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Destruction of chains in magnetorheological fluids by high frequency oscillation

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1. Introduction

Magnetorheological fluids (MRF) are characterized by magnetorheological effect – phenomena of reversible change in its rheological properties under action of the magnetic field. These media represent magnetosensitive fluid systems with solid disperse ferromagnetic phase. The size of magnetorheological fluid particles is of the order of $10^{-6} – 10^{-5}$ m. The Brownian motion for such systems is not essential.

In the magnetic field ferromagnetic particles acquire magnetic moment aligned to the field direction. Due to the interaction of magnetic moments and own mobility, the particles start to move and group into chain aggregates minimizing system's free energy. These aggregates have significant strength in the magnetic field; that results in the change of MRF rheological properties.

Thus, with the help of generating magnetic field, it is possible quickly (characteristic time is $10^{-3} – 10^{-4}$ s) control MRF flow parameters, heat and mass transfer, electric and magnetic properties. This is the basic parameter, characterizing quality of MRF, used in modern technology. For example, using the MRF in magnetorheological valves makes it possible to effect a quick change of hydraulic resistance. MRF allow to regulate resonance frequency in damping devices. Finishing operations of optical and semiconductor components using MRF allow to automate finishing process and to get surfaces with minimal microroughness.

The aim of this work is to investigate the chains formation in magnetorheological fluids in the magnetic field and destruction of them when the magnetic field is turned off under microscope observation. The response rate of this chains transformation corresponds to the rate of rheological properties changes and, consequently, defines reaction speed of magnetorheological devices.

There are earlier experimental observations on electrorheological fluids, reported in [1, 2] and MRF [2, 3]. The structure transformation in electrorheological fluids under shear deformation in the electric field was investigated in [1]. Upon application of the electric field, the static fluid rapidly formed a fibrous structure, followed by slight rearrangement within the fibres on a time scale of seconds. When strained less than a critical value, these fibres remained intact, and, if returned to the unstrained state, their structure appeared unaffected. When strained past a critical value, all the fibres in the fluid ruptured over narrow range of strains. At small rates of strain, the permanent restoration and destroying structure has occurred. At moderate shear rates, the most of fibrous masses are attached to one electrode, the fluid-like region is formed at the second electrode where all the macroscopic deformation occurs. Increasing the shear rate degrades the solid region and expands the fluid region [1].

The structure formations in electrorheological fluids and in MRF under oscillating shear flow are described in [2]. When the shear deformation amplitude was more than 0.15, the isotropic aggregates are transformed into sheets oriented perpendicularly to the flow. The parallel stripes and the serrated structure may be observed in the electric field of high strength [2].

The parallel stripes also are forming in MRF in the magnetic field under oscillating shear flow, when the deformation amplitude was more than 0.15. These stripes are stable under high magnetic intensity [2].

A model to simulate the motion of ferromagnetic particles in MRF is proposed, based on the analysis of the dynamic model, shown in [3]. The simulation results indicated that the particles at first form short chains, and then these short chains merge together and form longer chains. The simulation results agree well with the experimental observation [3].

Several papers are related to theoretical investigation and computer simulation of structure formation in electrorheological fluids [4] and MRF [5, 6] as well as the investigations in the rotating [7] and pulsed [8] magnetic fields, or the investigations of electrorheological fluids structure disruption by piezoactuation [9, 10]. Our work makes accent on the MRF structure disruption study by mechanical vibration after the magnetic field has been turned off.

2. Experimental setup

Our experimental setup for structure formation observation contains an electromagnet with MRF between its poles. The general view of the experimental setup is shown on Fig. 1. It consists of flat rectangular magnetic circuit with a gap of 0.5 mm. The dimensions of circuit are 30×35 mm, the width is 7 mm. The thickness of circuit is 0.5 mm. The magnetic circuit is manufactured from material with ferromagnetic properties. The copper wire coil is winded around the circuit on the side opposite the gap. The coil is supplied from direct voltage source. MRF was placed into the gap between the magnetic circuit poles. The observation of processes in MRF layer under magnetic field action was carried out with using of microscope with videotaping.

The piezoelectric transducer – vibrator was attached to magnetic poles of the experimental cell in order to define the influence of vibration on the structure transformation in MRF. Two kinds of vibrators were used. The first one generated small vibration of the poles in the direction along the gap width, the second – perpendicular to the circuit plane. The resonance frequency of the system is 65 kHz in the first case and 55 kHz in the second one.

Magnetic field in the gap of the magnetic circuit

$$B = \mu_0 \mu H \tag{1}$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m is magnetic constant, $\mu = 14.5$ is magnetic permittivity of magnetic circuit, H is magnetic field intensity, A/m.

Magnetic field intensity can be calculated assuming that the magnetic field force lined go only along of the magnetic circuit contour

$$H = \frac{Iw}{l} \tag{2}$$

where I is current in the coil, A, w is number of coil turns, l=0.103 m, is length of magnetic circuit contour.

The number of coil turns can be estimated from the measuring of coil resistance, $w = Rd^2/(8\rho r)$, where $R = 28.5$ Ohm is coil resistance, $d = 0.15$ mm is diameter of coil wire, $\rho = 0.0175$ Ohm·mm^2/m is specific resistance of copper, r~5.3 mm is spool radius.

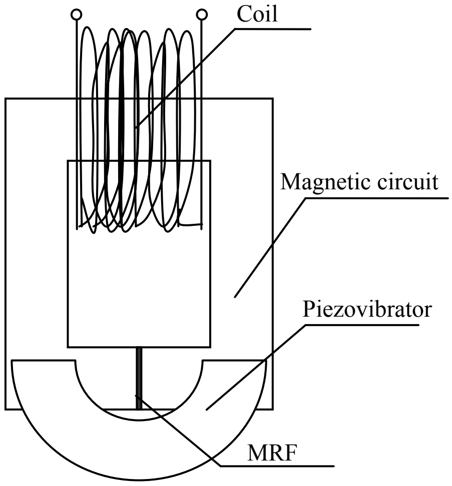


Fig. 1 General view of the experimental setup for the observation of MRF structure transformation

According calculation w ~ 850. In such approach the magnetic field induction in the gap of the magnetic circuit is proportional to direct current in the coil. The intensity reaches 30 mT at the current 0.2 A.

The experiments were performed with much diluted MRF on the base of carbonyl iron in order to obtain sufficient clarity.

3. Main results

The disperse phases particles are arranged chaotically in the absence of the field (Fig. 2, a). Dark regions correspond to particle clusters, transparent ones – to pure disperse medium. The particles begin to move when the field is turned on. As it is seen under microscope, the rate of moving is related to the induction of the

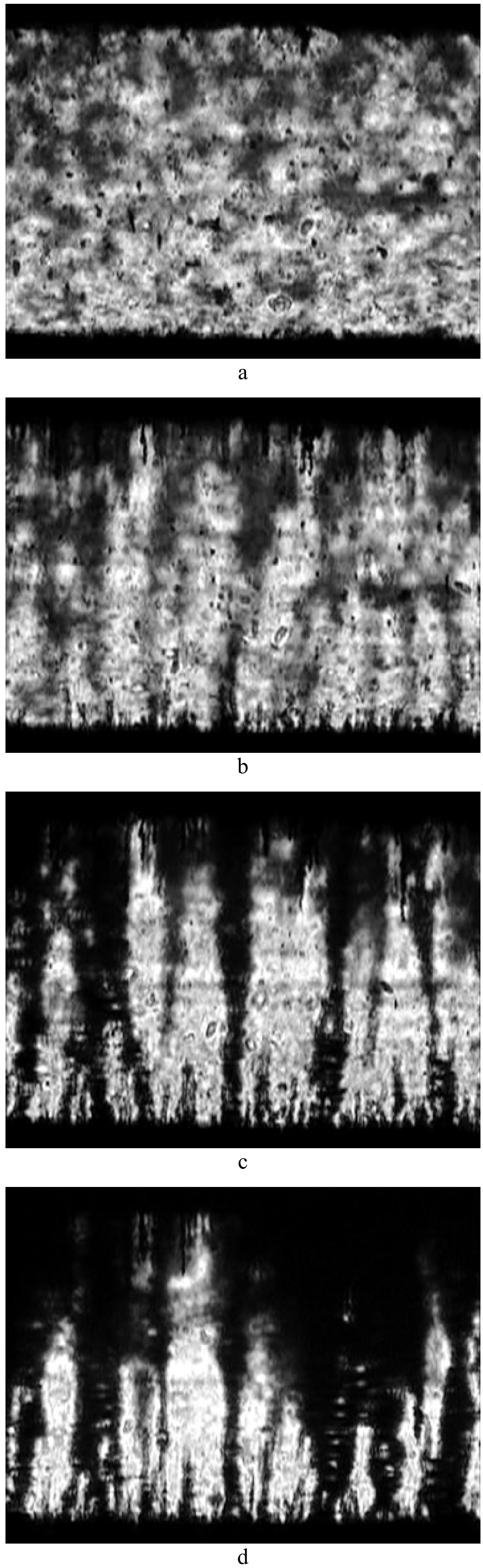


Fig. 2 MRF structure formation under gradual increase of the magnetic field: a – B=0, b – B=2 mT, after 2s, c – B=2 mT, after 5 s, d – B=10 mT, after 10 s

magnetic field. The more induction, the faster particles move.

Fig. 2 illustrates the structure formation when the magnetic field increases gradually. The time of equilibrium state establishment is about 7 – 8 seconds under minimal magnetic field induction 2 mT. This is slow reaction, not sufficient for effective work in magnetorheological devices. The further gradual magnetic field increment (to 30 mT) results in some structure growth and rearrangement (Fig. 2, d), but the structure does not significantly differ from the one attained under minimal field. The main structure forming is attained at first turning on of the magnetic field, though this process goes slowly.

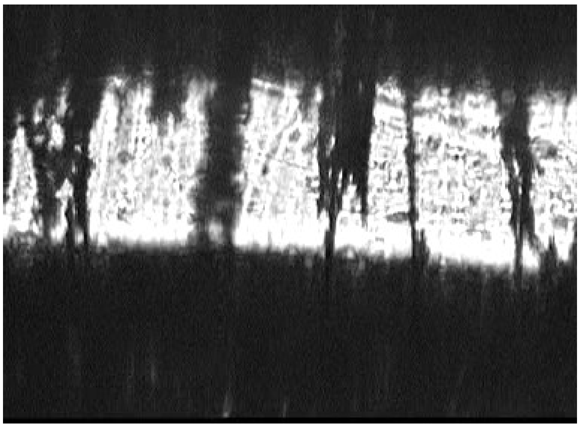
Under field induction 20 mT the transformation is faster. The chain-like structure is created within 0.5 s (Fig. 3, a). For all cases when the magnetic field was turned off, no significant changes occurred. The small part of structures was splitting off from the bulk. The reason of such behaviour is remnant magnetization of magnetic circuit and some inertia of particle motion. It needs for destruction of the chains to demagnetize the magnetic circuit poles and to shake fluid, e. g., with vibroimpulses.

For this purpose the piezovibrator attached to magnetic poles was used. When the piezovibrator was turned on (after magnetic field has been switch off), the vibration does not result in destroying aggregate, at least, at used amplitudes. The chains begin to quake and slowly creep under shaking, but save their form (Fig. 3, b). This is an essential difference from the case of electrorheological fluids where structures are disrupted under vibration after electric field has been switch off.

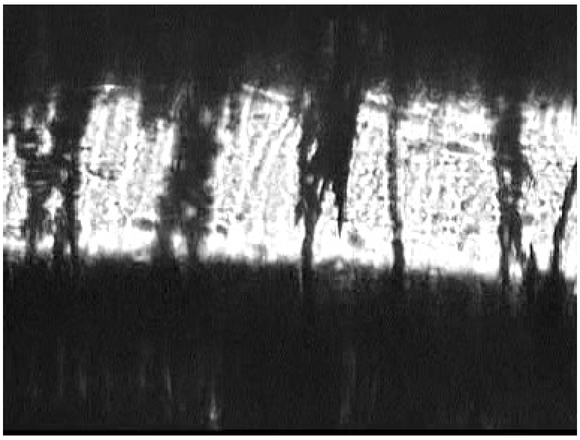
For chains destruction the magnetic circuit poles and MRF were subjected to demagnetization by applying alternate magnetic field with decreasing amplitude. The view of MRF microstructure after demagnetization is presented in Fig. 4, a. This is the same fluid sample that is shown in Fig. 3, b, but the magnetic particles were displaced and rearranged by alternate field. Then the vibration with the same amplitude was applied again. After demagnetization the vibration results in chain destruction as it is seen in Fig. 4, b. The columns of particles broke near the poles, rotated to the direction perpendicular their initial and slowly moved along the gap with moving disperse medium.

No significant difference was displayed in the cases of various directions of vibrations. It was noted that the piezovibrator created whirlwind motion of disperse media. Obviously, this fluid motion caused the structure break, but the poles and attached to them chain ends displacements is too small to provide aggregate destruction.

Thus, it is established that it is necessary to demagnetize and to shake magnetorheological fluid for structure disruption and initial state restoration after the field is turned off. Therefore, for effective utilization of

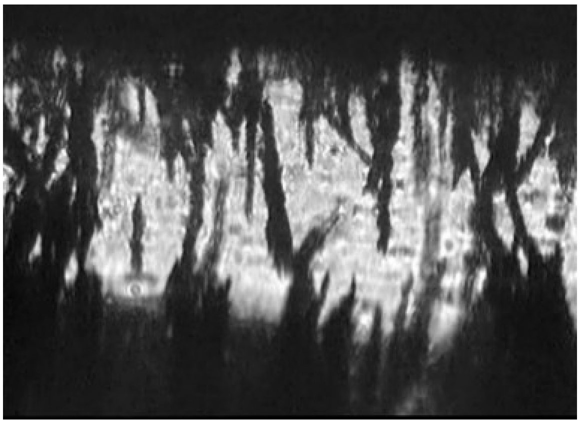


a

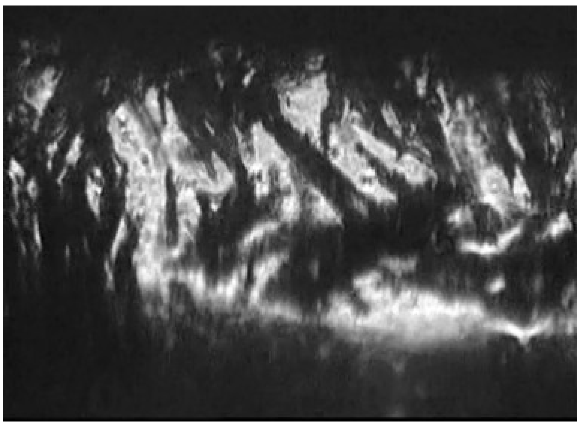


b

Fig. 3 Vibroactuation influence on MRF structure when the magnetic field is turned off: a – piezo shaker off, b – piezo shaker on



a



b

Fig. 4 Vibroactuation influence on MRF structure after demagnetization: a – piezo shaker off, b – piezo shaker on

MRF in some technical devices (e. g., hydraulic systems, vibrodamping devices, etc.) it is necessary to use magneto-soft magnetic materials as elements of magnetic circuit and apply mechanical oscillations to disrupt the remnant structures in the fluid.

4. Conclusions

The microscope observations of structure transitions in magnetorheological fluids show that magnetic particles start to move and group into chain aggregates when the magnetic field is turned on. The more magnetic field induction the faster particles move. The turning off the magnetic field does not result in significant changes in fluid structure because of the remnant magnetization of magnetic circuit. The subsequent vibration effect can not disrupt the structures too. It needs MRF to expose to demagnetization. After demagnetization the vibration results in chain destruction and initial state restoration.

Acknowledgements

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GRANDINIŲ ARDYMAS MAGNETOREOLOGINIUOSE SKYSČIUOSE AUKŠTOJO DAŽNIO VIRPESIAIS

R e z i u m ė

Straipsnyje pateikti struktūrinių virsmų magnetoreologiniuose skysčiuose, esant išoriniam poveikiui, stebėjimo rezultatai. Magnetinės dalelės, veikiamos magnetinio lauko, suformuoja išsitįsusias grandinines struktūras, kurios išlieka net išjungus magnetinį lauką bei vėliau paveikus mažos amplitudės virpesiais. Struktūroms suardyti ir pradinei būsenai atgauti, prieš sukeliant virpesius būtina išmagnetinti magnetinę grandinę.

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DESTRUCTION OF CHAINS IN MAGNETORHEOLOGICAL FLUIDS BY HIGH FREQUENCY OSCILLATION

S u m m a r y

The results of the microscope observations of structure transitions in magnetorheological fluids under external influences are presented. Magnetic particles form chain elongated structures when applying magnetic field. These structures retain after turning off the magnetic field and even subsequent low amplitude vibration influence. It needs to demagnetize the magnetic circuit before exposing vibration for full structure destruction and initial state recovery.

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С. Ходочинскас

РАЗРУШЕНИЕ ЦЕПОЧЕК В МАГНИТОРЕОЛОГИЧЕСКИХ ЖИДКОСТЯХ С ПОМОЩЬЮ ВЫСОКОЧАСТОТНЫХ КОЛЕБАНИЙ

Р е з ю м е

Представлены результаты наблюдений под микроскопом структурных переходов в магнитореологических жидкостях при внешних воздействиях. Магнитные частицы формируют вытянутые цепочечные структуры при приложении магнитного поля. Эти структуры сохраняются после снятия магнитного поля и даже последующего низко-амплитудного вибрационного воздействия. Для полного разрушения структуры и восстановления начального состояния необходимо перед вибрационной нагрузке размагнитить магнитную цепь.

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