FLOW OF A DIELECTRIC FERROMAGNETIC SUSPENSION IN A ROTATING MAGNETIC FIELD

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Experimental results are described and a qualitative explanation is given for the behavior of the dielectric ferromagnetic suspension Fe_2O_3–kerosene in an inhomogeneous rotating magnetic field. The graphs of the dependence of the angular and circular velocities of rotation of dielectric cylinders placed in the ferromagnetic suspension and also the graphs of the dependence of the torque on the magnitude of the field are given.

The rotation of a dielectric ferromagnetic liquid in a homogeneous rotating magnetic field, described in [1], has been discussed in detail in the theoretical work [2]. Such a field entrains the particles of solid magnetics, which results in a macroscopic motion of the entire volume of the liquid. In repeating the experiments of [1] with a γ-Fe_2O_3–kerosene suspension (mean size of the magnetics particles $\sim 0.2\ \mu$, volume concentration of the solid phase was 10-20%) in an inhomogeneous rotating magnetic field, some new phenomena were detected.

A thin-walled glass container of 80 mm diameter with the magnetic suspension (its basic curve of magnetization for 20 vol. % magnetics is shown in Fig. 1) was placed coaxially inside the hollow of a small bipolar asynchronous motor with three-phase winding producing a rotating field of 50 Hz frequency. The electric supply to the stator was obtained from a three-phase voltage regulator. A schematic diagram of the section of the equipment is shown in Fig. 2, where lines of equal field intensity in kA/m are also shown for a stator current of 4 A.

In view of the significant inhomogeneity of the field the dependences in all the graphs are shown on the stator current i and not on the field intensity H. The relationship between the stator current and the field is linear, since the stator is far from saturation.

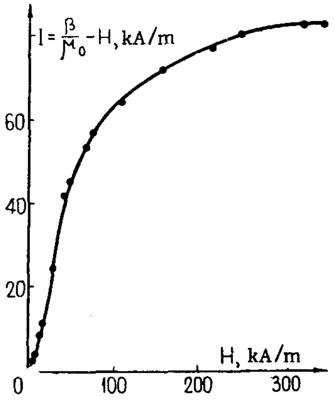

Fig. 1

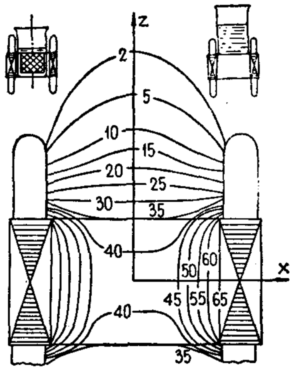

Fig. 2

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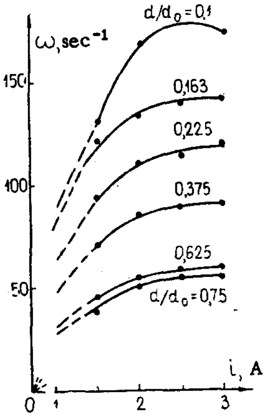

Fig. 3

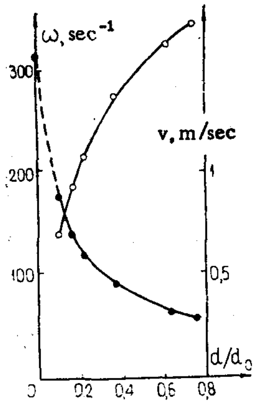

Fig. 4

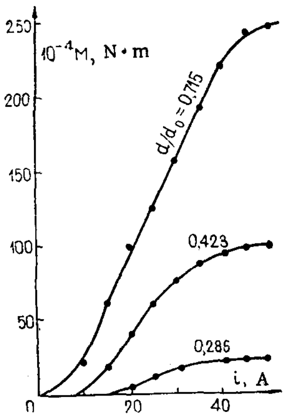

Fig. 5

On switching on the stator the magnetic suspension in the container placed at the middle of the stator hollow begins to rotate in a direction opposite to the direction of rotation of the field, i.e., opposite to the rotation of the conducting liquids. Dielectric cylindrical objects embedded in the magnetic suspension (see the diagram in the left upper corner of Fig. 2) always rotate in a direction opposite to the rotation of the magnetic field.

The curves of dependence of the angular velocity of rotation of textolite cylinders on the stator current are shown in Fig. 3 (d/d_0 is the ratio of the diameter of the cylinder to the inner diameter of the container). On increasing the stator current the angular velocity increases and attains its largest value at $i \sim 3$ A. "Saturation" of the angular velocity occurs at smaller H than the magnetization saturation of fixed suspension (Fig. 1).

The largest angular and circular velocities of rotation of textolite cylinders are shown in Fig. 4 as a function of their relative diameters d/d_0. It is seen from the graphs that on decreasing the diameter of the cylinders by a factor of 7.5 the angular velocity corresponding to saturation (filled circles) decreases by a factor of 3, whereas the circular velocity (open circles) decreases by a factor of 2.5. Extrapolating the diameter of the cylinder to zero we would obtain an angular velocity of about 314 sec^{-1} corresponding to the velocity of rotation of the field and the observed velocity of rotation of individual clumps of magnetics particles in a transparent liquid. A freely suspended container with the suspension in a rotating field begins to rotate in the direction of the field.

The observed phenomena can be qualitatively explained by the intrinsic rotation of each magnetics particle, which always occurs in the direction of rotation of the field. During the interaction with the container wall or with the surface of the cylindrical objects embedded in the suspension the rotating particles impart a part of their momentum to them due to the viscosity of the liquid; as a result the unsecured container or the cylindrical objects embedded in the suspension begin to rotate. The rotation occurs in the direction of rotation of the field or opposite to it depending on whether the particles interact with the outer or the inner side of the surface of the objects. Therefore, a macroscopic flow against the direction of the field is observed near the wall of the container, while near a fixed cylinder mounted inside the container the flow is in the direction of the field.

It is obvious that the friction of the rotating ferromagnetic particles at the cylinder embedded in the suspension is capable of rotating it and transfer a part of the power from the rotating magnetic field to the mechanism fixed to the axis of the cylinder.

Therefore, besides the measurements of the angular speed of rotation shown in Fig. 3, the moment of the forces acting on the dielectric cylinder from the side of the rotating magnetic suspension was also measured from the torsion of a spiral spring with its one end fixed to the axis of the cylinder and the other to a fixed support.

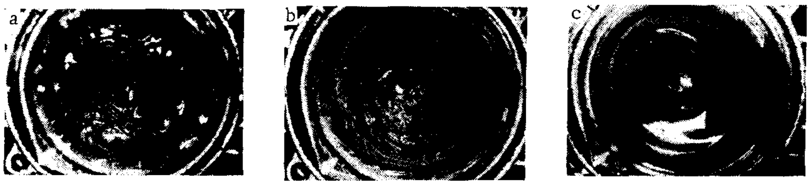

Fig. 6

Fig. 7

The results of this measurement are shown in Fig. 5 as a function of the stator current for three different diameters of the cylinder. An approximate estimate of the power at the axis of the rotating cylinder of 60 mm diameter is

$$N = {}^{1}/_{4} M_{\omega=0} \omega_{M=0} = {}^{1}/_{4} \cdot 240 \cdot 60 \cdot 10^{-4} = 0.36 \text{ W}.$$

Since a cylinder of this type rotates in the direction opposite to the roatation of the field, it can be used in automatic control systems supplementing the ordinary asynchronous motors when large powers are not required.

Observations of the free surface of the rotating ferromagnetic suspension showed that on placing the container in the frontal zone of the stator (see the diagram in the right upper corner of Fig. 2) the velocity and the direction of rotation of the suspension depend on the stator current, i.e., on the intensity of the magnetic field. At currents up to 1.5 A the suspension in the container rotates in a direction opposite to the field with angular speed of 2 $\sec^{-1}$. The free surface remains plane. With the increase of the current to 2A, active agitation is observed on the surface of the rotating suspension (Fig. 6a). An increase of the stator current to 2.5 A changes the direction of rotation, i.e., the rotation is in the direction of the field (Fig. 6b). A further increase of the current causes an increase in the velocity of rotation (Fig. 6c).

Analogous phenomena are observed on changing the position of the container in the stator. On placing the container in the region of iron of the stator the liquid rotates in a direction opposite to the rotation of the field. When the container is moved slowly into the region of the frontal parts of the stator, standing waves forming a right hexagon (Fig. 7a), violent agitation (Fig. 7b), and a change in the direction of rotation of the free surface (Fig. 7c) can be successively observed on the free surface of the rotating suspension. In certain positions of the container, simultaneous rotation of the liqud in opposite directions can be observed. In a container with inner fixed cylindrical object ($d/d_0 = 0.25$) the motion of the suspension becomes complicated. In a weak field the suspension near the wall of the container flows opposite to the direction of the field, while near the wall of the inner cylinder it follows in the direction of the field. On increasing the field intensity, the surface of separation of these flows becomes unstable and turns into several well-defined vortices, wherein the visible rotation of the suspension around the axis of the container stops.

Within the framework of fluid mechanics, the suspensions described above may be considered as liquids with a nonsymmetric stress tensor [3].

LITERATURE CITED

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