Vibration and impact properties of magnetorheological elastomers

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Abstract The paper describes experimental research into the dynamic properties of magnetoactive elastic polymers. Tests on a vibrostend show that in certain ranges the test material is able to change the frequency of resonance vibrations under the influence of magnetic fields. Experimental data obtained during testing a sample of magnetorheological elastomer under the load produced by an unbalanced rotor of an electric motor are presented. The results of impact load action are shown.

1. Introduction
Currently, work is underway in various areas to create controlled elastic polymer materials. In the future, research and development of small size and low energy-intensive methods and sources of influence on the elastic polymers controlled deformation - "smart materials" will allow their use in robotics - and defense technology, in the creation of artificial muscles, in prosthetics, sports products. Magnetorheological elastomers developed with the use of multicomponent materials for different directions are promising for many fields of science and technology [1-10]. A number of works are devoted to the study of these materials rheology. For example, in work [11] dynamic characteristics of magnetic hybrid elastomer as a sensor element with controlled properties are investigated. In researches [12] it is shown, that on a number of variable magnetic field modes a frequency resonance peaks can arise. In [13] is given the development of a structural-mechanical model to explain the results of experiments on cyclic elastomer samples. In work [14] in soft magnetoactive elastomers changes in elastic properties during deformation, hysteresis loops taking into account the influence of the magnetic field and various fillers are considered. In [15] a mechanical model containing elastic bonds and imitating dry friction at magnetic interaction of particles which essentially changes structure of a material in a polymeric matrix is offered. On the basis of magnetorheological material the development of active positioning system allowing to dampen arising oscillations in antiphase [16] is conducted.

This paper describes experimental studies of the magnetoactive elastic polymers dynamic properties. At tests on a vibrostend it is shown that in certain ranges the tested material is able to
change the frequency of resonance vibrations under the magnetic fields influence. Experimental data obtained during testing of a magnetorheological elastomer sample under the load produced by an unbalanced rotor of an electric motor are presented. The results of impact load action are shown.

2. Experimental technique and materials

In the conducted researches silicone elastomer, mark "CIEL" (PDMS), made in SSC RF JSC "GNIKhTEOS", Moscow, is used as polymeric matrix. On the basis of the existing equipment, IMASH carries out tests on the developed and provided samples of magnetoactive elastomers (in short - MAE). This silicone elastomer is a two-component material. Silicone components are mixed before manufacturing MAE, then a magnetic filler is added which is regrinded with silicone rubber on a trivalvet paintbrush and then the composition is poured into molds of a given size, where it is polymerized in given technological modes. Permalloy particles with 75 % wt. concentration were used in the investigated sample. The obtained samples are characterized by high elasticity.

To study the frequency properties of MAE vibration test and measuring equipment IMASH is used. The equipment composition includes a source of vibration effects - a vibrator that sets the generator, amplifying equipment, as well as vibration measuring instruments. Vibration measuring instruments are vibration sensors, amplifiers, power supplies, analog-to-digital converters, oscilloscope, software for easy recording, display and processing of information on the computer screen. The description of vibration testing and measuring equipment operation is given in [9].

Fig.1 shows a vibrator with a test item installed on its table - a magnetoactive elastomer and vibration sensors (piezoaccelerometers), measuring the incoming signals in millivolts (mV). The vibration passing through the sample is measured at the output, in the upper part, by another vibrating sensor. The frequency range of the vibrator is recorded.

![Figure 1. Vibrator table with the test specimen and vibration sensors.](image)

3. Experimental results and discussion

In experimental studies, magnetoactive cylindrical specimens with a diameter of 28 mm and a height of 30 mm were used. The experimental work method included determination of the studied material resonance frequencies shift under the action of different magnetic fields (shown in Figure 2). The effect of different magnetic fields on the sample changed depending on the setting of the spacer distance between the sample and the magnet. Figure 2 (a) - (d) shows the horizontal axis of the sample in Hertz (Hz); on the vertical axis the voltage in millivolts (mV) on the piezoaccelerometers on the vibrator table: inlet, lower end of the sample (red) and outlet, upper end of the sample (blue). The voltage of 1 mV corresponded to accelerations of 7.4 m/s². The specimen maximum force of attraction (tear-off) was measured in Newton (H). The amplitude-frequency response - AFC, shown in Fig. 2(a), when mounting the fixture with a spacer at a distance of 15 mm from the test specimen, the magnetic
force was 1.15 (H). The AFC, shown in Figure 2 (b) at a distance of 4.5 mm, was 3.9 (H). The AFC, shown in Figure 2 (b), was 15 (H) when the magnet was placed close. As can be seen from the dependencies shown in Figure 2 (a), (b) and (c), the maximum possible effect of magnetic forces on the sample material leads to an increase in resonance frequencies from 50 to 125 Hz. At the resonance frequencies the amplitudes of oscillations at the sample output increase up to 3.5 times. Resonance frequencies in this experiment shift and increase more than 2 times in relation to the case of absence of magnetic forces on the sample. Loads of the sample with weights from 20 to 50 grams reduced the resonance frequency to 20 Hz; shown in Figure 2 (d).

Thus, the following conclusions can be drawn from the tests carried out. The sample exposure to magnetic fields of different strengths allowed smoothly changing, increasing the zone of resonance

Figure 2. Amplitude-frequency characteristics of the test specimen under the action of various magnetic fields and loads.
frequencies by several times. An important physical factor is that the change in intrinsic properties and displacement of the resonance frequencies in the sample can be controlled during operation. According to the carried researches results the controlled support device active damping of oscillations was developed, which allows withdrawing the operated product from resonance frequencies [17].

3.1 Vibration and impact tests

3.1.1 Vibration tests. In order to be used in the technical applications of the material being developed, it is necessary to know its vibration and impact dynamic characteristics under different fixation conditions and operating conditions. In vibration and impact testing, the test specimen was suspended from 0.5 mm diameter threads; shown in Figure 3.1.1.3. At the inlet and outlet ends of the specimen, 20 grams of pesaccelerometers were mounted; a micro-electric motor was also mounted at the inlet; and a permanent magnet was mounted at the outlet. Exposure to the sample by a magnetic field of a neodymium magnet created a magnetic induction field of 1.2 T (tesla). An unbalance was created on the rotor of the electric motor, which transmitted the set values of vibration through the sample depending on the speed and unbalance values of the rotor. The rotor speed of the motor was raised to 12000 rpm.

![Figure 3. Test sample and recording of signals on an oscilloscope.](image)

Oscilloscopes were recorded at the input and output of the test sample depending on the change in speed of the unbalanced electric motor rotor. Oscilloscopes were recorded in Figure 4 (a), (c), (e) in the absence of a magnetic field and (b), (d), (f) in the presence of a magnetic field. Figure 4 (a) and (b) show the recording of waveforms at motor speed 6120 rpm. Figure 4 (c) and (d) show the recording of oscillograms at 7680 rpm engine speed. Figure 4 (e) and (f) show the recording of waveforms at 10680 rpm engine speed. The millivolts (1 mV=7.4 m/s) are stored on the vertical axis; one division on the waveforms corresponds to 200 mV. On the horizontal axis, milliseconds (ms) were stored: one division corresponded to 2 ms. Input signals recorded from the motor side on all oscilloscopes are shown in lighter (yellow) color and have higher amplitudes of acceleration compared to output signals with lower amplitudes of acceleration shown in blue.

In contrast to the tests carried out on the vibrator, the dynamic characteristics of the sample were recorded here under different boundary conditions and in the out resonance zone (over 100 Hz). Oscilloscope records show changes in dynamic response under different test conditions and effects on the specimen. The ratio of the acceleration output signals to the input signals shows the level of vibration damping on the test specimen: in all cases considered, it is located in the range from 2 to 6.4 times. In case of absence a magnetic field influence on a sample the greatest damping of fluctuations is observed at rotation speed of the electric motor 10680 rpm. Exposure to a magnetic field leads to an increase in amplitudes of oscillations, both at input and output, in comparison with the absence of a
magnetic field, at all speeds of the motor. At the input the vibration increased from 1.4 to 1.6 times, at the output from 2 to 3.4 times.

![Vibration waveform records for sample input and output.](image)

**Figure 4.** Vibration waveform records for sample input and output.

3.1.2. Impact tests. In this series of tests, impacts of different forces were sequentially generated from both ends of the test specimen. Figure 5 (a) shows a record of a stronger impact at the end of the specimen where the motor was attached: the input signals are shown in yellow (lightest) and the output signals in blue (darkest). On a horizontal scale one division was 0.8 ms (milliseconds), on a vertical scale one division was 5 V (volts). The impact acceleration recorded on the load phase oscilloscope peaked at 29.6 V. The shock rise time was 536 microseconds. The angle of the rising front is steeper compared to the angle of the falling front of the shock wave. Free damping oscillations of the motor housing were applied to the angle of the shock wave decline front, which was about 595.6 Hz and had a duration about 1.68 ms. The shock-wave decline front is longer than the rise front and is about 4 ms.
Maximum shock wave coming to the sample opposite end or phase shift of acceleration peaks is 3.3 ms. The peaks of acceleration, after passing the shock wave along the sample, at the opposite end were about 5.3 V. The time of full shock attenuation on the specimen when exposed to the input side (motor) was 5.8 ms.

Figure 5 (b) shows a record of the impact from the sample other, free end: input signals shown in blue, output signals in yellow. On a horizontal scale one division was 2 ms (milliseconds), on a vertical scale one division was 1 V (volts). Here, as well as at the first impact (from the motor side) the angle of the rising front is steeper compared to the angle of the shock wave falling front. The rising edge of the shock wave lasts 0.2 ms. The front of the shock wave decline is longer than the rising front and is about 0.8 ms. Phase shift of acceleration peaks is 3.4 ms. The acceleration peaks at the opposite end of the shock wave damping were about 0.5 V. The time of full shock attenuation on the specimen when exposed to the output side was 6 ms. The oscillogram of the shock wave recording on the test material showed the time of its passing about 1.2-1.4 ms. The velocity of the wave propagation was about 23 msec, respectively.

4. Conclusions
The conducted researches have shown potentially wide perspective of the magnetic elastomers use as dynamic dampers, vibration protection devices, active and controlled links in the technique.

The investigated samples have shown good damping characteristics: at different force of impacts acceleration at an output can essentially decrease.

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