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A method for magnetic field determination inside magnetic fluids

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Abstract

The method is based on the phenomenon of levitation of a nonmagnetic spherical body immersed in a magnetic fluid situated in a magnetic field characterized by a vertical gradient oriented from top to bottom. This structure of the field has been obtained in a wedge-shaped air gap. Taking into account the levitation condition and the hyperbolic structure of the field, a theoretical formula for the z coordinate was used. The comparison between experimental and theoretical data allow to obtain the magnetic field intensity inside the magnetic fluids.

Keywords: Magnetic field; Magnetic fluids; Levitation

1. Introduction

The levitation effects [1] allow a lot of technical applications of magnetic fluids, especially for materials separation [2–4] and sensors [5]. In this paper we present a new application of the first order of levitation phenomenon. This is a method for the analysis of the magnetic field intensity around a spherical nonmagnetic body levitated in magnetic fluid. The method may be used for theoretical and experimental investigations of the magnetic field inside magnetic fluids.

2. Theoretical analysis

It is well known that one of the simplest structures of the magnetic field is that of the field of line current, a sector of which corresponds to that of a wedge-shaped air gap. The value of the magnetic field intensity in the wedge $H = A_0/z$ decreases with distance z from the apex of the wedge to the point taken into consideration on a vertical line, and increases with parameter $A_0 = NI/\theta$, where I is the current intensity in the coils of the electromagnet, N is the number of the turns and θ is the wedge angle in radians.

The ponderomotive force exerted by the wedge-shaped field on a nonmagnetic spherical body immersed in a magnetic fluid has been computed [2] and expanded in powers of the parameters

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characterizing the position of the body as follows:

$$F_z = \mu_0 \chi_F V_S \frac{A_0}{z^3}\left[1 + 0.7\left(\frac{r}{z}\right)^2 + 0.33\left(\frac{r}{z}\right)^4 + \cdots\right], \quad (1)$$

where $\mu_0 = 4\pi \times 10^{-7} H/m$, χ_F is the susceptibility of the magnetic fluid, V_S is the volume and r is the radius of the nonmagnetic spherical body. If we take into account only the first term from the right-hand side of relation (1), the levitation condition of the nonmagnetic body will be

$$(\rho_S - \rho_F)g = \mu_0\chi_F \frac{A_0^2}{z^3}, \quad (2)$$

where ρ_S is the density of the body, ρ_F is the density of the magnetic fluid and g is the gravitational acceleration.

If we make use of the relation $A_0 = Hz$ we will obtain the equilibrium function:

$$z = \frac{\mu_0\chi_F}{(\rho_S - \rho_F)g} H^2 \quad (3)$$

for a levitated body in a magnetic fluid in a wedge-shaped air gap characterized by a structure,where

$$H = \frac{A_0}{z}. \quad (4)$$

The equilibrium condition is satisfied in the intercrossing point of the curves which represents functions (3) and (4).

The portion MN of the curve (a) shown in Fig. 1 has been drawn taking into account the values of the magnetic field for $A_0 = A_0(I)$, as a result of the variation of current intensity in the coils of the electromagnet. The minimum value $M(z_b, H_b)$ has been obtained for the bottom level and maximum value $N(z_t, H_t)$ for the top level of the magnetic fluid in the experimental vessel.

It is very important to remark that the same function (3) may be obtained starting from the levitation condition as follows:

$$(\rho_S - \rho_F)g - \, = \mu_0\chi_F H \frac{dH}{dz}, \quad (5)$$

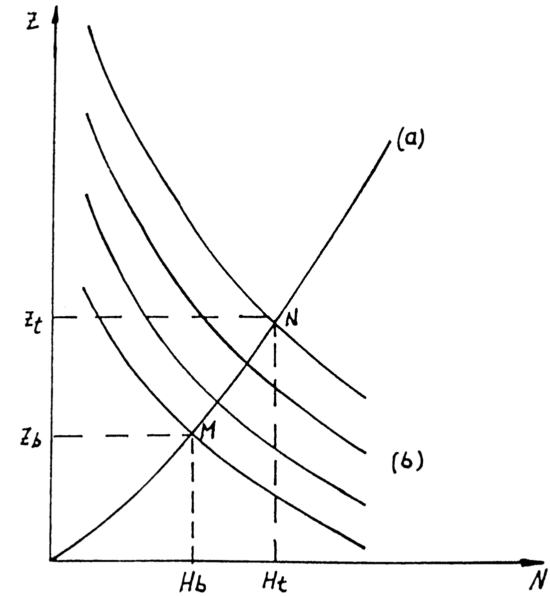

Fig. 1. Theoretical curves. (a) Parabolic curve representing the equilibrium condition. (b) Hyperbolic curves family representing the structure of the field in the wedge-shape air gap.

where $H\,dH/dz$ is computed for the structure of the magnetic field in the wedge-shaped air gap.

3. Experimental results and discussion

The experimental set-up shown in Fig. 2 allows to obtain the levitation of the nonmagnetic

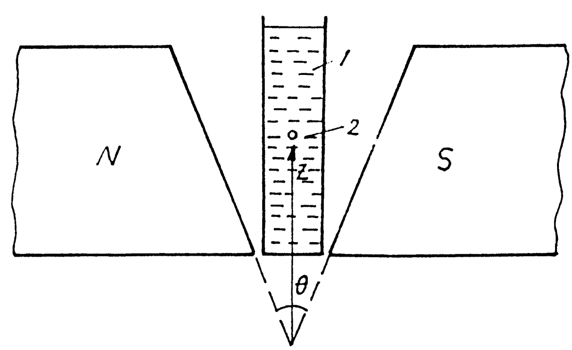

Fig. 2. Experimental set up: (1) magnetic fluid and (2) nonmagnetic spherical body levitated.

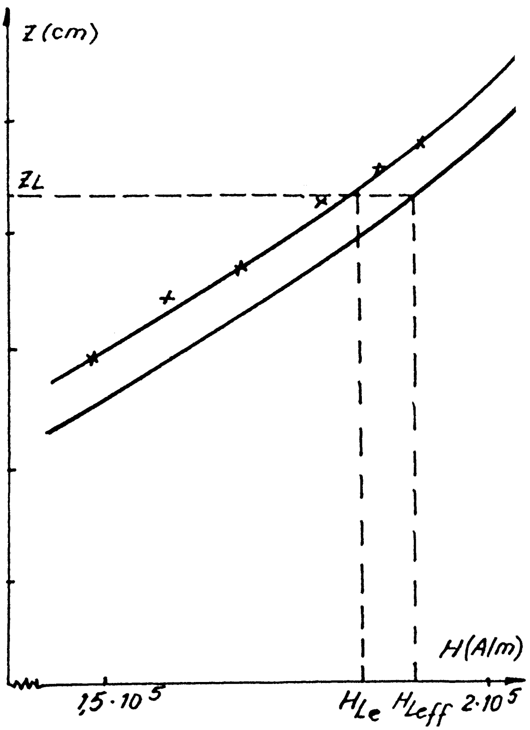

Fig. 3. Height z of the levitation point as a function of magnetic field intensity H at respective levels. (1) Theoretical curve and (2) experimental curve

spherical body in a cylindrical vessel filled with magnetic fluid at any point of the z axis between z_b and z_t through variation of the current intensity in the coils.

Fig. 3 shows the theoretical curve (1) and the experimental data curve (2) obtained for an aluminum spherical body ($\rho_S = 2700$ kg/m^3) immersed in a magnetic fluid ($\rho_F = 885$ kg/m^3 and $\chi_F = 0.015$).

The theoretical curve (1) shows the levitation level z_L as a function of the effective field H_{Leff} which acts on the nonmagnetic spherical body. This field may be written as follows:

$$H_{Leff} = H_{Le} + H_{Li}, \tag{6}$$

where H_{Le} is the external field at the levitation level and H_{Li} is the inner field created by the magnetic fluid at the same level as a result of its magnetization. From Eqs. (3) and (6) we can write:

$$H_{Li} = H_{Leff} - H_{Le} = \left(\frac{z_L}{C}\right)^{1/2} - H_{Le}, \tag{7}$$

where

$$C = \frac{\mu_0 \chi_F}{(\rho_S - \rho_F) g}. \tag{8}$$

The experimental data show an inner field around the spherical nonmagnetic body of about 7.5×10^3 A/m. This field may be created by magnetic dipoles of the monodomainic particles lying along the applied external magnetic field.

4. Conclusions

A new method is developed to measure the local intensity of the magnetic field inside magnetic fluids. Based on the phenomenon of levitation of a nonmagnetic spherical body immersed in a magnetic fluid, the method allows the determination of the magnetic field structure around the sphere.

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