Vibration studies of a magnetoelastic material

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Abstract. This article contains the results of research on the vibration characteristics of elastomer samples. Experimental studies of the dynamic properties of magnetoactive elastomer materials under the action of magnetic fields on a vibration complex are conducted. A kinematic sinusoidal excitation is given on the table of the vibrator from the side of the support on the tested product. The accelerations at the sample output are recorded. Oscillograms of accelerations at the input and output of the sample under the action of a magnetic field are obtained. The range of displacement of resonant frequencies under the influence of a magnetic field is shown. The justification for creating an electromagnet lifting force that overcomes the elastic force of the test material is given. Computational modeling is performed to create an elastic deformation of a magnetoactive elastomer, both static and dynamic, using a magnetic field.

1. Introduction

Synthetic elastomers belong to polyurethanes, that are the heteroceptive polymers widely used (including as substitutes for rubber) in industrial products in aggressive environments and high alternating loads.

The material under study has a magneto deformation effect, as well as a number of other effects that are described in a number of works [1-6]. Due to a number of its unique properties, the class of material being developed and studied can be widely used in engineering.

The possibility of practical use in the industry of new samples of technical products depends primarily on such dynamic characteristics as the location of the resonance frequency spectra and their vibration amplitudes, the level of vibration cancellation, as well as, for example, on such physical and mechanical properties as high elasticity and durability. The experimental analysis of the oscillation characteristics of prototypes carried out in this work includes the use of laboratory test equipment for receiving and processing signals from sensors (of accelerations) using computer technologies, quantitative processing and qualitative evaluation of recorded experimental data. Based on the results of experimental studies conducted on laboratory testing equipment, a number of interesting dynamic properties of the tested materials were discovered. Despite the research has a fairly narrow range of tests, the properties of materials studied in the work can be very valuable and useful when used in a number of technic areas. Tests are carried out in the laboratory on specially created for this purpose vibration testing complexes. Modern vibration testing systems are complex systems that include various devices. They are used for cyclic and multiple reproduction of vibration loads in the specified dynamic
ranges, for controlling, registering and recording the received vibration characteristics on the computer for further analysis.

2. Experimental tests

2.1. Tests on the vibration complex.

The method of gradual or smooth scanning of the fluctuation frequency of the prototypes used here is a reliable and proven method [7]. The essence of the method is a multi-cycle passage of the specified frequency range, in these tests 10 to 350 Hertz at a constant level of acceleration at the input of the test products (samples fixed on the vibrator table). The amplitudes of the impact values (acceleration amplitudes) at the sample input can change stepwise in the range allowed by the technical capabilities of the vibrator for different test series.

The vibration complex includes a source of vibration. They are a vibrator, a setting generator, amplifying equipment, as well as vibration measurement tools and other necessary equipment. Vibration measurement tools are vibration sensors. They are piezo accelerometers, amplifiers, power supplies, analog-to-digital converters, software for easy recording and displaying information received during recording on the computer screen.

Figure 1 shows a vibrator with fixed prototypes and piezo accelerometer sensors. In figure 1a) without the influence of a magnetic field; in figure 1b) when exposed to a magnetic field.

![Vibrator with prototypes and accessories.](attachment:image1.jpg)

Figure 1. Vibrator with prototypes and accessories.

The presented system is a system with kinematic excitation from the side of the support on the tested product. The sample was given a load in the form of constant acceleration of vibrations at the vibrator input (the incoming signal on the sample) at the input in the entire studied range of fluctuation frequencies. Over the entire excited frequency range, the amplitudes of the sample's fluctuation accelerations at the output showed good stability (immutability) of the instrument readings during multiple similar series of tests. Despite the fact that the vibration test modes incorporated in the vibrator are clearly unacceptably permissible nature and are relatively low, the quality side of the obtained characteristics cannot significantly change at the maximum permissible test loads.

Figure 2 shows the oscillograms of accelerations at the input and output of the sample (in this case, the magnetic field was absent). In all the figures, the horizontal axis shows the frequency of oscillations in Hertz (Hz), the vertical axis shows the accelerations taken from the sensor in millivolts (mV); 1 mV was equal to 8.2 m/s \(^2\).
Figure 2 shows the oscillogram records of the input sinusoidal acceleration signals on the vibrator table, indicated in red (at the elastomer input). The acceleration signals recorded at the output of the elastomer are shown in green. The above oscillogram records of sinusoidal signals show a gradual increase in the amplitudes of the output signal accelerations, approaching the maximum resonant values of frequencies in the range of 80 Hz. In this case, the phase shift of the output signal relative to the input signal was 90 degrees. In the pre-resonant frequency zone of 15-20 Hz, as well as in the post-resonant frequency zone, near 200 Hz, the amplitudes of the input and output signals are small and slightly different. In the area of oscillation frequencies above 200 Hz, the amplitudes of the oscillation output signal gradually decrease. For example, at frequencies near and above 340 Hz, the amplitudes of the output signal in relation to the input signal are significantly reduced.

In the next series of tests, a neodymium magnet with a constant field was installed on the table vibrator under the prototype. The force of sample attraction created by the magnetic field was 14.5 N (Newtons). In this case, the shift of resonant frequencies to the range of 150 Hz was recorded. In figure 3 the output oscillogram record is shown in red. In figure 3, the input oscillogram record on the vibrator table is shown in blue. The green color shows the oscillogram record on the vibrator table when it is rotated 90 degrees, i.e. when its axis is positioned in the horizontal direction. Comparison of oscillograms with the records of resonant frequencies of the considered cases of loading the prototype, as presented in figures 2 and 3, shows the offset of resonant frequencies from 80 to 150 Hz.

2.2. Research in the electromagnetic field.
One of the ways to create an elastic deformation of a magnetoactive elastomer, both static and dynamic, using a magnetic field is to create a lifting force $F_{\text{electr.}}$ of the electromagnet that overcomes the elastic force of the material $F_{\text{elast.}}$. Figure 4 shows an experimental sample with sensors and a U-shaped...
electromagnet between the poles of which a magnetoactive material prototype is installed for creating static deformation and vibration in it.

To do this, the prototype is placed between the poles of the U-shaped electromagnet, so that the loose butt (end) of the prototype forms a gap equal to a certain value $x$, greater or equal to the amplitude of the elastic deformation $\Delta x$ of this sample.

The lifting force $F_{electr.}$, that occurs when a direct current $I$ flows through the electromagnet windings $w$ causes static elastic deformation $\Delta l$ of a magnetoactive elastomer prototype a having a diameter $d$ and a height $h$, placed in the magnetic field of an electromagnet with induction $B$. As is known, the formula for the lifting force of an electromagnet has the form [8].

$$F_{electr.} = \frac{B^2}{2\mu_0}, \text{ where } \mu_0 = 4\pi \cdot 10^{-7} \text{ (GN/m)} \text{ is the magnetic permeability of vacuum (air),}$$

$$B = \mu \cdot \mu_0 \cdot H \text{ is the magnetic field induction, } H - \text{ magnetic field strength, } \mu - \text{ magnetic permeability of a ferromagnet.}$$

If it is necessary to create a dynamic deformation in a magnetoactive elastomer, for example, harmonic or shock, as opposed to static, which uses constant magnetic fields (permanent magnets), it is possible to use both electromagnetic vibrators and solenoids, and electromagnets, of a particular design.

If you use a solenoid in the form of a cylindrical coil, on the axis of which there is a constant or variable magnetic field with magnetic induction and strength $H$, then to create magnetic forces on the axis of the solenoid, greater or equal to the deformation forces, significant values $B$ and $H$ will be need and calculated by the formulas:

$$B = \frac{\mu \cdot \mu_0}{2} \cdot n \cdot I \cdot (\cos \alpha_2 - \cos \alpha_1),$$

$$H = \frac{n \cdot I}{2} \cdot (\cos \alpha_2 - \cos \alpha_1)$$

where $n = \frac{N}{L}$ is the number of turns per unit of the solenoid length, $\alpha_1$ and $\alpha_2$ the angles between the solenoid axis and the straight lines from an arbitrary point on the axis to the solenoid ends:

$$\cos \alpha_1 = \frac{l_1}{\sqrt{R^2 + l_1^2}}, \quad \cos \alpha_2 = \frac{L - l_1}{\sqrt{R^2 + (L - l_1)^2}}, \quad \text{where } L \text{ is the solenoid length, } R \text{ is the radius of the solenoid cylinder, } l_1 \text{ is the length from one of the ends of the solenoid to an arbitrary point on the solenoid axis.}$$

The maximum values $B_{\alpha}$ and $H_{\alpha}$ are located at a point in the middle of the solenoid axis:
\[
B_n = \mu \cdot \mu_0 \cdot \frac{L}{\sqrt{4 \cdot R^2 + L^2}}, \quad H_n = n \cdot I \cdot \frac{L}{\sqrt{4 \cdot R^2 + L^2}}.
\]

at \( L \gg R \) magnetic field on the axis of a long solenoid at a point far from its ends:

\[
B = \mu \cdot \mu_0 \cdot n \cdot I, \quad H = n \cdot I.
\]

When an alternating current electromagnet flows in the winding, its lifting force will also be variable. Acting on ferromagnetic particles embedded in the polymer matrix using a variable lifting force in the matrix, variable elastic forces will occur.

3. Conclusion
It was found that it is possible to shift the resonant frequency by almost 2 times using the influence of a magnetic field on the test material. The possibility of creating static and dynamic elastic deformation in the prototype is shown. One of the options for controlling the vibration and elastic characteristics of a magnetoelastic polymer material is considered.

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