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To cite this article: G V Stepanov et al 2013 J. Phys.: Conf. Ser. 412 012031

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Magnetodeformational effect of the magnetoactive elastomer and its possible applications

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Abstract. Magnetodeformational effect (deformation in non-uniform magnetic field) of magnetoactive elastomer has been studied experimentally. It has been shown that in non-uniform magnetic field this material is able to be reversibly deformed by 250%. In dynamic regimes the deformations under elongation are up to 80% while the ones under compression are 2%. Effective frequency range of the material is up to 100 Hz. As a possible application of the material a magneto controlled valve of flow rate (gas, liquid) was developed.

1. Introduction

This work is aimed to a development of new polymer composite materials, namely, magnetoactive elastomers (MAE) based on highly elastic polymeric matrices filled with magnetic microparticles of iron and magnetite. The novel feature of these materials is the ability to change their properties in magnetic fields and thus, perspective for design of magnetic field controlled various devices. New elastomers have low Young’s modulus (of the order of tens of kPa) and occupy an intermediate position between rigid magnetic composites and magnetorheological fluids. In the course of magnetic field controlled structuring of the magnetic filler within polymer matrix new materials demonstrate the following properties:

(a) a unique ability to undergo quick and controllable large-scale deformations in external gradient magnetic fields (magnetodeformational effect) \([1-3]\);
(b) a unique ability to undergo quick and controllable large-scale deformations and essential changes in elastic and viscous properties under the action of external homogeneous magnetic fields (magnetostriction and magnetorheological effect) \([5-6]\). In particular, 100-fold increase of the modulus magnetic field of up to 0.3 T has been observed;
(c) new effect of shape memory or plasticity induced by magnetic field. It is found that in some cases the deformation of the material is virtually fixed by the magnetic field. One may say that the material ‘remembers’ its shape in the presence of magnetic field \([3, 5, 6]\).

In this study, results of experimental studies of magnetodeformational effect of new magnetic elastomers, their dependence on the material composition and strength of magnetic fields were shown, as well as possibilities of their practical applications were demonstrated.

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2. Experimental
Magnetic field responsive elastomers used in this work consist of a highly elastic polymeric matrix filled with magnetic particles. Polymer matrices were synthesized on the basis of compounds “SIEL” produced by GNIIChTEOS. As magnetic filler magnetite particles of 0.2-0.5 μm in diameter and carbonyl iron were used. Homogeneous mixture of all the components was poured in moulds and heated at 120°C for 1 h. Anisotropic samples were obtained by polymerization of composition in homogeneous magnetic field of 30 mT under heating for 1 h. Magnetic particles tend to form chain-like structures under the influence of uniform magnetic field and columnar particle aggregates parallel to the field direction are fixed in the course of polymerization. As a result, materials thus obtained have highly anisotropic properties, namely, their elastic and deformational properties depend on the direction of deformation. In particular, Young’s moduli of the material differ by 4 times depending on orientation.

3. Results and discussion
Under the action of non-homogeneous magnetic field samples of magnetic elastomer can be deformed (elongated) by several times. In Figure 1 dependence of the elongation of anisotropic sample synthesized on the basis of magnetite with filler concentration of 50 mass% were plotted. The direction of deformation either coincides with the direction of the magnetic filler structure orientation (parallel orientation) or is perpendicular to it (perpendicular orientation). The sample on the basis of magnetite has very low Young’s modulus of around 10 kPa, thus, the deformation in non-homogeneous magnetic field reaches to 250%.

![Figure 1. Dependence of the sample elongation in non-homogeneous magnetic field on the field strength at the free end of the sample.](image)

Deformation depends on the direction of elongating magnetic field and direction of magnetic filler columnar structure within samples. The reason for this can be realized from the material structure which is shown on the photo in Figure 2. Concentration of the filler on this photo is low for the structure of the material could be observed in a thin layer by tunneling optical microscope. As one can see from the photo magnetic particles form chains within the material. Elastic properties of polymer composite are defined by the presence of polymer matrix in the space between the filler particles. One can observe on the photo that there is practically no free space between the particles along the filler chains. When the sample is elongated along this direction the composite demonstrates high elasticity because between the particles the amount of polymer capable to elongation is low.

Studies of dynamical properties of magnetic elastomers upon elongation and compression were performed by placing samples above magnetic coil. As one can see in Figure 3 the highest amplitude of deformation is observed at low frequencies of magnetic field. Maximal deformation under elongation was 80%. Sometimes in the vicinity of 50 Hz a resonance was observed along with a decrease of amplitude. In Figure 3, a typical dependence of deformation amplitude under sample
elongation on the frequency of alternating magnetic field was plotted. An analogous experiment was performed for a sample of magnetic elastomer which was compressed in non-homogeneous magnetic field. The value of relative compression at low frequency was equal to 2%. Magnetodeformational effect was used for creation of active damper or actuator [7] as well as a magneto controlled valve.

Figure 2. Photo of the structure of the anisotropic sample of magnetic elastomer.

Figure 3. Dependence of elongation of vibrating sample on the frequency of alternating magnetic field.

Magnetic field controlled valve is simple in design; it does not contain plenty of mechanically moving parts as other valves used up to date. It is controlled by an electric current, or a magnetic field, with the minimal overall dimensions and capable to control small gas flow.

In general the valve has the body containing lock-element made of ME composite with the through channel. Outside of the body an electromagnet and/or a constant magnet is placed. ME composite deforms under the action of a non-homogeneous magnetic field. The degree of this deformation can be controlled by the value of the field intensity, or electric current. Thus, the deformed ME composite can either completely lock the channel or only partly decrease its diameter and hence controls gas flow. It is possible to create a system of several electromagnets, besides; the lock-element of the valve can be supplied with the backpressure channel (Figure 4).

In Figure 5 the basic characteristics of the magnetic control valve are shown. Dependence of the valve capacity on magnetic field is considerably non-linear but by special construction it can be corrected to become more linear. It is possible to keep the gas flow in a given interval with the use of an electronic feedback.
**Figure 4.** 1-the Case, 2-ME-composite, 3-an electromagnet, 4-the core of an electromagnet, 5-the channel of the valve, 6-A bend of the ME-composite under action of a magnetic field, 7-constant magnet.

**Figure 5.** Dependence of air flow from differential pressure for various magnetic fields.

**Acknowledgments**
This work was supported by the Ministry of Science and Education of Russia

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