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# The sedimentation of magneto-rheological fluid monitoring system based on resistivity measuring

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## 1. Introduction

Magnetorheological fluids (MRF) consist of a hydrocarbon, silicone, or aqueous carrier fluid, and magnetic particles, which is micrometres size. [1,2,3]. When a magnetic field is applied on this fluid, the particles become polarized and are arranged into chains and clusters, which cause the reversible changes of the yielding shear stress and the viscosity [4]. Iron powder is the most commonly used particles in the M R Fluid as it has high saturation magnetization. When influenced by a magnetic field, these particles are arranged to form very strong chains with the positive pole of one particle being attracted to the opposite pole of another particle. Once the particles are attracted, the fluid has a change in its rheological properties [5].

One of the main problems in the design of magnetorheological fluids is the phenomena of their sedimentation. Sedimentation of particles is very hazardous when using MR fluids in some of them application. It can be used in dampers, shock absorbers, clutches, etc. [6,7,8] Because of sedimentation of the particles operation of the device can be unstable and cause some errors. The decreasing of the sedimentation velocity of the particles can be achieved by adding surfactants to the composition, or utilize a dispersed solid colloidal stabilizer to give plastic, thixotropic properties to the carrying medium [9]. The control of sedimentation is one of the main factors for increasing stability of the MR fluid. There are some devices constructed for determining of MR fluid sedimentation. Most of them are based on the evaluation of the inductance of a coil surrounding the test tube containing the MR sample [10]. The others are using ultrasonic sensors to determine the level of sedimentation [11]. Ultrasonic propagation velocity in MR fluid changes dependent on magnetic field and is strongly related to sedimentation in this fluid.

One more way to determine sedimentation of magnetorheological fluid is analysed in this paper. Measuring of the resistivity of the magnetorheological fluid depends on some parameters. First of all, it depends on a magnetic field strength applied on MR fluid [4, 12]. If no magnetic field is applied, the resistivity of the MR fluid is very high (400 – 700 MΩ, or more). The next factor, which really affects the resistivity of the MR fluid is the time, the magnetorheological fluid is applied by magnetic field [13, 14, 15]. Firstly, the resistivity of MR fluid decreasing, but when the process stabilizes, it remains constant. The other parameter which influences the resistivity of magnetorheological fluid is temperature of the testing fluid [16,17]. The viscosity and resistivity of MR fluid gradually declines when temperature rises above 100°C. It influences the properties of magnetorheological fluid. The method, to determine sedimentation of MR fluids, which is used in this work, is not fully described in any other literature. The aim of our research was to establish the sedimentation in MRF. We decided to measure the electric resistivity of magnetorheological fluid in magnetic field for diagnostic of sedimentation. The electric resistivity of MR fluid was measured when the fluid was conditioning and later, when sedimentation occurs. This method and according procedure are described below.

## 2. Theoretical base

Theoretical model in the year 2013 was created by Xi Chen [4]. In this model the ferromagnetic particles and the liquid particles with the same size are considered as miniature resistors, whose different ways of distribution under different external magnetic fields are the origination of the change of the sample's electrical conductivity. Thus the whole MRF could be equalled to a series–parallel circuit consisting of the miniature resistors. There assumed that the particles are of uniform size for simplification—the diameter is $d$ and the resistance is $r_1$ for each $Fe_3O_4$ particle, the resistance of the carrier liquid with the same size is assumed to be $r_2$ .

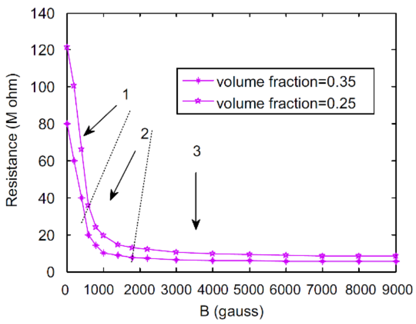


Fig. 1 The curves of the MRF resistance responses to the magnetic field. The resistance decreases with the increasing magnetic field; three stages can be identified according to the different decline rates of the resistance, which is labelled by (1) (0–700G), (2) (700–1800 G) and (3) (1800 G–9000 G). [4]

Ideally, the $Fe_3O_4$ particles are distributed evenly in the carried liquid when there is no magnetic field applied, so the original MFR resistance can be written as:

$$R_0 = \left(4\pi dL^2 / V\right)\left[nr_1 + (1-n)r_2\right]. \tag{1}$$

where $n, V$ and $L$ are the volume fraction of the MFR, the distance between the metal plates and the volume of the detect container respectively.

The diagrammatic sketch of the four-stage magnetization process of this model introduced in the introduction part is shown in Fig. 1. Eq. (1) describes the MRF resistance in the first magnetization stage. In stage two, the $Fe_3O_4$ particles will start chaining; in this procedure the adjacent particles will close up due to the interaction between the particles and it could be approximated in terms of dipoles located at the centres of the particles.

Representation of the resistance dependence on the magnetic field in stage two:

$$\begin{gathered}\frac{1}{R(H)} = \frac{1}{R_1} + \frac{1}{R_2} \approx \frac{S_1}{r_2 L / d - b(r_2 - r_1)H^{3/4}} + \frac{1}{\left(4\pi dL^2 / V\right)\left[nr_1 + (1-n)r_2\right]} \Rightarrow \\ \Rightarrow R(H) = \frac{\left(4\pi dL^2 / V\right)\left[nr_1 + (1-n)r_2\right] \cdot \left(r_2 L / d - b(r_2 - r_1)H^{3/4}\right)}{3nm_1 L\left(nr_1 + (1-n)r_2\right) / d + r_2 L / d - b(r_2 - r_1)H^{3/4}}; \\ H \in \left(0, \left(\frac{L}{bd}\right)^{3/4}\right).\end{gathered} \tag{2}$$

where $R_1$ is the resistance of the chains in the forming process under the magnetic field $H$. $R_2$ is the resistance of the other part (except the chains) of the sample, which is approximately the same with $R_0$, the whole resistance of the sample is the parallel resistances of $R_1$ and $R_2$.

In stage three, the incomplete chains formed in stage two will close up to form new complete chains under the force of the magnetic field. The final resistance of this stage is:

$$\frac{1}{R} = \frac{3Vnm_2}{4L^2 d\pi r_1} + \frac{1}{R_0}. \tag{3}$$

Put simply, this process is just like many resistors being added parallel to the circuit, so the whole resistance will keep decreasing, but the downtrend will slow down compared with that in stage two. Then, when the magnetic field continues raising, the chains and the discrete particles will gather round; it is easy to understand that the aggregating of the scattered chains into a column will not change the samples' resistance, but the adhering of the discrete particles to the aggregating column will enhance the sample's conductivity by increasing the column's effective cross-sectional area. The resistance will decrease very slowly until it is saturated. This model can be used as a base to determine sedimentation testing practical procedure. The resistance repression in stage four:

$$R(H) = \frac{1}{1 / \frac{4L^2 d\pi}{3Vnm_2} r_1 \frac{A_0}{A(H)} + 1 / R_0} = 1 / \left( \frac{3Vnm_2}{4L^2 d\pi} r_1 \left( 1 + \gamma \left( H - \frac{-\alpha + \sqrt{\alpha^2 + \frac{3\beta Vn(m_2 - m_1)}{\pi d^2 L}}}{2\beta} \right) \right) + \frac{1}{R_0} \right). \tag{4}$$

## 3. Experimental setup

Glass tube with MR fluid *3* was placed inside the electrical coil *1*, which was connected to power supply *5*. To measure the electrical resistivity sensor *4* was placed inside the tube. Its contacts were connected to ohmmeter *2*. The magnetic field was applied to this fluid. After fixed time set by timer *6* (20 seconds) the measurement were made. The amount of time was set experimentally, when resistivity stabilizes.

The illustrative scheme of the experimental setup is shown in Fig. 2.

The sensor was made of two copper plates, with a gap of *1* millimetre between them and attached to the headstock. It is shown in Fig. 3.

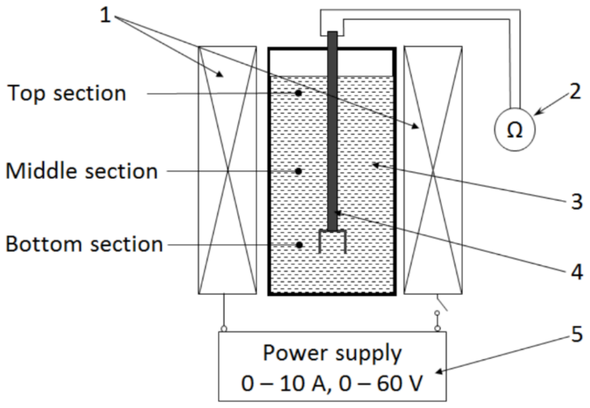


Fig. 2 Experimental setup: *1* – electrical coil, *2* – ohmmeter, *3* – tube with MR fluid, *4* – sensor for measurement of electrical resistivity, *5* – power supply

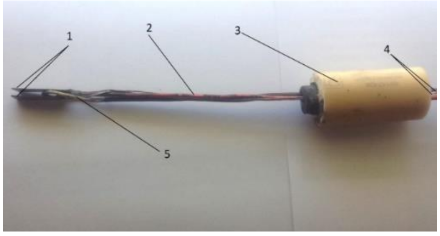


Fig. 3 The resistivity measurement sensor: *1* - iron pads, *2* – headstock, *3* – plug, *4* – contacts, *5* - wire

Only the inner side of the plates was electro conductible. To measure resistivity between them, the contact wires *2* were derived from both plates. To place the sensor in desirable height the plug *3* was used. For clearing the gap between plates wire *5* was used. Resistance of magnetorheological fluid was measured by multimeter Peak-Tech 2005. Its' resistance measuring range is 0,1Ω – 2 GΩ.

The sensor was placed in the magnetorheological fluid made in USA, LORD company. The detailed characteristics of both fluids used in an experiment are shown in Table 1.

Magnetic field strength was adjusted by regulating the voltage of power supply. Magnetic field strength dependence on voltage is shown in Table 2.

Table 1

The characteristics of MR fluids

| **Parameter** | **MRF-140CG** | **MRF-122EG** |
|---|---|---|
| Base liquid | Hydrocarbon | Hydrocarbon |
| Operating Temperature, °C (°F) | -40℃ to 130℃ | -40℃ to 130℃ |
| Solids Content by Weight, % | 85,44 % | 72 % |
| Appearance | Dark Grey Liquid | Dark Grey Liquid |
| Density | 3,54 – 3,74 g/cm$^3$ | 2,28 – 2,48 g/cm$^3$ |
| Flash Point, °C (°F) | >150℃ | >150℃ |
| Viscosity, Pa-s @ 40°C (104°F) | 0,280 (±0,070) Pa·s | 0,042 (±0,020) Pa·s |

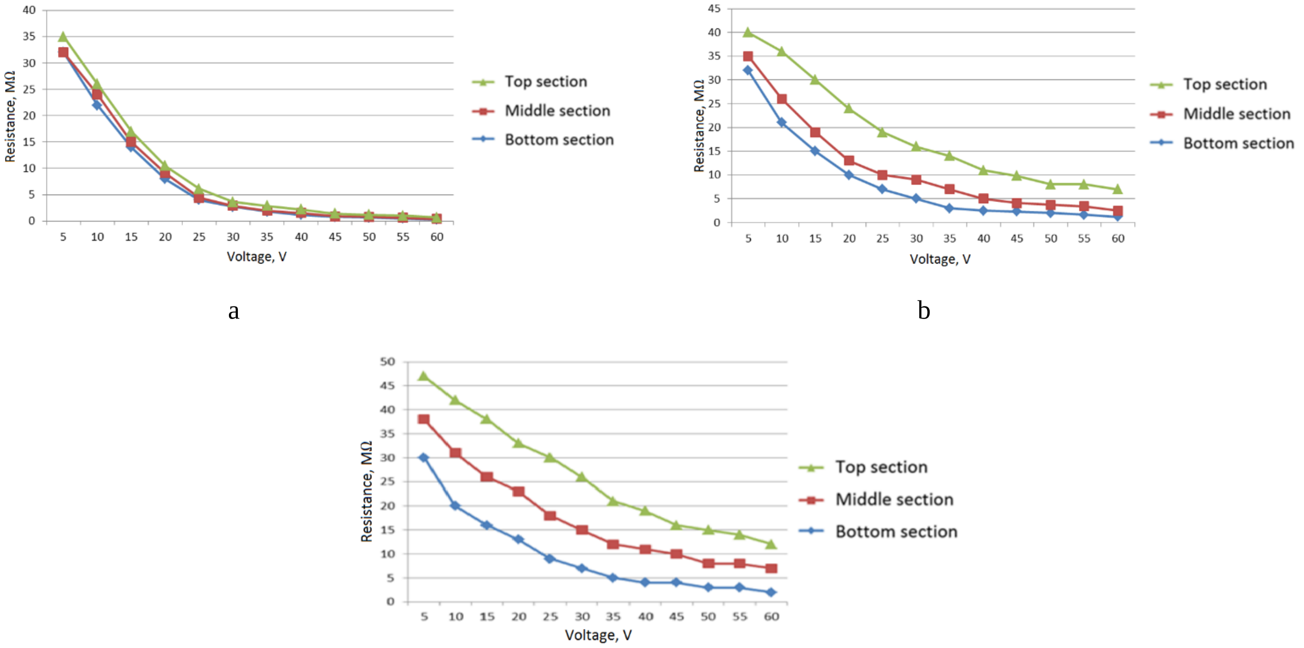
Table 2

Magnetic field strength B calculated by different voltage V

| U, V | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B,A/m | 7245 | 14491 | 21736 | 28982 | 36227 | 43473 | 50718 | 57964 | 65209 | 72454 | 79700 | 86945 |

## 4. Experimental results

The resistivity dependence on magnetic field strength was measured for the MR fluid MRF-140CG. Results are shown in Fig. 4.



a

b

c

Fig. 4 Fluid MRF-140CG resistivity dependence on magnetic field strength (voltage): a - when the fluid is conditioning, b – when the fluid is stayed for one week, c - when the fluid is stayed for two weeks

Experimental results showed, that resistivity differ if fluid is stayed. The more time passed, the greater difference between layers of the fluid occurs.

## 5. Conclusions

Two different type of MR fluid were tested, and we can see that the resistivity of magnetorheological fluid depends on concentration of particles in it. Also we can conclude that after some time resistivity in different sections of tube with fluid, differs. When the fluid is affected by sedimentation, resistance in the upper section is higher than in the lower part. Knowing the initial value of resistance in the upper section of the MR fluid and measuring it after some time, we can decide how strong the sedimentation is affected the MR fluid. That's how this procedure works. We could place the sensor in the for example new created fluid in laboratory and know how much time does it take to reach the sedimentation point, where the fluid is no longer able to work properly. If it occurs, we have to mix it. Sensor has got one limitation. When we pull it down in the testing tube, fluid from above layers could be stuck by the sensor, so after every measurement we recommend to clean iron pads with attached wire.

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# THE SEDIMENTATION OF MAGNETO-RHEOLOGICAL FLUID MONITORING SYSTEM BASED ON RESISTIVITY MEASURING

## Summary

The aim of the research was to determine the resistivity of magnetorheological fluid in magnetic field when sedimentation occurs. The resistivity was measured with special created device. Three sections of magnetorheological fluid contained in glass tube were measured: top of the fluid, the middle and the bottom. The resistivity of the fluid was measured when it was conditioning and after constant time intervals. The resistivity changing showed that the results were suitable to the procedure for estimating the sedimentation of magnetorheological fluids.

**Keywords:** magnetorheological fluid, electric resistivity of MRF, sedimentation of MRF.

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