Creation of a magnetoelastic material deformation

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Abstract. The paper contains the results of studies of the conditions for creating deformations in magnetoelastic elastomers. To create deformation, tension and compression of the material, it is proposed to use a system of electromagnets. The substantiation of the creation of the lifting force of the electromagnet, which overcomes the elastic force of the test material, is given. An analytical calculation of the forces of magnetic fields acting on a magnetoelastic elastomer is presented. A functional diagram and design of a device for creating deformation under the action of the generated magnetic fields are presented. The proposed technological solution can be used in many areas.

1. Introduction
In production processes for the motor activation of elements and parts included in robotic devices, hydraulics, pneumatics, electromechanics, and also their combinations are often used [1]. However, it is not always possible and advisable to use these devices in mini and micro-mechanisms that ensure their movement.

One of the ways to create motor activation of mini and micro-mechanisms is to use a combination of electromagnets that form controlled magnetic fields, with permanent magnets with high potential energy of a magnetic field with inductions above 1 T (for example, a neodymium-iron-boron magnet), capable of storing the obtained magnetization. Currently, work is underway to create magnets with a magnetic induction significantly exceeding the magnetic induction of neodymium magnets. Various methods can be used in structures to create elastic and easily reversible deformation of a magnetoactive elastomer by exposing it to magnetic fields [2-5].

2. Development of a functional diagram and device
One of the ways to create elastic deformation: tension-compression of a magnetoactive elastomer is to create sufficient forces acting on the structure of its material using magnetic fields, the force of which exceeds the force of intermolecular bonds that prevent deformation of the elastic component of the polymer [6-7].

The creation in a magnetoactive elastomer, abbreviated as MAE, of dynamic deformation, for example, harmonic or shock, is possible by using both electromagnetic vibrators, solenoids and electromagnets of one design or another. The effect arising from the dynamic deformation of the MAE material consists in the appearance of the so-called lifting electromagnetic forces, overcoming the elastic forces inherent in the constituent components and the technology of the manufactured material.

Figure 1 shows a functional diagram of a device with a lever drive for creating deformation or displacement of MAE by means of exposure to magnetic fields. The control circuit for the movement
of the electromagnet body consists of controller -1, program memory - 2, programmer - 3, Li-ion power supply - 4 and piezoceramic sensor - 5.

The operation of the device consists in converting the elastic compression-stretching deformations of MAE-6 into translational movements of the rod-7 by a given value g.

In figure 1 in the functional diagram, element 2 is a memory card with the recording of the programs of the modes received from the programmer 3, the operation of the MAE magnetomotive.

The indicated electronic circuits can be both packaged microcircuits and unpackaged chips. The testing of the MAE magnetomotive operating modes is carried out at the Arduino.

![Drive control circuit](image)

Figure 1. Drive control circuit.

A closed magnetic circuit consists of a magnetic field source of an Nd-magnet - 8, a soft magnetic conductor of a magnetic circuit - A (Armco-iron), a base - 11, a ring - 9 of MAE, which holds the body of a cylindrical electromagnet and a cylindrical elastically deformable MAE element that closes the magnetic circuit and fixed from one end to the Nd - magnet, and from the other - through a piezoceramic sensor - 5 at the bottom of the electromagnet body - 10.

To create the possibility of deformation, tension and compression of the MAE, it is proposed to use flat electromagnets. One of the options for the arrangement of electromagnets is used to fill them in MAE, their sequential arrangement at a distance determined by calculation.

Let us consider in more detail the details of the design of the MAE magnetomotive device.

A cylindrical glass made of an ARMKO soft magnetic alloy or other similar material, electrical steel, permalloy or similar ferromagnetic soft magnetic alloys, is the basis of the structure; it has an inner cylindrical protrusion and is intended for fixing an Nd magnet on it.

The technology for fixing the Nd magnet is as follows: 1 - a cylindrical non-magnetic mandrel is made with an inner diameter equal to the diameter of the Nd magnet and a wall thickness equal to the size of the gap for moving the cylindrical electromagnet; 2 - the mandrel is installed on a cylindrical protrusion; 3 - the end face of the magnet facing the cylindrical protrusion of ARMCO is lubricated
with superglue and pushed towards the protrusion; 4 - at some distance from the end face, the Nd magnet is attracted by the magnetic field to the end face and is glued to it.

The cylindrical electromagnet has a winding with \( n \) turns.

\[ F = \frac{B_{Nd} \cdot B_{elm} \cdot S}{l_0^2} = \frac{B_{Nd} \cdot \mu_0 \cdot n \cdot I_{elm} \cdot S}{l_0^2} = C_{Nd-elm} \cdot I_{elm} \]

shows dependence

\[ F_{Nd-elm} = C_{Nd-elm} \cdot I_{elm} \]

for the given operating mode of this device under consideration [8].

However, for other modes, dependences on other parameters included in the magnetic force formula can be considered.

The magnetic induction of the Nd magnet \( B_{Nd} \approx 1.7 \) T, the magnetic permeability of the ferromagnet in MAE \( \mu \) is \( \approx 2000 \), and the magnetic constant \( \mu_0 = 4 \cdot \pi \cdot 10^{-7} \) H·A\(^{-2}\). The area of interaction of the Nd-magnet with the electromagnet from the side \( S \) and the thickness of the MAE with the value \( k = l_0 \) are selected based on the specified technical conditions for using the propulsion device.

From the formula of the magnetic force \( F_{Nd-elm} = C_{Nd-elm} \cdot I_{elm} \) it turns out that the magnitude of the force can be adjusted from zero to the maximum with a corresponding change in the current strength through the winding of the electromagnet from 0 to \( \text{max} \).

The strengths \( F_{Nd-elm} \) and currents \( I_{elm} \) are determined by the purpose of using the device, as well as the energy of the Li-ion power source.

Figure 2. Elements of the modules of the propulsion chain of the MAE magnetomotive device.
For example, an LT494 chip can be used to the output of which an electromagnet winding can be connected.

The set modes of operation of the device, static or dynamic, are formed by the programmer. The created and used programs are stored in a memory device, a memory card. Correction and stabilization of the operating modes of the controller is carried out using feedback signals coming to the controller input from the piezoceramic sensor.

A snapshot showing one of the experimental links or modules of the device being created is shown in figure 3.

![Figure 3. An example of a driving chain module.](image).

Such modules can be used to assemble both linear propulsion chains and spatial matrix structures that perform motor actions due to elastic deformations, consisting of a multitude of polymer joints made of MAE, operating under the action of alternating magnetic forces $- f_{Nd-em} = F_{Nd-em} \cdot \sin(\omega \cdot t)$. Here, $\sin(\omega \cdot t)$ a sinusoidal load is applied to the elastic moving element MAE and further to the rod, which is fixed on the same axis with the Nd - magnet of the magnetomotive.

3. Conclusion
The design of the MAE magnetomotive device has been developed. The MAE magnetomotive modules are assembled, multiplexed, combined into linear circuits, spatial matrices of motive activity, depending on the technical conditions and the assigned tasks. Chains created from MAE magnetomotive cell modules can be used in various fields of science and technology. The proposed design schemes can be used in active spatial modular structures of multifunctional robotic systems.

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