AN ESTIMATE AS TO THE POSSIBILITY OF UTILIZING MAGNETORHEOLOGICAL SUSPENSIONS IN COMPRESSION EQUIPMENT

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This paper is devoted to an investigation of the characteristics of a simple type of magnetic-fluid compression seal (MFC) in which the pressurizing medium is a stable magnetorheological suspension (MRS) of noncolloidal magnetic particles of iron carbonyl. The formulation of such a problem is governed by the following factors. First of all, the saturation magnetization M_S is substantially greater than that traditionally used in compression seals of colloidal magnetic fluids (MF), e.g., for the compositions utilized in a magnetic field of strength H = 150 kA/m we have M_{SMf} = 50 kA/m, while M_{SMRS} = 120 kA/m. Since the pressure difference between the seal cavity and the ambient medium at one stage of the magnetic-fluid compression is determined by the relationship [1]

$$\Delta p_m = \mu_0 M_s H h/\delta, \tag{1}$$

where h and δ are the height and thickness of the annular compression layer, it is obvious that the MRS exhibits clear advantages. Secondly, unlike the magnetic fluid, the MRS in the field acquires clearly defined plastic properties characterized by a fluidity limit $\tau_0 \sim H^2$. As a result, the compression ring of the suspension can maintain the pressure difference Δp both with the magnetic component Δp_m from (1) and by means of the plastic component $\Delta p_p = 2\tau_0 h/\delta$, in which case $\Delta p = \Delta p_m + \Delta p_p$. Thus, in the single-stage compression with $\delta = 10^{-4}$ m and $h = 10^{-3}$ m the calculated pressure difference for the MRS amounts to a quantity on the order of $4 \cdot 10^5$ N/m² ($\tau_0 \approx 10^4$ N/m² [2]), while for the magnetic fluid it is 10^5 N/m², i.e., we have a fourfold excess in compression sealing capacity. However, we should take into consideration that the increase in plasticity as well as in the effective viscosity of the MRS in the field carry with it a significant increase in the intrinsic moment of friction and the loss of one of the advantages of MFC. Thirdly, realistic prospects of utilizing MRS, such as, for example, in elements of electrohydro automated systems, as well as in positional pneumatic and hydraulic drives [3, 4], require estimates of the possibility of utilizing suspensions as a compressing agent, since the presence of the suspension in the hydraulic systems of such devices assumes that they will also be used in MFC.

The experiments were conducted on an installation schematically presented in Fig. 1. The design of the metering cell was executed in analogy with the device used in [5], i.e., the cell can be connected to the rotational "Reotest-2" viscosimeter 1 which serves to measure the moment of friction and as the drive to rotate the magnetic operating shaft 2. The MRS was placed in the annular gap 3 of core 4 and retained by a magnetic field generated by coil 7 (w = 650 turns). In the compression-sealing chamber 8 we have a smooth increase in air pressure, and the instant of compression seal breakdown was determined visually, by observing the free surface of the suspension illuminated by lamp 9. Simultaneously, from the readings of manometer 5 we established the breakdown pressure p', and here Δp = p'.

We noted variations during the course of the experiments in the thickness and height of the clearance, in the number of revolutions n, and in the current I in the coil; the parameters varied over the range h = 1-10 mm, n = 0-240 rpm, I = 0.25-2.5 A, δ = 0.075, 0.15 mm. For purposes of comparison, all of the experiments were replicated with utilization of a magnetic fluid.

The nature of the breakdown of the compression seal depends on the form of the pressurization medium. In all of the regimes the destruction of the magnetic-fluid ring occurred with a suddenness that caused the compression seal to be ejected from the clearance, and this was accompanied by a rapid drop in pressure within chamber 8 (with a closed valve 6). In the case of MRS, however, we observed progressive accumulation of fine air bubbles at the free surface, and a slow change in the pressure.

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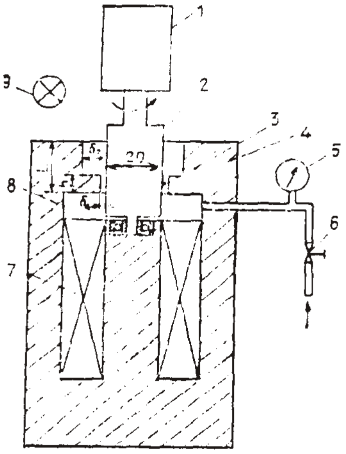

Fig. 1

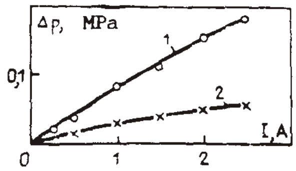

Fig. 2

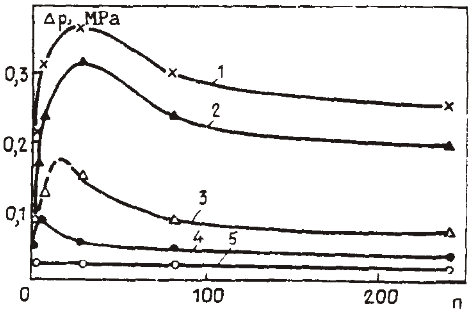

Fig. 3

Fig. 1. Diagram of the measuring cell. Explanations in text.

Fig. 2. Static (n = 0) characteristic of MFC: MRS (1), MF (2).

Fig. 3. Effect of shaft rotation frequency on the retaining pressure difference Δp: for MRS with I = 2.5 (1), 1.5 (2), 1.0 (3), 0.5 A (4) and for MF with I = 1 A (5); h/δ = 27.

In statics (n = 0) the values of the pressure drop maintained by the MFC with MRS significantly exceeded the values obtained with utilization of MF, exceeding the latter in the case of I = 2.5 A by a factor of approximately four (Fig. 2). In the dynamic regime, with an increase in the number of shaft revolutions, the pressurization sealing capability of the magnetic fluid diminishes, as was described in the earlier experiment [6] (Fig. 3). For an MRS the pressure difference with an increase in n surprisingly increases markedly, passin through a maximum value and then dropping off, remaining greater than the Δp with n = 0 for I > 1 A. The frequency at which we observe Δp_{max} has a tendency toward increase with the growth of I. A change in the thickness of the annular layer, and, consequently, also the shear velocity $\dot{\gamma} = (D + 2\delta)^2 n/[2(D + \delta)\delta]$, leads to a proportional displacement of the extremum ordinate on the function Δp − Δp(n).

The MRS, unlike a MF, is a markedly heterogeneous medium, and the disruption of the pressurized seal in statics occurs preferably as a result of the "sucking through" of the streams of air through the structural framework (formed by anisotropic aggregates consistin of ferromagnetic particles), primarily at the sites of its defects. Small shear creates a certain amount of chaos, thus enhancing the growth of the averaged number of parallel bon between individual aggregates of the structure [7], a reduction in the size and number of defects, and the destruction and crushing of the streams (plaits) of air. As a result, the breakdown pressure increases. For values of $\dot{\gamma}$ exceeding some optimum value, Δp drops because of the intense destruction of the aggregate by a shear flow and because of the reduc tion in the magnetorheological effects, so that with a magnetizing current I < 1 A and larg values of $\dot{\gamma}$ the effects degenerate. The increase in I which causes the intensification of

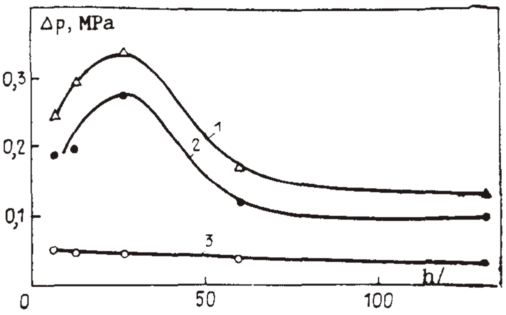

Fig. 4

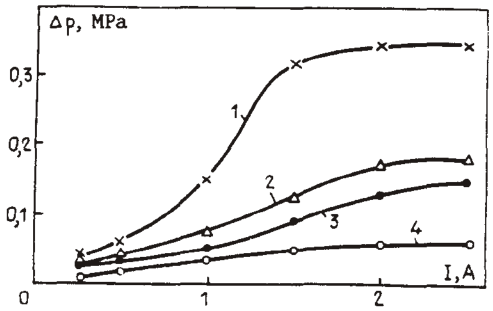

Fig. 5

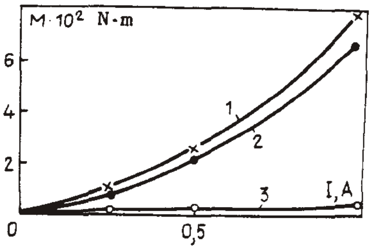

Fig. 6

Fig. 4. The pressure drop Δp as a function of h/δ for MRS with n = 27 rpm (1) and 81 rpm (2) and for MF with n = 270 rpm, I = 2 A.

Fig. 5. Pressure drop Δp as a function of current I in a magnetized coil for MRS with h = 2 (1), 4.5 (2), and 10 mm (3) and for MF with h = 2 mm (4), n = 27 rpm; δ = 0.075 mm.

Fig. 6. Frictional moment in MFC for MRS with n = 81 rpm (1) and 27 rpm (2) and for MF with n = 81 rpm (3). h = 4.5 mm, δ = 0.075 mm.

field strength in the clearance as well as that of the axial field gradient promotes the sealing of the structure and the strengthening of the aggregates, which shifts the value of $\dot{\gamma}$ at which Δp attains a maximum in the direction of increase.

The experiments revealed the optimum ratio h/δ (Fig. 4). The greatest pressure difference was observed for h/δ = 27 (h = 2 mm, δ = 0.075 mm) and (in opposition to [1, 2]) it diminished with an increase in the values of h. Apparently, this was associated with the structural features of the MFC measurement cell. Indeed, a calculation of the magnetic circuit of the device yields the following expression for the intensity of the field in the working clearance:

$$H=\frac{Iw}{\delta_1+r\mu_0\pi Dh[(\delta_1/\delta_2)(L/h-1)+1]}, \qquad (2)$$

where r = const is the magnetic resistance of the magnetic conduit, with the exception of the resistances of the air gaps δ_1 and δ_2 (noted in Fig. 1). We see from (2) that for fixed values of I, with a reduction in h, the intensity of the fields in the working clearance rises to a value at which the segment of the surface adjacent to the sealing ring becomes saturated. Subsequent thinning of the ring does not strengthen the field and Δp diminishes. It is probable that the saturation is connected to the attainment of a plateau by the curves showing Δp as a function of current I in the winding of the magnetization coil (Fig. 5). Transition from a magnetic fluid to a magnetorheological suspension, as was noted earlier, leads to a considerable rise in the frictional moment on the shaft (Fig. 6).

CONCLUSIONS

1. The possibility of utilizing a magnetorheological suspension as the working medium in an MFC is quite realistic. The effectiveness of such a seal increases for low numbers

of shaft revolution or, in statics, when the intrinsic moment of friction is absent or plays no significant role. In such operating regimes the advantages in comparison with magnetic fluids are substantial, since the retaining pressure of the MRS sealing ring, all other conditions being equal, as had been assumed, is greater by a factor of approximately four.

2. We have ascertained the unique feature in the functioning of an MFC with an MRS, and this involves the increase in the value of Δp in the dynamic regime in comparison with statics, as well as the presence of a maximum on the functions $\Delta p = \Delta p(n)$.

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