Vibration and shock tests of magnetoactive elastomers

A Ja Minaev¹, Ju V Korovkin¹, H H Valiev²

¹Federal budget – funded research Institute of Machines Science named after A.A. Blagonravov of the Russian Academy of Sciences, 4 Maly Kharitonyevsky Pereulok, Moscow 101990, Russia
²Federal budget – funded research Institute of applied mechanics of the Russian Academy of Sciences, 7 Leningradskiy prospekt, Moscow 125040, Russia

E-mail: minaev0804@ya.ru

Abstract. The results of the study magnetic elastomers samples on vibrating stands are presented. For the test materials amplitude-frequency characteristics were obtained. The shift of the resonant frequencies under the influence of external magnetic fields was determined. Based on the data obtained, a damper device is proposed that is controlled in an automatic mode. The characteristics of experimental oscillograms of impacts, which can be used to create shock-damping devices, are analyzed.

Keywords: magnetoactive elastomer, amplitude-frequency characteristics, oscillograms of impacts, actively controlled damper.

1. Introduction
Modern engineering requires materials with a set of fundamentally new and multifunctional properties that could be controlled by external influences. The corresponding class of materials, which is called Smart materials, includes magnetoactive elastomers (MAE) [1-6]. This new type of highly elastic magnetically controlled composites is presented by a polymer matrix with nano or micro-sized magnetic particles embedded in them. They have a small Young's modulus (on the order of several tens of kPa), which puts them in an intermediate position between traditional rigid magnetic composites and magnetorheological fluids. Using the dependence of their rheological properties on the external magnetic field, it is possible to create controlled damping devices in vibration-proof structures, as well as to use them as elements of robotics. The direct study of changes in the dynamic properties and location of the resonant frequencies in such materials under the influence of external magnetic fields is of great interest. Here experimental studies in this topic were carried out by us with the help of upgraded test equipment [7] with software for analytical processing, storage and display of test results on a computer. MAE samples were investigated, in which the SIIE L two-component silicone elastomer manufactured by GNIChTEOS [8] was used as the polymer matrix. In the manufacture of MAE, the silicone components were mixed, an iron magnetic filler in the form of nano and microparticles was added, which was rubbed with silicone rubber on a three-roll paint mill, and the composition was poured into molds, where the polymerization occurred to the finished product. The obtained samples were studied on the vibration stand.

2. Experiment
2.1. Vibration tests
Dynamic tests of MAE samples were carried out on a vibration stand (Figure 1). The stand includes vibrators with a variable oscillation frequency, a master oscillator, amplifying equipment, as well as measuring tools. Vibration measurement tools are vibration sensors - piezo accelerometers, amplifiers, power supplies, analog-to-digital converters, software for conveniently recording and displaying the received information on a computer screen and further processing. Electromagnetic vibrators provide the necessary oscillations of the core with a table mounted on it with fixed equipment. Figure 1 shows two vibrators that are part of the experimental stand. On the first vibrator, the equipment is made in the form of a hollow cylinder, inside which there are two mounting disks. The test material is fixed on the upper disk. Magnets are fixed on the lower disk. The upper and lower discs are moved and rigidly fixed relative to each other. Thus, it is possible to adjust the various magnetic fields acting on the samples. On the second vibrator, the equipment is made in the form of plates, with a test sample and a permanent magnet mounted on them, with the possibility of moving them at different distances relative to each other along threaded rods that are fixed on the table of the vibrator. The ability to adjust various strengths of the magnetic fields on the first and second vibrators is created by adjusting the size of the gaps between the test material and the magnets.

Figure 1. Vibrators with equipment on the tables

During testing on an experimental test bench with a smooth rise in frequency of up to 400 (Hz) and under the influence of magnetic fields in the case when the force of attraction of the sample was up to 14.5 (Newton), a change in dynamic properties was observed, characterized by a shift of resonant frequencies to higher values. Figure 2 shows the amplitude-frequency characteristics (AFC), obtained for some intermediate arrangement of resonant frequencies in the range of 80-85 (Hz). In figure 2 the horizontal axis shows the frequency in Hertz (Hz), the vertical axis shows the output - A(mV) acceleration signals taken from the sensor in millivolts (mV); 1 (mV) corresponded to 8.2 (m / s^2). In this figure are indicated by the AFC - 2, 4, 6, 8 and 10 the signals recorded from the acceleration sensor on the vibrator table (Uvib), i.e. at the entrance of the sample. AFC- 1, 3, 5, 7, and 9 correspond to the signals recorded at the output of the sample (Usample). The signals supplied from the output of the virtual generator, i.e. from the output of the computer sound card were transmitted to the input of the power amplifier and then to the terminals of the vibrator shown in figure 1.
2.2. Impact tests
For use in subsequent applications, the dynamic impact characteristics of a magnetoactive elastomer were investigated. The test sample was located on the suspension. The impact was made on the upper part of the sample end. The acceleration sensors were located at the top (input) and at the bottom (output) of the sample ends. Oscillograms of shock characteristics were obtained with different impact strength. Accelerations, converted to volts (V) and millivolts (mV), were recorded at the input and output as a function of time (ms). The oscillograms in figure 3, shown in blue and violet, are recorded at the input, the sensor was located in the upper part of the sample end; oscillograms shown in red are recorded at the output, the sensor was located at the bottom of the sample end. The following phases of the shock process can be distinguished. The phase of loading a sample with a shock force lasts from zero to a maximum value within 1 (ms) with a maximum acceleration equal to 2050 (m / s²), which corresponded to a signal on the sensor equal to 0.25 (V). The unloading phase lasts until the shock acceleration disappears, and it
differs slightly in time from the duration of the load phase. The speed of propagation of longitudinal waves in the body of the test material was on average from 20 to 50 (m/s). Frequency of free damped oscillations 205-306 (Hz). The total damping time is 12-15 (ms). In the series of tests for impact, we recorded damping of accelerations at the output of the sample compared to the input acceleration several times, which indicated good impact-absorbing characteristics of this material.

![Oscillograms of the two shocks](image)

**Figure 3.** Oscillograms of the two shocks. a) - 1st impact; b) - 2nd impact
3. Discussion of the results

These studies have shown that by adjusting the elastic-rigid characteristics of the magnetically controlled supports, the damped product can be rebuilt from the resonant frequencies arising during the operating modes of the product. Figure 4 conventionally shows three resonant modes; on the vertical axis is the amplitude — A in mV, on the horizontal axis is the frequency in Hertz. Offset or withdrawal of resonant frequencies can be carried out to the region of higher frequencies: frequency response — 2, or to the region of lower frequencies: frequency response — 3, relative to the operating frequency: frequency response - 1, as shown in figure 4.

![Figure 4. Possible modes of resonance frequency shift](image)

The obtained results allow us to propose a device of a controlled damper for active oscillation suppression, which includes a damped product, control vibration sensors, electromagnets of direct and reverse polarity, a magnetically controlled elastic support, and transducer blocks. The signals from the vibration sensors mounted on the damped product go to the analog-to-digital converter unit and then to the computer. The computer compares the signals. After a comparative analysis and processing of signals using a predetermined program, when the permissible vibration values on a monitored product are exceeded, the computer sends a control signal to a digital-to-analog converter unit to create magnetic fields of an appropriate force. The elastic properties of the damper support change. There is a shift or withdrawal of the resonant frequencies. The signals to control the electromagnets are set by the program embedded in the computer.

4. Conclusions

These studies show the ways to use a fundamentally new class of controlled polymers - magnetoactive elastomers. This class of materials is characterized by the ability to control the oscillatory or vibration processes occurring in the sample under study when exposed to magnetic fields. The device of actively controlled damper can be used in exact vibration-proof technologies, where it is necessary to automatically control and maintain the minimum level of objects vibrations used in various fields of technology. These tests have shown that controlled magnetoelastic dampers can also be used for soft and shock damping, for example, in robotics.
5. References

[1] Sorokin V V, Stepanov G V, Shamonin M, Monkman G J, Khokhlov A R, Kramarenko E Yu 2015 Hysteresis of the viscoelastic properties and the normal force in magnetically and mechanically soft magnetoactive elastomers: effects of filler composition, strain amplitude and magnetic field *Polymer* 76 191-202

[2] Becker T L, Zimmermann K, Borin D Y, Stepanov G V, Storozhenko P A 2018 Dynamic response of a sensor element of magnetic hybrid elastomer with controlled properties *Journal of magnetism and magnetic materials* 449 77 -82

[3] Nadzharyan T A, Kostrov S A, Stepanov G V, Kramarenko E Yu 2018 Fractional rheological models of dynamic mechanical behavior of magnetoactive elastomers in magnetic fields *Polymer* 142 316-29

[4] Alekhina Yu A, Makarova L A, Rusakova T S, Semisalova A S, Perov N S 2017 Properties of magnetorheological elastomers in crossed ac and dc magnetic fields *Journal of the Siberian Federal University. Series: Mathematics and Physics* 10 45-50

[5] Melenev P.V., Kovrov V.V., Raikher Yu.L., Rusakov V.V., Stepanov G.V., Polygalova L.S., Kramarenko E.Yu. 2014 Structural-mechanical model of elastic-plastic behavior of soft magnetic elastomers *Computational mechanics of continuous media* 7 423-33.

[6] Mikhailov V P, Bazinenkov A M, Dolinin P A, Stepanov G V 2018 Dynamic modeling of an active damper *Vestnik Mashinostroenia* 3 34-6

[7] Minaev A Ya, Korovkin U V 2018 Studying the dynamic properties of magnetoactive elastomers and the development of damping supports // *Assembly in mechanical engineering, instrument-making* №1 10-2.

[8] Korovkin Yu V, Minaev A Ya, Stepanov G V 2014 Dynamic properties of magnetically active elastomer composites in laboratory tests *Russian Engineering Research* 34 299–302