Study of magnetically active elastomers resonance and damping properties

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Abstract. The dynamic properties of magnetically active elastomers based on silicone polymer matrix with various ferromagnetic fillers under the external magnetic fields influence using a vibration-testing complex have been studied. The amplitude-frequency characteristics and the investigated composites resonance frequencies changes under such influences are established. Calculated dependences for determination tested samples damping properties are given. Analysis of the obtained data revealed a damping coefficients decrease in the investigated materials with a magnetic forces increase acting on the investigated magnetoactive elastomers.

1. Introduction
In recent years there has been extensive research into the new composites development with unique properties that allow them to be described as 'smart', 'intelligent' materials [1-5]. This paper considers the magnetic fields effects on magnetically active elastomers (MAE) with a variety of effective dynamic responses [6-8]. Using the weak magnetic fields influence, as an example, on the fully reversible and easily MAE controllable deformation will make it possible to create fundamentally new products for application in various fields of science and technology. At this and subsequent research stages, it seems very important to use vibration stands in combination with vibro-measuring equipment to determine these composites physical and mechanical characteristics. This makes it possible to evaluate the magnetic fields force effects on the change in MAE such dynamic characteristics as resonance frequencies and damping coefficients.

2. Mission statement
This research purpose is to obtain new experimental data for the creation and improvement of high-tech new MAE materials. The synthesized isotropic prototypes tests showed a significant their dynamic properties dependence on the external magnetic fields. For further versatile investigations and the resonance and damping properties study of the developed MAE materials it is necessary to establish the damping coefficients dependence on the
magnetic fields influence and the composite fillers structure. For the experimental tasks solution it seems expedient to use and improve the vibration-testing apparatus.

3. Description of the vibration-measuring test facility

One of the options for using the created vibration measuring complex is considered below. The vibrometric complex functional block diagram schematically is shown in figure 1. It includes the following devices: a vibrator -1; sensors (piezoaccelerometers) - 2 and 3; charge amplifiers for the piezoaccelerometers - 4 and 5; analog-digital converters - 6; a sound card - 7; a computer - 8; an amplifier of signals on the vibrator - 9; the magneto-reactive material test sample - 10. The complex basic element is an electromagnetic vibrator 1, which provides specified vibratory movements along the core axis of the table with the tested item fixed on it. The sample vibration accelerations, measured by sensors 2 and 3, are recorded and presented in the form of amplitude-frequency characteristics for further processing and the obtained dependences analysis. One of the accelerometers - 2, installed on the input for recording the vibrator vibrations on its upper surface, i.e. on the vibrator table close to the examined sample, and the other one, installed on the output - 3 on the upper sample surface.

![Figure 1. The vibrocomplex functional diagram for the investigation of magnetically active elastomers vibration properties](image)

The piezoelectric accelerometers used are capacitive sensors which convert vibrational acceleration into a voltage proportional to this acceleration in volts at their output contacts. At practically usable frequencies an accelerometer may be thought as an electrical oscillator with a high internal capacitance C. It is known that the capacitor charge is determined by the following expression:

\[ q = e \cdot C \]

where \( q \) – charge, \( e \) – capacitor voltage, \( C \) – capacity. When acceleration is applied to the accelerometer, both the output voltage and the charge are generated at its contacts. Since the accelerometer output level is extremely low, a fraction of a mV in voltage, piezoelectric accelerometers in combination with either a charge amplifier or a voltage amplifier are required for further signal processing and also to reduce the high output impedance value. In our case the accelerometers are used with Charg Amplifiers Type Brul @ Kjaer. However, analogue methods of
recording, storing, processing and using analogue signals received at the outputs of amplifiers 4 and 5 (Figure 1) require complex hardware. Therefore, for further use of the received signals, they are digitized by means of analog-to-digital conversion. The complex is equipped with the LA20USB analog-to-digital converter to convert analogue signals into the digital form. The outputs of amplifiers 4 and 5 are connected to channels 0 and 1 of the analog-to-digital converter. The analog-to-digital converter hardware (the measurement board) works together with the software, which includes several software blocks designed for different measurement purposes. In our case, ADCLab software was found to be the most suitable for vibrodynamic studies, designed to be a virtual oscilloscope and spectroanalyzer. With this software, you can see the signal and its spectrum as measured by the analogue-to-digital converter board in real time. The digitised analogue signals are recorded as digital files and stored in appropriate memory segments or on the clipboard. The software allows you to save the signal image together with the scaling grid to the clipboard or to a file. It is also possible to paste the signal image into any document using a text or graphic editor. The magnetically active elastomers samples were subjected to vibrations on the electromagnetic vibrator shown in Figure 2. The vibrations frequencies and amplitudes of the vibrator's operating table were set using the digital virtual generator program "Scope_146". The digital virtual generator of this program works together with the existing or built-in sound card (soundcard) in the computer. Generated frequency range is from 0 Hz to 10000 Hz. The frequencies can be changed in increments of 0.5 Hz. The soundcard output amplitude can be adjusted from 0 V to 1 V. To operate the vibrator it is necessary to supply sufficient electrical power to its coil, constituting W in the entire frequency range. In order to create such power, we used the LV-103 "Robotron" power amplifier, to whose input we fed the virtual oscillator signals from the sound card output of the computer. At the vibrator coil ends connected to the output of the power amplifier, voltage amplitudes were set with such a calculation so that there would be no waveform distortion in the operation of the vibrator. The oscillation amplitude over the entire dynamic frequency range was 1 V.

Figure 2. The test specimens examples with sensors attached to the vibrator table

Figure 2 shows two types of samples mounted on the vibrator table. The test sample –1, figure 2 a is cylindrical in shape and has dimensions: diameter 30 mm and length 28 mm. The test sample - 2, figure 2 b is close to the cylindrical form (shapeless), due to lower elasticity and accordingly easier deformability in comparison with the first sample has dimensions of 50 mm.
The test MAE specimens were made in the SSC of JSC GNIChTEOS. The carbonyl iron powders P 10 grade modified by hydrophobizator GKZh-94 were used as magnetic filler of SIEL mark silicone polymer matrix. This ensures a stable bond between the polymer and the surface of the isotropic magnetic filler. The magnetic filler concentration was 80 wt%. Specimen - 1 has high elasticity with Young’s modulus of about 50 kPa. Specimen-2 has higher elasticity than specimen-1. A comparison of the resulting dynamic characteristics is discussed in the next section.

4. Experimental results and discussion

4.1 Records of the resonance characteristics of the test specimens

Figure 3a and 3b show the amplitude-frequency characteristics (AFC) plotted when the magnet is placed at a distance of 9.5 mm from the test specimen. In this case, the influence of the magnetic field is considered as "weak"; the force of the magnet pulling away from the specimen was 1.79 N. Figure 3a shows the AFC for sample - 1. Figure 3b shows the AFC for sample 2. In figure 3 as well as in figure 4 the vertical axis shows the signals in millivolts (mV) received from the sensors and which corresponded to an acceleration 7.4 m/s². In red in Fig. 3 and fig. 4, and also in pink in Fig. 4 b shows the resonance curves plotted when registering signals from sensors located at the output, i.e., at the sample upper end. In blue and black in Fig. 3 and fig. 4 shows the curves when registering signals from sensors installed at the input, i.e., on the vibrator table. The resonant frequencies for sample -1 were in the range 85-95 Hz and for sample 2, according to the first peak, around 35 Hz. The resonance frequency ratio of sample 1 to the resonance frequency of sample 2 is 2.4 to 2.7 times.

![Graphs showing AFC for sample 1 and sample 2](image)

**Figure 3.** Resonance characteristics at weak magnetic forces influence on specimen – 1 a), and, respectively, on specimen – 2 b)

The effect of stronger magnetic fields for the case where the sample detachment force was 14.5 N is shown in the amplitude-frequency response plotted in Figure 4a for sample –1. Figure 4b shows the AFC for sample – 2. The resonant frequencies for sample –1 were in the range 150 Hz. The resonant
frequencies for sample – 2 were in the range 70 Hz. For this test case, the ratio of the resonance frequency of sample –1 to the resonance frequency of sample – 2 is 2.14 times.

![Graph showing resonance characteristics for samples 1 and 2](image)

**Figure 4.** Resonance characteristics at strong magnetic forces influence on test specimen – 1 a), and, respectively, on test specimen – 2 b)

### 4.2 Determination of damping coefficients

The damping coefficients determination for both specimens types, shown in figure 2, was performed according to experimental data of amplitude and frequency response obtained under various exposure to magnetic fields conditions and frequency modes at the vibration test facility. During the tests the incoming signals - and outgoing signals - of specimens vibration resonant frequencies are recorded. The processed records of the amplitude-frequency characteristics with characteristic resonances specimen - 1 and specimen - 2 are shown in figure 3 и 4. The obtained and transformed dependences can be written in the form [9].

\[
A_{out} = \frac{A_{in}}{b \sqrt{\frac{c}{m}}}
\]
Here $b$ is the damping factor, $c$ is the elasticity and $m$ is the sample mass. The sample natural vibration frequency $\omega_0 = \sqrt{\frac{c}{m}}$. The damping coefficients $b_i$, where $i = 1, 2, 3, \ldots$, for each registered resonance frequency $-\omega_1$, are determined experimentally depending on the magnetic fields strength. By obtaining by experimental method for each considered case amplitudes of oscillations on the sample input $A_{\text{in}-i}$ and amplitudes of oscillations on the sample output $A^{*\text{out}-i}$ we find dependences for determination of damping coefficients $b_i = \frac{A_{\text{in}-i}}{A^{*\text{out}-i}} \times \omega_1$. Dependences of investigated samples damping coefficients change as a result of various magnetic fields influence are shown in figure 5. The initial data obtained by experiment and calculated damping coefficients at change of samples resonance characteristics for weak magnetic field are shown in Fig. 5 a. When tested under weak exposure to a magnetic field conditions, sample 1 in comparison with sample 2 has the damping coefficients lower values; in this case, it decreases by a factor of 4.6. The change in the damping coefficients, taking into account the effects of shifting the samples resonant frequencies under the strong magnetic field influence, is shown in Fig. 5 b. The magnetic field influence on sample 1 in comparison with sample 2 also led to a decrease in the damping coefficients, as in the first case; in this case it decreases by a factor of 3.6.

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    xlabel=Hz,
    ylabel=$b_i (10^{-3})$,
    xmin=30, xmax=90,
    ymin=0.5, ymax=2.0,
    xtick={30,50,70,90},
    ytick={0.5,1.0,1.5,2.0},
    legend style={at={(0.5,-0.15)},anchor=north},
]
\addplot[color=black,mark=none,domain=30:90,samples=100] {1/\sqrt{x}};
\end{axis}
\end{tikzpicture}
\end{center}

(a) weak field
The analysis of the dependencies plotted in Figure 5 shows that the damping coefficients vary over a fairly wide range. When exposed to a strong magnetic field, samples - 2 have the greatest influence on the damping coefficients change as compared to samples - 1.

In all the cases considered, the damping coefficients in the studied material decrease as the magnetic forces acting on the sample increase with the shift of resonance frequencies. The results obtained from the experimental data can be used to verify the damping properties of the materials being developed and investigated.

5. Conclusions and implications

The presented test vibration-measuring complex use allows obtain experimental data about test specimens resonance and damping characteristics taking into account the magnetic fields influence on them. Amplitude-frequency characteristics, which show a resonance frequency shifts range with a change in the magnetic field influence strength on the experimental specimens, are constructed. The analytical dependences for damping coefficients finding according to resonance frequencies and their amplitudes on the base of experimental data obtained are given. It is shown that when a stronger magnetic field is applied to the sample - 1, damping coefficients in the considered ranges decrease on the average 1.3 times. A similar magnetic field strengthening on sample - 2 resulted in a damping coefficients decrease by a factor of 1.7 on average. The maximum possible damping coefficients were obtained for sample - 2 with a weak magnetic field. The obtained results show a possible way to study and check the damping properties and create damping models of the developed and investigated perspective MAE materials. Further improvement of the tested new composite polymeric materials - magnetoactive elastomers allows one to control their dynamic properties by magnetic fields influence, which results in creation of actively controlled devices and dampers with feedback.

6. References

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