FERROMAGNETIC ELECTRICALLY CONDUCTING LIQUIDS

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Magnetic suspensions were prepared based on the metals tin, bismuth alloys, Ingas (an indium-gallium-tin alloy), and powdered nickel, with particle dimensions of order 50 μ. The Ingas-nickel suspension is a conducting liquid at room temperature. In a nonuniform field of 0.6 tesla stratification of the suspension was observed, with the formation of magnetic bridges. The magnetic properties of suspensions with various ferromagnetic powder contents were studied. Measurements were made by the ballistic method. The temperature dependence of the induction and the Curie temperature of a nickel-tin suspension were obtained. The dependence of the saturation induction of sample suspensions of nickel-tin, nickel-Ingas, and nickel-paraffin on the volume fraction of ferromagnetic substance was studied at room temperature. For a nickel content of up to 25% the saturation induction is proportional to the nickel concentration.

A dielectric ferromagnetic liquid – a suspension of magnetic particles with dimensions in hundredths of microns in kerosene – was described in [1]. Such fine particles make it possible to obtain stable suspensions despite the difference in densities, owing to the effect of thermal motion on the magnetic particles.

In many experiments (see, for example, [2]) liquids are required which have a good electrical conductivity in addition to magnetic properties. This is desirable so that the magnetic particles would not have to be very small.

In the Magnetohydrodynamics Laboratory of the G. M. Krzhizhanovskii Power Institute similar magnetic liquids were prepared, which moreover are not toxic and are sufficiently stable for the use of magnetic particles with dimensions 1-50 μ. A variety of applications of an electrically conducting magnetic liquid is made possible by the fact that two components of the electrodynamic force may simultaneously act on it, in the general case differing in magnitude and direction: $j \times B$ and $^1/_2 B^2 \nabla \mu^{-1}$

The first of such suspensions obtained by us were based on nickel and tin or bismuth alloys. The dimensions of the nickel particles were about 50 μ, so that they were not subject to thermal motion. Thanks to the good wettability and closeness of the densities of the components, the suspensions were quite stable and uniform.

The conductivity of the nickel-tin suspension at room temperature, determined by the current and voltage (on a MVL-7 instrument), was found to be $8.2 \cdot 10^6$ mho/m.

In the interval between the Curie point and the melting point of the tin or the bismuth alloy, amounting to 100-200° C, the medium was a liquid, conducting and magnetic.

In Fig. 1a is shown the shape of the free surface in the field of a permanent magnet at a liquid temperature approaching the Curie point, while Fig. 1b clearly shows the attraction of the liquid to the magnet poles after cooling and transition to the ferromagnetic region. Under repeated heatings the surface again became flat. The uniformity of the suspension in a magnetic field and without it was controlled by freezing a sample and photographing a thin slice under the appropriate magnification. When it was frozen in a

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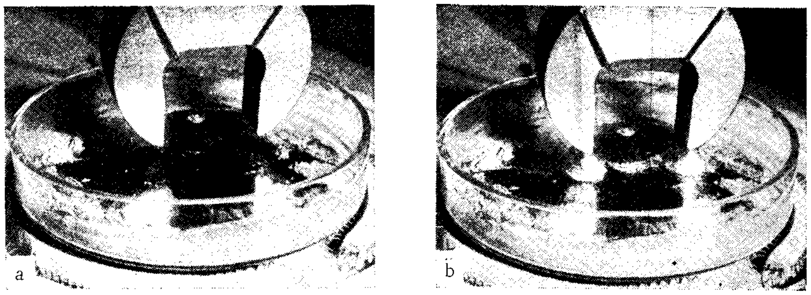

Fig. 1

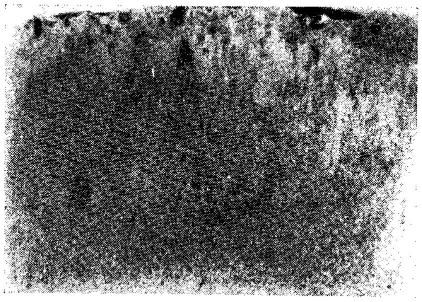

Fig. 2

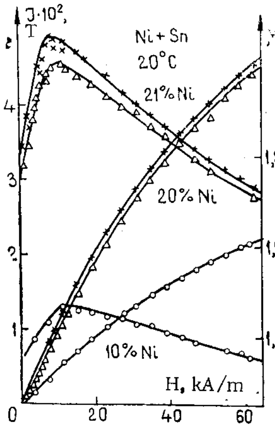

Fig. 3

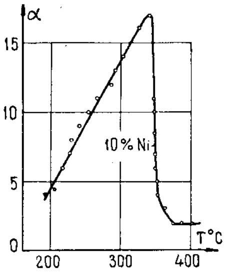

Fig. 4

magnetic field of about 0.6 tesla, a structure was observed of suspended particles oriented along the lines of force, i.e., magnetic bridges, which are clear in in the upper portion of the slice shown in Fig. 2.

The basic magnetization curve of a suspension of 10% nickel in tin was measured at various temperatures by the ballistic method on a BU-3 apparatus in a toroid filled with the suspension. The maximum induction obtained was 0.015 tesla for a field intensity of 7200 A/m. For the same specimen at a temperature of 20° C an induction of 0.36 tesla at 200 kA/m was obtained.

Direct measurement of magnetization as a function of the field was performed for three volume concentrations of nickel (10, 20, and 21%) in a frozen sample by the differential method. The results are shown in Fig. 3. For the 21% concentration the maximum relative magnetic permeability of the sample of $\mu = 2.1$ was attained, after which it decreased steadily with increasing field.

The Curie point of the 10% nickel suspension was determined by the temperature dependence of the induction in a weak field. As is clear from Fig. 4, it was 356° C, which agrees exactly with the handbook data for nickel. (In Fig. 4 the ordinate is the quantity $\alpha = cB$, proportional to the magnetic induction in the sample, but the proportionality constant c is unspecified since it is unimportant here).

Suspensions of nickel, not only in tin, but also in Ingas (indium-gallium-tin alloy) were studied. The melting temperature of Ingas is 10.5° C, and its density 6.4 g/cm^3. Ingas wets nickel rather well. A magnetic suspension was obtained at room temperature – an electrically conducting liquid that was very convenient in experimental practice.

The uniformity of distribution of the ferromagnetic particles with the depth of the liquid sample may control the magnetic properties along the depth. It appeared that the particle concentration increased somewhat in the upper layers of the suspension. This is explainable by both the presence of smaller nickel particles and the presence of particles insufficiently wetted by the Ingas. In a strong nonuniform magnetic field (480 kA/m) the formation of magnetic bridges was observed. Ferromagnetic particles were drawn in the direction of increasing magnetic field, as a result of which the ferromagnetic phase contained in the liquid sharply decreased. Such a stratification was not observed in fields up to 40 kA/m when working with particle dimensions of approximately 50 μ.

Measurements of the magnetic properties of the suspensions were performed in a solenoid on a BU-3 apparatus. Suspensions of two different volume concentrations of ferromagnetic substance were studied: 19 and 6.5%. The resulting dependences of the magnetization on the field are shown in Fig. 5. The maximum value of the magnetization was 0.04 tesla in a field of 56 kA/m. Values of the relative magnetic permeability obtained in these experiments are shown in the same figure. Its maximum values for concentrations

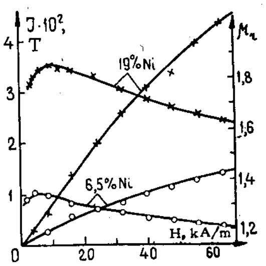

Fig. 5

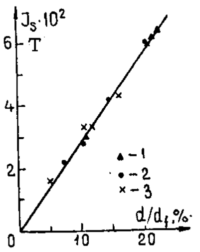

Fig. 6

of 6.5 and 19% were $\mu = 1.33$ and 1.86 respectively. Measurements of the magnetization of these suspensions repeated after 30 days showed no attenuation of their magnetic properties.

The dependence of magnetization saturation on the volume fraction of ferromagnetic substance in the suspension was also studied. Measurements of the magnetic properties were carried out not only for nickel-tin and nickel-Ingas suspensions of various concentrations, but also for nickel-paraffin samples. Saturation values of the magnetization were obtained at room temperature by extrapolating the function $I = f(H^{-1})$ to the region $H^{-1} \to 0$. The resulting saturation magnetization is shown as a function of the volume fraction of ferromagnetic substance in Fig. 6.

The results of the magnetic measurements attest to the fact that chemical reactions of the nickel powder with the tin and Ingas do not occur, since the magnetization curves of these suspensions for identical concentrations coincide with the magnetization curves for nickel in paraffin.

LITERATURE CITED

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