THE DAMPING DEVICE BASED ON MAGNETOACTIVE ELASTOMER

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In this work, the potential of magnetoactive elastomers for the use in active-damping devices is discussed. The compression characteristics of the elastomer in an alternating magnetic field have been preliminary investigated to obtain an estimate for the potential dynamic parameters of the proposed device. According to the obtained dependence, the amplitude of the reaction decreases with the increasing frequency. This is determined by the frequency characteristic of the elastomer as well by some losses of current in the coil and core of the electromagnet. The stiffness of the proposed device for various levels of the control signal has been also investigated. For the largest control signal of 2 A the stiffness of the damper is about 5 N/m. The experimental studies of the transition process of the damper as a function of an applied external load (positioned at a zero point after loading) allow to test the time of response of the device, which does not exceed 500 ms.

1. Introduction. *Magnetoactive elastomer* (MAE) is a type of material, which has been recently developed. It is a composite of a high elastic polymeric matrix and magnetic powders. The special composition imparts to the MAE a complex of new properties such as a significant magnetodeformation effect, change of elasticity in the presence of magnetic field as a magnitostriction effect, and a shape memory effect.

The magnetoactive elastomer can be considered as a so-called smart material. So far, in the scientific community there are no agreement in terminology because of the material principle novelty. In dependence of joint properties and which of these properties has been taken into account, the MAE is regarded as a magnetoelastic composite or a magnetoelastic [1–3], magnetorheological elastomer [4, 5] as well as an elastomer-ferromagnetic composite and an elastic magnet.

This paper is a continuation of the works on studying magnetic fluids, magnetorheological suspensions and magnetoelastics. The magnetoactive elastomer is an intermediate material between magnetic fluids and rigid magnetoelastics. A distinctive feature of the MAE, developed by us, is a highly elastic matrix like for magnetic gels and a high magnetization like for magnetorheological elastomer. This combination defines a complex of its unique properties.

The main application field of such materials is damping devices and shock-absorbers [4]. It is possible to use the magnetodeformation effect for designing micromotors, valves and peristaltic pumps. The application for the magnetostriction and shape memory effect will be also found soon.

In this work, the basic properties of MAE used in active damper device designing, the construction of a prototype of such device and its experimental studies are presented. The basic properties of MAE are also studied, e.g., deformation in non-uniform magnetic fields in stationary and dynamic modes, magnetostriction and anisotropy of elasticity.

2. Study of the basic properties of magnetoactive elastomer used for damping devices.

2.1. Experimental studies of magnetodeformation effect. The magnetoactive elastomer was developed as a magnetic controllable material capable to respond to the applied magnetic field. Therefore, first of all the property of MAE to extension in a non-uniform magnetic field has been investigated. The elongation of a cylindrical MAE sample suspended above a pole of an electromagnet due to the magnetic field tension was measured. In experiment, a MAE sample synthesized on the basis of silicon rubber and magnetite particles sized 0.2–0.3 μm and 50% of volume concentration was studied. The modulus of elasticity of the initial material (without powders) is about 1–1.5 kPa. In addition, the elongation of the structurally same, but polymerized in a magnetic field, sample was studied. In this case, the sample had anisotropy in elasticity, namely, different material elasticity determined by the stress direction.

If the direction of applied strain and the direction of a magnetic field applied during the sample polymerization are same, then the sample shows the maximum elasticity. In the case, when these directions are perpendicular to each other, the elasticity is minimum. The experimentally measured deformation of an anisotropic magnetite-based MAE sample with the modulus of elasticity of 3 kPa depending on the applied magnetic field is shown in Fig. 1. A sample of 1 cm in size was placed under the electromagnet pole. The magnetic field was measured at the surface of the electromagnet. Each experimental point was measured at the same position of the extensible sample relative to the electromagnet surface. Therefore, all measured values are comparable.

As shown in Fig. 1, the size of relative elongation of the sample in a non-uniform magnetic field is significant and amounts up to 250%. The modulus of elasticity of such anisotropic (structured) samples depends on the direction of structuring during synthesis of the sample. So if the direction of structurization and the direction of deformation are parallel (Fig. 1, open squares), the sample is less elongated than its elongating in the perpendicular direction (Fig. 1, solid squares).

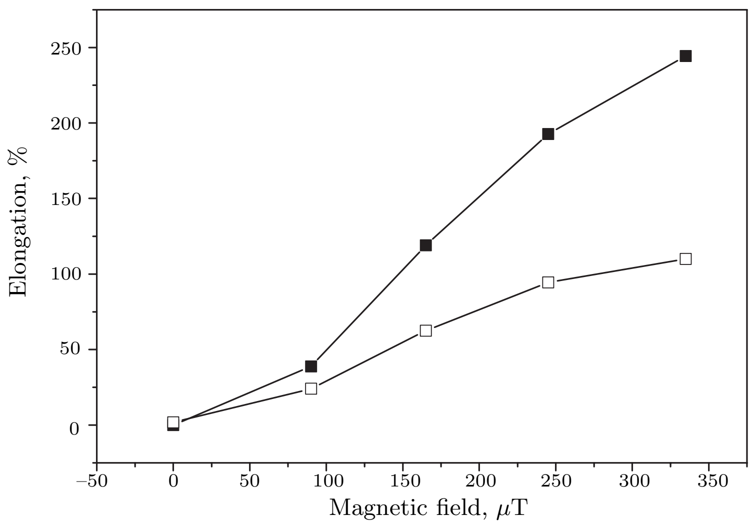

Fig. 1. Dependence of elongation of the anisotropic MAE on the applied magnetic field for two directions of sample orientation (perpendicular – solid squares; parallel – open squares).

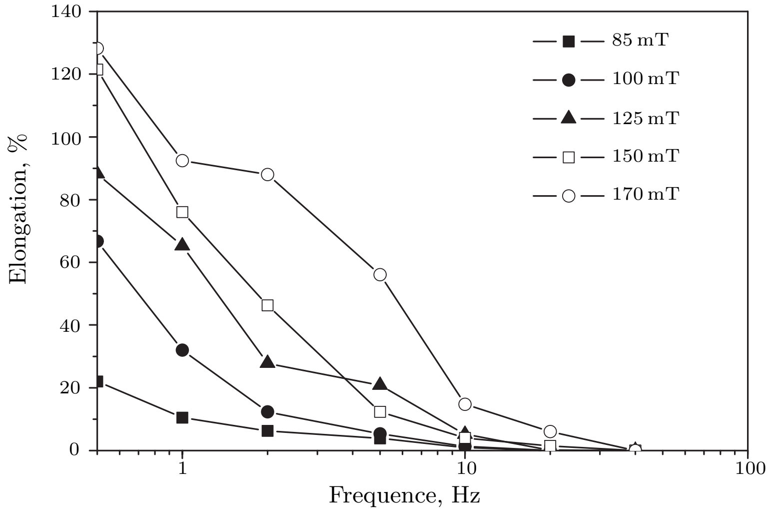

Fig. 2. Elongation of MAE (modulus of elasticity $E = 3\,\mathrm{kPa}$) as a function of the alternating magnetic field frequency (the anisotropic sample is perpendicular to the applied field orientation) for various magnitudes of the applied field.

The experiments, studying the dependence of the sample elongation on the alternating magnetic field frequency, were carried out to estimate the response time of MAE to the variation of the applied magnetic field. The results are presented in Fig. 2. As shown in Fig. 2, the sample deformation is directly proportional to the gradient of an applied magnetic field and inversely proportional to the frequency of an alternating magnetic field. The amplitude of deformation decreases with the increase of the alternating magnetic field frequency. Composite materials with a very low modulus of elasticity are low-frequency material. For the composites with a greater stiffness, the working frequency characteristics can be extended up to 300 Hz.

2.2. The compression of magnetoactive elastomer in alternating magnetic fields. The compression characteristics of the elastomer in an alternating magnetic field were preliminary investigated (Fig. 3) to evaluate the potential dy-

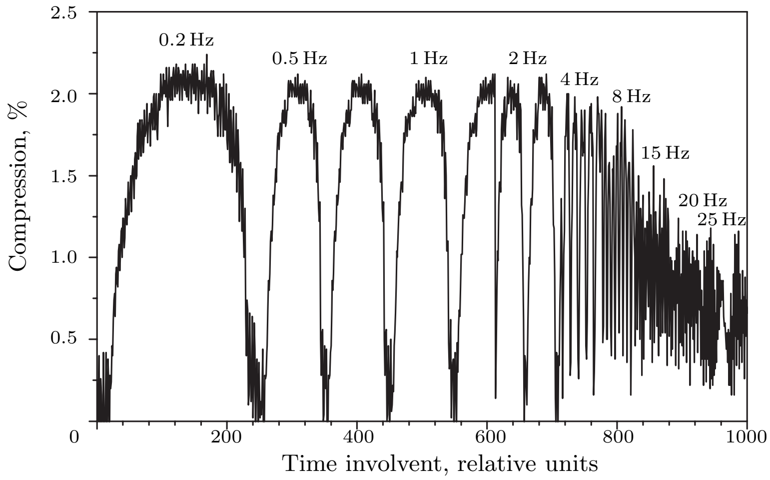

Fig. 3. Relative compression of MAE for various frequencies of the applied alternating magnetic field.

namic parameters of the proposed damping device (see the description below). In these experiments, a cylindrical elastomer sample with the modulus of elasticity $E = 50\,\text{kPa}$ was used. The modulus of elasticity of the initial material (without powders) is about 20–25 kPa. This sample has a low compression if compared with the elastomers used in the experiments on elongation. According to the obtained dependence, the amplitude of the reaction decreases with the increasing frequency. This is determined by the frequency characteristic of the elastomer as well by some losses of current in the coil and core of the electromagnet.

3. Damping device prototype. There are lots of types of vibroprotection systems for various technical applications. By a principle of control, the devices for vibroprotection can be classified as passive and active. Active systems of external influence suppression are usually used for the vibroprotection of precision equipment such as systems of microlithography, analytical equipments for surface analysis, etc. Active vibroprotection elements are electromechanical systems with a negative feedback, which provides stable position of the vibroprotected platform in space. The principle of work of the active systems is the following. The sensor of vibration measures the acceleration, which is applied to the platform with a vibroprotected object. The signal from the sensor proceeds to the system of feedback. After amplifying. the signal in antiphase proceeds to the damping device which, being displaced in the opposite direction, neutralizes the platform's acceleration. As a damping device in the active system of vibroprotection, an element abile to very rapidly and precisely move can be used (responsibility in a milliseconds range, precision of motion in a micro- and nanometer range). Traditionally, the role of such element is played by piezo and magnetostriction activators. Due to the unique properties considered above, the MAE might be a promising candidate to be used as an actuator element in the damping device design.

The schematic design of the proposed damping device based on the MAE is presented in Fig. 4. By controlling the magnetic field of the coil, it is possible to adjust the sizes and the modules of elasticity of the tube- and column-shaped MAE. Thus, the platform will be moved along the vertical axis. With the active scheme of damping, the signal from the sensor is processed by a control system and the motion of the platform is provided by the appropriate law. In case of proportional regulation, the platform, under the action of external force, will oscillate at a

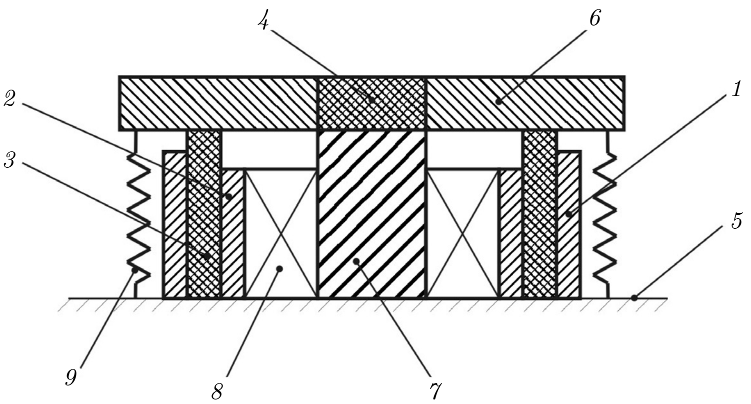

Fig. 4. Schematic design of the damper (*1*,*2* – limiting plugs; *3*,*4* – tube- and column-shaped MAE elastomer; *5* – thrust, *6* – moved non-magnetic platform; *7* – core; *8* – electromagnetic coil; *9* – elastic motion link.

frequency ω, and its displacement u is defined as

$$u = u_0 \sin(\omega t) - a \sin(\omega t) = (u_0 - a) \sin(\omega t), \qquad (1)$$

where u_0 is the amplitude of oscillation, a is the signal amplitude, t denotes time.

The system of feedback will be increasing the signal amplitude until the platform acceleration is equal to zero.The band of the operating frequencies of active systems is defined by a frequency band at steady operation of the feedback electromechanical system. In case of non-harmonic vibrations $u = u(t)$, the signal from the sensor of acceleration integrated two times by hardware and in antiphase proceeds to the coils. So the amplitude of oscillation of the platform aspires to zero:

$$u = u(t) - \alpha \int\int u''(t)dt \Longrightarrow 0. \qquad (2)$$

4. Experimental study of the damping device.

4.1. Dynamic response. In many aspects, the dynamic responsibility of the damper is determined by the time of transients in the MAE as well as by the dynamic characteristics of the control system. To estimate the dynamic possibilities of the device, a contactless measuring system of movings with a capacity sensor was used.

The dependence of the time of transient (positioning at zero point after loading) on the external loading was measured. The experimental results are illustrated in Fig. 5. The measured precision of the platform position was 1 μm. The maximum external loading on the damper was 16 N and the maximum value of the operating signal did not exceed 2 A. The analysis of the transition process of the damper shows that the time of response of the device will not exceed 500 ms. As shown in Fig. 5, the time of transient has a non-linear dependence on the loading. It decreases when the load increases.

4.2. Stiffness of the damping device. The stiffness of the proposed device for various levels of the control signal has been also investigated. The experimental characteristics of the damper stiffness are presented in Fig. 6. The part of the response curve from 0 to 10 N is characterized by some non-linearity resulting

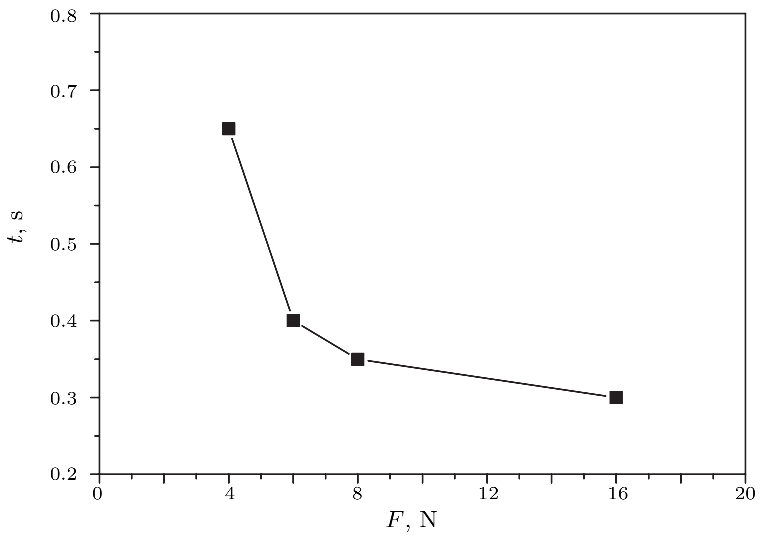

Fig. 5. Time of the damper transients versus external loadings.

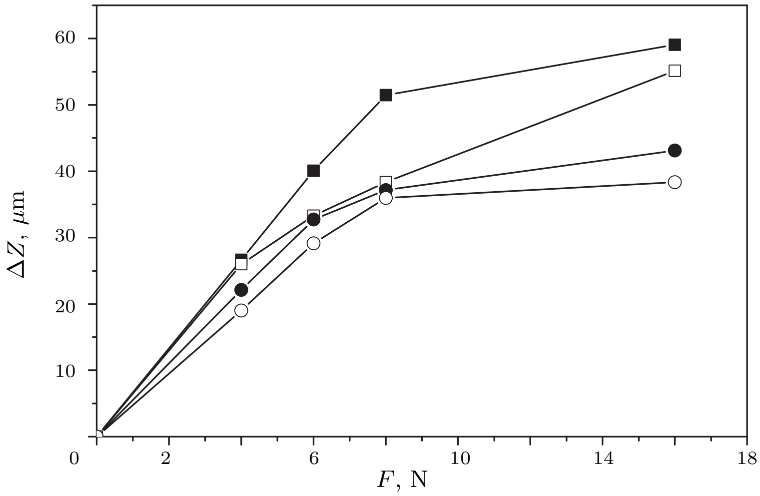

Fig. 6. Relative motion of the damper platform ΔZ versus the external load F for various control signals I ($I = 0.5$ A, solid squares; $I = 1$ A, open squares; $I = 1.5$ A, solid circles; $I = 2$ A, open circles).

from micro-gaps in the construction of the prototype. The linear part of the curve for loads above 10 N characterizes the stiffness of the device. For the largest control signal of 2 A the stiffness of the damper is about 5 N/μm.

5. Conclusions. Due to the special features and properties of the MAE, the developed damper can potentially provide submicron precision and high dynamic characteristics. The experimental studies of the transition process of the damper as a function of the applied external load (positioned at a zero point after loading) allows to test the time of response of the device, which does not exceed 500 ms.The stiffness of the proposed device for various levels of the control signal has been also investigated. For the largest control signal of 2 A the stiffness of the damper is about 5 N/μm. Further investigations of the MAE and the proposed prototype are necessary for developing an effective vibroprotection device and an active control system for it. The parameters of motion precision at a submicron level and the behaviour of the system at oscillations with critical frequencies for potential use of the device will be also investigated.

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