of calculation of magnetic field there are three domains with different magnetic properties: (1) "m" is the domain occupied by a permanent magnet; (2) "f" the volume of magnetic fluid, and (3) "∞" is outer nonmagnetic space and space of nonmagnetic core with magnetic permeability of vacuum μ_0.

The drop between the magnet and the plate has some equilibrium form. Specifically, the problem is that part of magnetic fluid surface is free. Therefore, the shape of this free surface has to be defined in each concrete case. For the considered problem the magnetic forces are the most significant in shaping of the surface, so gravity and surface tension can be ignored. Then the free surface of the magnetic fluid coincides with the surface of constant values of magnetic field intensity [1].

Displacement of the plate in the axial direction causes change of the drop shape, and magnetostatic force F acting on the plate from the side of magnetic fluid develops. The smaller the distance between a plate and magnet, the greater the aforementioned force.

The next part of this paper will be devoted to theoretical and experimental determination of this force.

The theoretical solution of the problem is done numerically using the variant of finite elements method developed in Ref. [3]. The first step of the solution procedure is the calculation of the magnetic field from the Maxwell's equations in all domains. After finding a

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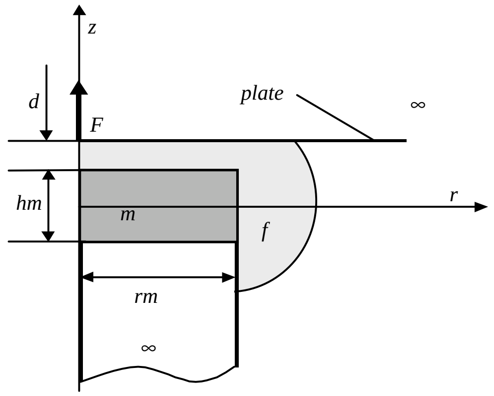

Fig. 1. Geometry of the magnetic fluid support problem.

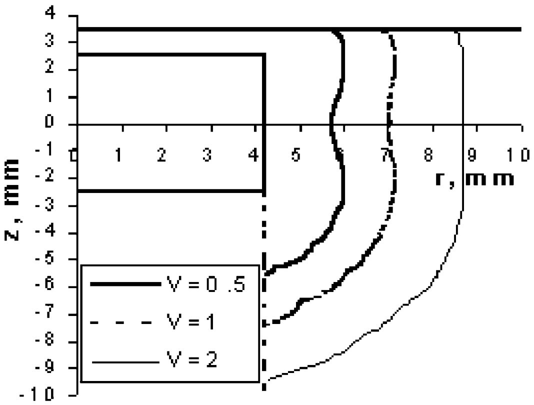

Fig. 2. Dependence of the shape of magnetic fluid drops on a volume of magnetic fluid V (cm^3).

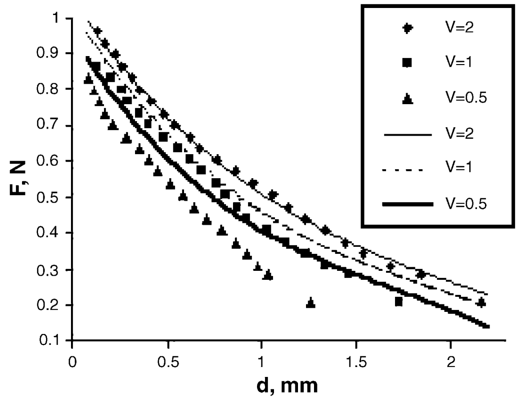

Fig. 3. Dependence of the magnetic force F on the distance from the permanent magnet to the plate d for different drop volumes V (cm^3) (dots—the experimental data, lines—theoretical ones).

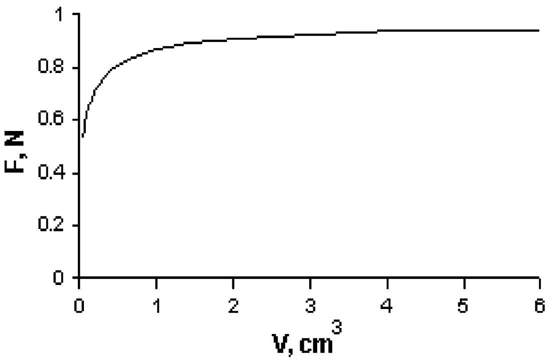

Fig. 4. Dependence of the magnetic force F on the volume of magnetic fluid V ($M_I = 460\,kA/m$, $r_m = 4.2\,mm$, $h_m = 5\,mm$, $d = 0.2\,mm$).

magnetic field distribution, the shape of the drop surface is calculated as a line of constant value of magnetic field intensity H. Then distribution of magnetic field is found again taking into account the shape of magnetic fluid drop calculated on the previous step. This iterative process is stopped when solutions cease to change.

Typical calculated shapes of magnetic fluid free surface are presented in Fig. 2.

3. Experiment and discussion of results

In the experiment, a plate is placed horizontally on three identical supports described above. The cylindrical permanent magnet has radius $r_m = 4.2\,mm$, height $h_m = 5\,mm$, constant magnetisation $M_m = 460\,kA/m$ directed along magnet axis z. The magnetic fluid on the base of the transformer oil and the magnetite has magnetisation of saturation $M_S = 54.2\,kA/m$. The same parameters are used in numerical calculations. The weight of different value is placed on the plate, and the distance between plate and magnet is measured.

The magnetic force dependencies are presented in Fig. 3. Near the magnet this force is of order 1 N and as would be expected, decreases fast when the distance from magnet increases. The force increases with the increasing of magnetic fluid volume. A more detailed description of this fact is shown in Fig. 4. At magnetic fluid volumes more than 1 cm^3 this dependence comes to saturation and the force practically becomes independent on fluid volume. It is clear that parts of fluid volume situated far from magnet give smaller contribution to force.

Fig. 5 demonstrates practically linear increasing of the magnetostatic force in support with increasing of the permanent magnet magnetisation.

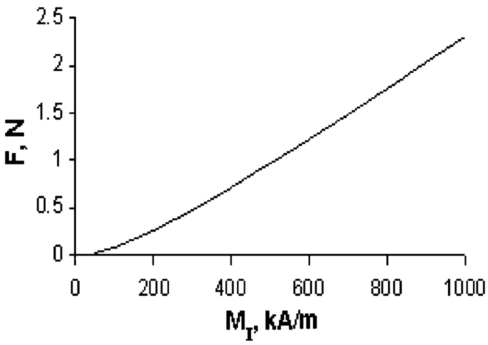

Fig. 5. Theoretical dependence of the magnetic force F on the magnetisation of the permanent magnet M_I ($V = 1\,cm^3$, $r_m = 4.2\,mm$, $h_m = 5\,mm$, $d = 0.2\,mm$).

4. Conclusion

The investigation shows effectiveness of the use of magnetic fluid for elastic support for static pressure up to $5\,N/cm^2$. Characteristics of the support can be controlled by the geometric and magnetic parameters of magnetic fluids and permanent magnets. The supporting force significantly decreases with the increasing of the distance from the magnet. The force decreases about 10 times with the distance increasing of one quarter of the magnet radius. The use of large volumes of magnetic fluid for this kind of support is not effective, because the supporting force quickly comes to saturation.

Acknowledgements

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