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THE BRUSHLESS PERMANENT MAGNET MICROMOTOR IN THE SMALLEST DRIVE SYSTEM

ABSTRACT *The article presents the results of the work of contactless fractional-horsepower motor (micromotor) with excitation from constant magnets, which can be used in MEMS (Micro-Electro-Mechanical Systems).*

These MEMS are used in Medicine, flaw detection, military equipment and in microrobots of different usage.

Also article presents the results of mathematics Simulation of magnetic field in work zone of micromotor and the analysis of the basic datas and characteristics of experimental Sample with electronic device System control. The Sample of micromotor is made in the form of glass body with the usage of technology of making slim multi capillary glass tubes. The rotor of micromotor is made in the form cylindric constant magnet from FeNdBr material. Basic datas: lengt – 6 mm; outside diameter – 2,5 mm; the number of phase – 3; rotation rates – 9600 rpm; stress (voltage, tension) – 0,5 V.

Electronic unit (block) with microprocessor device realizes the work of micromotor in sensorless regime and allows to control the rotation speed in the rotation speed in the range 1:1000.

The results of theoretical research agree with experimental datas, received in the process of experimental micromotor Sample.

Keywords: *brushles motors, permanent magnet motors, MEMS, mathematical analysis*

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1. REPORT

Successes and achievements of nanotechnologies have made an essential impact on all areas of science and technics for the last ten – fifteen years. Electromechanics is not an exclusion one can to ascertain with confidence appearance and development of a new branch: nanoelektromechanotronics (NEMT), representing among themselves supertiny products of electromechanics inextricably related and the microelectronics, the managements integrated with microprocessor devices [1, 2].

In modern NEMT systems valve electric motors with excitation from high-energy constant magnets on the basis of rare-earth materials of type iron – neodim-boron and samary-cobalt and hare a wide application. These engines are accepted to call contactless or brushless valve electric motors [3, 6, 8].

The other widespread type of electric motors for NEMT are microelectric motors operating principle of which is based on the phenomena of an electrostatic induction occurring in non-linear dielectrics, for example, in ferroelectric materials. Such "dielectric" NEMT systems can have the most tiny sizes, as, for example, the [4] micromotor described in this work, having length of no more than 15 microns at external diameter of 150 microns.

Micromotors under consideration and electric drives on their basis are applied in special nanotechnological systems: technological microrobots, its medical equipment, flaw detector devices and in the military technics. In turn industrial development of NEMT products demands working out and application of special nanotechnologies of planar and other types [7].

This article is devoted to the problems of working out the design of NEMT systems executed with application of fiber glass technology and use of highcoercitive magnito-firm materials for a rotor [8, 10], and also research and calculation of the magnetic field created by a magnetized rotor in a working zone of the microelectric motor. The solution of these questions is a basis of optimum designing NEMT of systems as a whole.

The winding micromotor of such engine represents z_1 conductor of led-tin solder filling microscopic apertures in a thin polycapillary glass cylindrical tube. In order to a m – phase winding the quantity of stator conductors should be defined by the formula:

$$Z_1 = 2 \cdot p \cdot m \cdot q; \quad (1)$$

where

- $2p$ – number of a rotor poles;
 m – number of a winding phases;
 q – number of conductors on a pole and a phase.

Taking into account, to take the number of rotor poles for high-speed cars it is expedient as two ($2p = 2$), and number q – whole (1, 2, 3, etc.), so according to (1) z_1 can accept following values: 6, 12, 18, 24, etc.

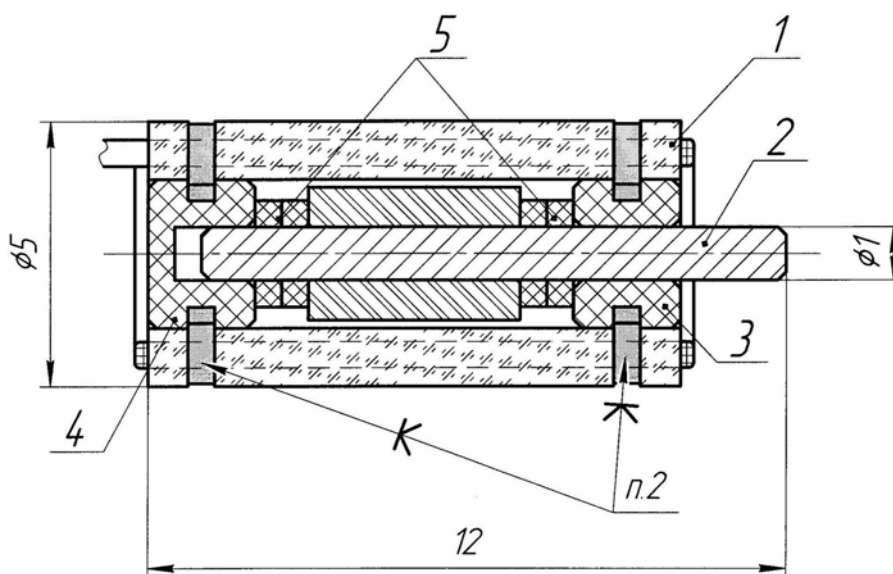


Fig. 1. The micromotor construction

Modern technological possibilities allow to make polycapillar glass tubes of rather small diameters (3 – 2 mm and less) with number of apertures z_1 equal to 12 and more, that in turn allows to increase proportionally supply voltage at the given frequency of a rotor revolution of the electric motor according to expression:

$$E_1 = 2,22 \cdot Z_1 \cdot f_1 \cdot \Phi_{m1} \cdot k_{01}; \quad (2)$$

where

- $f_1 = \frac{P \cdot n}{60}$ – frequency of electric current in winding conductors;
 n – number of rotor turns in mines;
 Φ_{m1} – amplitude of the first harmonic of the magnetic stream created by a magnetized rotor and linked with winding a stator;
 k_{01} – winding coefficient dependent on a winding step.

From expression (2) follows that, windings e.m.f. and frequency of rotor revolution are defined by value of magnetic stream Φ_{m1} which can be found in its turn on the basis of calculation of the magnetic field created by a magnetized rotor in surrounding space. According to definitions it is possible to write down:

$$\Phi = \int_S \overline{B_r} \cdot \overline{ds} = l_\delta \int_0^{2\pi} B_r \cdot r \cdot d \cdot \alpha ; \quad (3)$$

where

- l_δ – length of an active part of a rotor;
- r – radius of the cylindrical surface S which is passing through axes of conductors of a stator winding;
- B_r – a radial component of an induction of a magnetic field in a zone of an arrangement of conductors of a stator winding.

Let's consider calculation of a magnetic field magnetized before saturation of a cylindrical rotor of magnetohard highcoercitive material of type neodim-iron-boron. If to accept a number of simplifying assumptions laplas equation can be solved analytically. These assumptions are reduced to following quite defensible positions:

- 1) length of a rotor much more than its diameter ($l \gg 2r_0$);
- 2) the rotor material has a diametrical structure (drawing 2);
i.e. the axis of easy magnetization coincides with an axis x ;
- 3) a back of a hysteresis loop B (H) in the second square it is linear,
i.e. it is unequivocally defined by points: B_r – a residual induction and H_{cb} – coercivite force on an induction;
- 4) space surrounding a rotor (glass, winding conductors is) not magnetic,
i.e. magnetic permeability everywhere is identical and equal $\mu = 1$.

Having assumptions (1 and 2) the rotor is magnetized homogeneously along an axis x (Fig. 2a) and after removal external magnetising fields ($\overline{H_0} = 0$), homogeneous magnetization of M (Fig. 2b) remains in it.

Laplas equation for scalar magnetic potential φ_M (in case of absence of currents in nearby space) with the account accepted assumptions in cylindrical system of coordinates, will look like [8]:

$$\frac{1}{r} \cdot \frac{\partial}{\partial \cdot r} \left(r \cdot \frac{\partial \cdot \varphi_M}{\partial \cdot r} \right) + \frac{1}{r^2} \cdot \frac{\partial^2 \cdot \varphi_M}{\partial \cdot \alpha^2} = 0 \quad (4)$$

In the work solution of this equation is stated to a method of division of Furje variables for the case of the polarized dielectric cylinder in a homogeneous field [8]. By analogy it is possible to show, that for the magnetic cylinder in a homogeneous external field (Fig. 2a) its magnetization \overline{M} , intensity \overline{H}_i and induction \overline{B}_i will have the same direction coinciding with an axis x and will be constant on all volume cylinder. Under these conditions it is possible to enter the concept of the demagnetization factor and to define intensity of a magnetic field as the sum of external field \overline{H}_0 and a field caused by magnetization:

$$\overline{H}_i = \overline{H}_0 - N \cdot \overline{M}; \tag{5}$$

where

N – demagnetization coefficient of a cylindrical rotor [9].

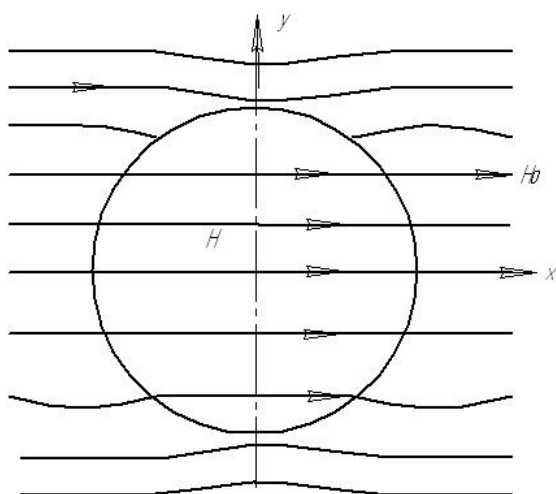


Fig. 2a. A field of vector H at magnetization of the cylinder in a homogeneous external field vector \overline{H}_0

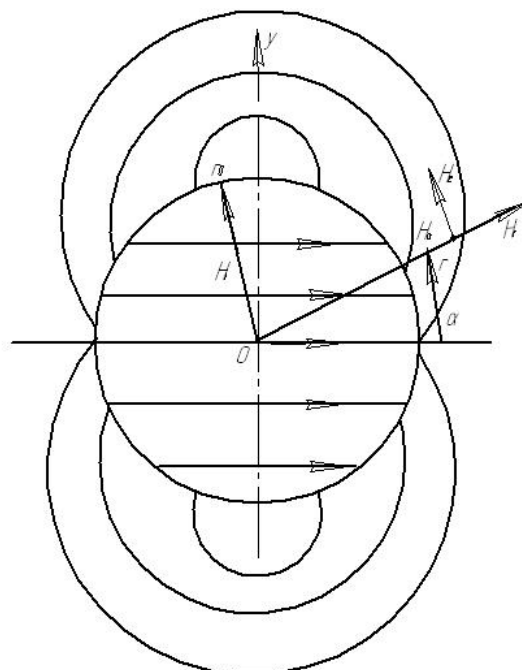


Fig. 2b. The magnetic field of the magnetized cylindrical rotor
 \overline{H}_i – intensity of a field in a rotor;
 \overline{H}_e – out of a rotor

Taking into consideration, that $N_x + N_y + N_z = 1$ and that $N_x = N_y$ owing to symmetry, and $N_z = 0$ (the cylinder is indefinitely long), we shall receive: $2N_x = 1$, or $N = N_x = 1/2$ for our case.

After removal of an external magnetizing field ($\overline{H}_0 = 0$) expression (5) will become:

$$\overline{H}_i = -N \cdot \overline{M} \quad (6)$$

The Bond between the vectors describing magnetic field, in substance looks like:

$$\overline{H}_i = \frac{1}{\mu_0} \cdot \overline{B}_i - \overline{M} \quad (7)$$

Substituting (6) in (7), we shall receive:

$$\overline{B}_i = \mu_0 \cdot (1 - N) \cdot \overline{M} \quad (8)$$

or taking into account (6):

$$\overline{B}_i = -\mu_0 \cdot \frac{1 - N}{N} \cdot \overline{H}_i \quad (9)$$

Let's refer to a demagnetization of rare-earth magnetohard materials [10], presented qualitatively in Fig. 3.

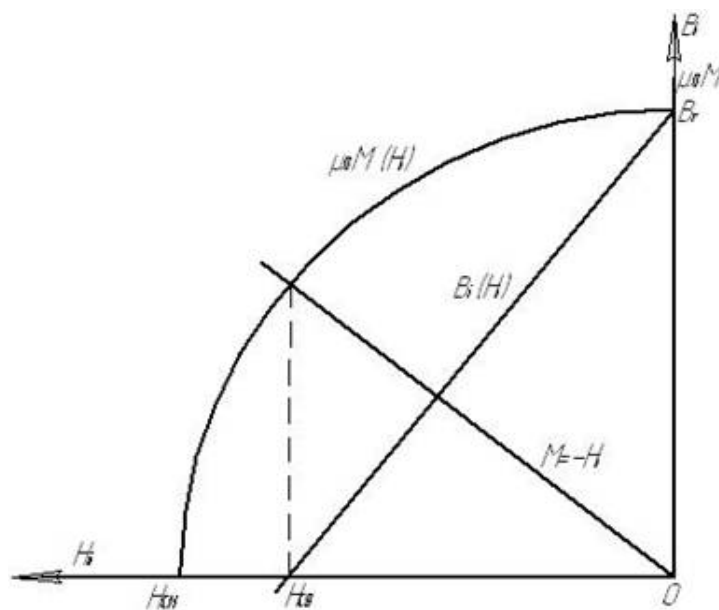


Fig. 3. Demagnetization curves of rare-earth magnetohard materials

It is possible to present dependence $B_i(H_i)$ in the form of the straight line equation:

$$B_i = B_r + \frac{B_r}{H_{CB}} \cdot H_i \quad (10)$$

Substituting H_i from (9) in (10) we will receive expression for a magnetic induction in a cylindrical rotor:

$$B_i = \frac{B_r}{1 + \frac{N \cdot B_r}{\mu_0 (1-N) \cdot H_{CB}}} \quad (11)$$

and taking into account (8) corresponding magnetizations value:

$$M = \frac{B_r}{[\mu_0 \cdot (1-N) \cdot H_{CB} + N \cdot B_r] \cdot \mu_0 \cdot (1-N)} \quad (12)$$

Under formulas (18) and (19) dependences of radial and tangential components of magnetic induction B_{er} and B_{et} in a stator working zone, created by the rotor magnetized up to saturation from magnetohard a material such as " iron – neodim-boron " with parameters have been designed: a residual induction = 1,1 , coercitive force on an induction = 900 kA/m. These dependences are submitted on Fig. 4b, and Fig. 5b.

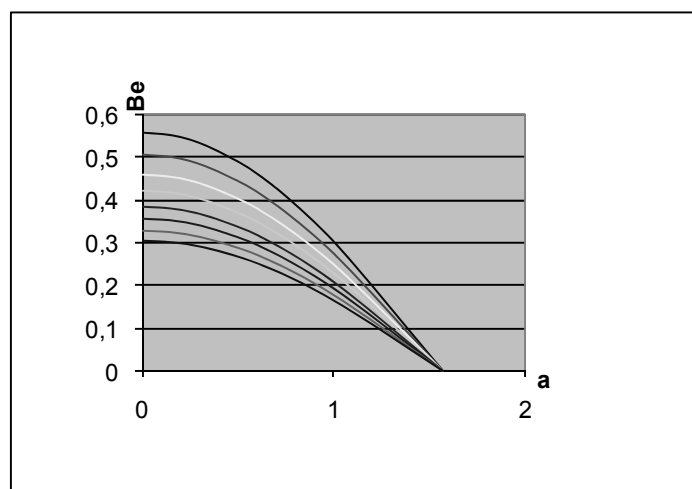
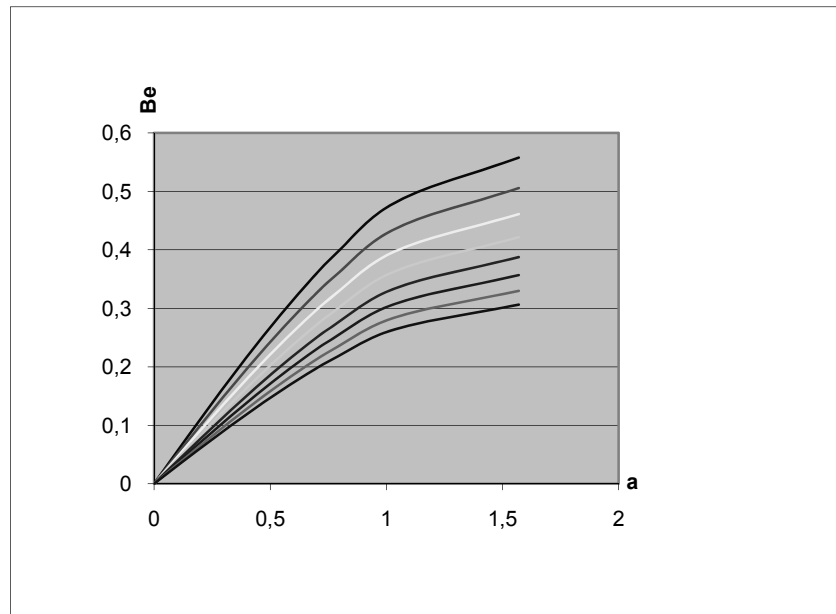


Fig. 4. Change of a radial making magnetic induction from a corner and radius on a stator cylindrical surfaces

a)



b)

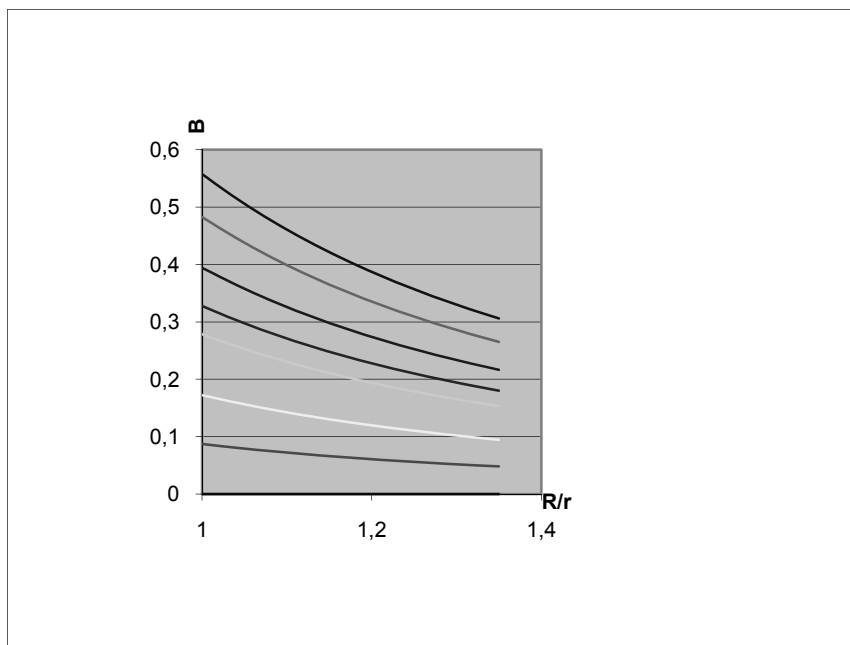


Fig. 5. Change of a tangential making magnetic induction from a corner and radius in a stator working zone

In more complex cases (multipolar systems, presence of nonlinear areas, etc.) the problem by definition of a field in a working zone of a micromotor is solved a numerical method with application of known programs (Elcut, Maxwell, etc.).

2. CONCLUSION

In the report the analytical decision for calculation of the magnetic field created by a bipolar rotor from of a material of type iron – neodim-boron is resulted. Expressions which can be used at calculation and designing supertiny electromechanic systems are received.

Authors offer a design nanomotor with application of new fiber glass technology for a stator manufacturing and windings of such engine.

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BEZSZCZOTKOWY MIKROSILNIK Z MAGNESAMI
TRWAŁYMI W NAJMNIEJSZYM
UKŁADZIE NAPĘDOWYM

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STRESZCZENIE *Artykuł przedstawia wyniki pracy dotyczącej bezstykowego silnika o mocy ułamkowej (mikrosilnika) ze wzbudzeniem od magnesów trwałych, który może być użyty w MEMS (Micro-Electro-Mechanical-Systems). MEMSy stosowane są w medycynie, detekcji wad, wyposażeniu wojskowym i różnych mikrorobotach.*

Praca przedstawia również wyniki matematycznej symulacji pola magnetycznego w strefie pracy mikrosilnika i analizę podstawowych danych i charakterystyk eksperymentalnego egzemplarza próbnego ze sterowaniem elektronicznym. Próbnny egzemplarz jest wykonany w postaci korpusu ze szkła z użyciem technologii cienkich, multi – kapilarnych rurek szklanych. Wirnik mikrosilnika jest wykonany w postaci cylindrycznego magnesu trwałego wykonanego z FeNdBr. Podstawowe dane: długość – 6 mm, średnica zewnętrzna – 2,5 mm, liczba faz – 3, prędkość obrotowa – 9600 obr/min, napięcie – 0,5 V.

Jednostka elektroniczna (blok) z mikroprocesorem realizuje pracę mikrosilnika w reżymie bezczujnikowym i pozwala sterować prędkość obrotową w zakresie 1:1000. Wyniki badań teoretycznych zgadzają się z danymi doświadczalnymi uzyskanymi w pracy eksperymentalnej mikrosilnika próbnego.