SOME FEATURES OF THE MAGNETORHEOLOGICAL EFFECT

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The rheological properties of magnetorheological suspensions (MRS) are investigated in a wide concentration range of particles of the disperse ferromagnetic phase in the presence of a magnetic field. It is shown that, along with an increase in the concentration of ferromagnetic particles, the range of control of the viscous stress increment in an MRS can be broadened by changing the size and shape of the ferromagnetic particles, introducing nonmagnetic particles into the dispersion medium as well as by heating the medium to the Curie temperature.

The possibility of control of the rheological and thermophysical properties of magnetorheological suspensions (MRS) within wide limits by applying a magnetic field has allowed their use for creation and upgrading of modern technologies: electrohydraulic systems, precision polishing of parts made of glass, ceramics, and semiconducting materials, of heat exchangers, etc. [1, 2].

In a magnetic field of a prescribed intensity an MRS acquires distinct viscoplastic properties, and the magnetoviscous effect achieved (an increase in the effective MRS viscosity) is determined by such factors as the magnetic properties and size and shape of particles of the disperse ferromagnetic phase, as well as their concentration.

Among the great variety of disperse ferromagnetic materials produced (powders of ferrites and magnetodielectrics), magnetorheological technologies employ powders of carbonyl iron used to create high-frequency devices in the radioengineering industry. Their doubtless merit is high values of magnetic susceptibility and saturation magnetization. The most widely used and cheap powders of carbonyl iron of the type R-10, R-20, R-100, etc., contain spherical particles sized to microns and are distinguished by polydispersivity. The range of particle size distribution lies within 0–20 μm. Here, the mean particle size differs insignificantly (from 1 to 3.5 μm) in the various powder modifications. The electromagnetic parameters of all powder modifications of carbonyl iron are practically unchanged in the range of frequency characteristics of systems with magnetorheological control. Therefore, in order to broaden the possibilities of control in magnetorheological technologies, use is made of the concentration factor.

Depending on the sphere of application and the required range of control of rheological characteristics, the concentration of the ferromagnetic filler in actual MRSs can be varied within wide limits (from 2 to 50 wt. %). To investigate the influence of the concentration of particles of the ferromagnetic disperse phase on MRS rheological properties in a magnetic field, we used suspensions based on particles of carbonyl iron of modification R-10 with a mean size of 3.5 μm. The dispersion medium of all MRSs was prepared on the basis of hydraulic oil, grade AMG-10, with stabilizing additives in form of submicronic particles added to impart sedimentation and aggregation stability to the suspension. These particles formed coagulation structures that prevented sedimentation of heavy ferromagnetic particles and were capable of thixotropic transformations.

The rheological properties of the MRS in a magnetic field were measured by a rotary magnetorheometer based on a standard rotary viscosimeter. The magnetorheometer was equipped with an inductor of a radial magnetic field which provided application of external fields with an intensity of 0–200 kA/m to a Couette flow of the
Fig. 1. Increment of viscous stresses in MRS $\Delta \tau$ versus concentration of ferromagnetic particles in magnetic fields of different intensities $H$: 1) $H = 20$ kA/m; 2) 30, 3) 40, 4) 50, 5) 80. $\varphi$, %; $\Delta \tau$, Pa.

investigated fluid. The entire measuring cell of the device was thermostatted. The arrangement made it possible to control the investigated suspensions in the range of $0-90^\circ$C.

A dependence of the increment of shear stresses of the MRS on the concentration in a magnetic field $\Delta \tau = f(\varphi)$ is shown in Fig. 1 (here $\Delta \tau = \tau_m - \tau_0$, where $\tau_m$ and $\tau_0$ are the shear stresses of the MRS at the prescribed shear rate in the magnetic field and without it, respectively.

It is found that in the range of low volumetric concentrations of particles of the dispersed ferromagnetic phase ($\varphi < 8\%$) the dependence $\Delta \tau = f(\varphi)$ is nearly linear. With an increase in the content of magnetic particles to moderate concentrations ($8\% < \varphi < 30\%$), the character of the plot changes. In this range only an insignificant increase in viscous stresses in a magnetic field is detected, which is attributed to an increase (by 5-10%) in the volumetric concentration of ferromagnetic particles. However, with a further increase in the concentration ($\varphi > 30\%$), the role of the concentration factor markedly enhances. In this case, with increasing $\varphi$ the shear stresses undergo almost a quadratic increment. Such a tendency of the concentration dependence to an increase in viscous stresses is manifested for all intensities of magnetic fields (20–80 kA/m) and shear rates implemented in the experiments.

The range of control of the viscous stress increment in the MRS in the presence of a magnetic field can be considerably extended by increasing the portion of coarse particles in the composition of the polydispersed ferromagnetic powder. It is found that an increase in mean particle size of from 3 to 20 $\mu$m results in a threshold increase in the control range in magnetic fields with an intensity of up to 100 kA/m.

One more way of the improving the sensitivity of the rheological characteristics of an MRS to a magnetic field is to use a dispersed ferromagnetic phase based on anisodiametric particles. From this standpoint, particles in the form of long cylinders or elongated ellipsoids are considered to be most effective. The magnetization energy of an anisodiametric particle with its major axis collinear with the intensity vector of the magnetic field, with all other factors being equal, is much smaller than that of a spherical particle. In this respect, particles with an axis ratio of 10:1 are most effective. However, particles of corresponding size of ferromagnetics with sufficiently high magnetization are not produced. Therefore, for investigation of the influence of particle size on the rheological characteristics of the MRS the only alternative is to modify the shape of spherical particles of carbonyl iron by mechanical methods with the purpose of imparting some anisodiametric property to them. With particles of modification R-10, this was accomplished in an attritor by means of cold plastic deformation. As a result of such treatment, the particles acquired a configuration close to that of a contracted ellipsoid with an axis ratio of approximately 3:1.

Investigations of the magnetic properties of an MRS prepared on the basis of modified particles of carbonyl iron ($\varphi = 10\%$) show that the saturation magnetization corresponds to that obtained for a suspension of spherical particles of the same concentration. This indicates that for the mentioned technology of particle treatment, their internal structure changes insignificantly and, as a consequence, their electromagnetic parameters are retained. However, an analysis of the curves of static magnetization of the given MRS and one based on spherical particles shows an increase of magnetic susceptibility in low-intensity fields (0–100 kA/m). The magnetic susceptibility undergoes an almost twofold relative increase, which is attributed to the change in the shape of particles. In