Loops with molecular current as a magnet model

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Abstract: This paper presents a magnet model. It assumes surface molecular current in the active wall. The surface current is a result of order atoms in magnet. A mathematical model and finite element method analyzes of magnets are presented.

Keywords: magnet, passive magnetic bearing, active wall, molecular current

Magnetic levitation or magnetic suspension is a method by which an object is suspended with no support other than magnetic fields. Magnetic force is used to counteract the effects of the gravitational and any other accelerations.

Magnetic levitation solves many technical problems. The main problem is elimination friction of between kinematic pair. Magnetic suspension system can work in high vacuum and in active environment (e.g. oxygen, fluid gas etc.).

1. Introduction

A magnetic bearing is a bearing that supports a load using magnetic levitation. Magnetic bearings support moving machinery without physical contact between stator and rotor of a machine. The bearings can be divided into active and passive magnetic bearing. The active magnetic bearings use a feedback loop between position of rotor in relation to stator and magnetic forces. There is an air gap between rotor and stator and the control system of active magnetic bearing maintains constant air gap.

The passive magnetic bearing does not have the feedback loop. The magnetic suspension forces and damping forces are the result of magnetic phenomena. Passive bearings are made from permanent magnets or superconductors.

The main element of passive magnetic bearing is magnets. They are used as a source of magnetic field and a source of molecular current. The magnetic force effects interaction between magnets as a source of magnetic field and magnets as a source of molecular current or induced current in a conductive material.

This paper presents a magnet model as a source of molecular current. It can be replaced by a model of closed loop with molecular current.

2. Molecular current

The magnets are characterized by magnetization vector. This vector writes degree of order of molecular structure of magnet. The order was obtaining during make a magnet. The magnetization of magnet is as follows:

$$\vec{\mathbf{M}} = \left.\frac{\sum_{i}^{N} m_i}{\Delta V}\right|_{\Delta V \to 0} \quad (1)$$

where: m_i – magnetic moment for i atom, ΔV – volume of magnetic material, N – number of magnetic dipoles.

Fig. 1. Magnetic flux density around disc shaped magnet with magnetization M_z

Rys. 1. Indukcja magnetyczna wokół magnesu o kształcie dysku z wektorem magnetyzacji M_z

The magnetic moments of magnets were adjusting parallel during magnetization of magnet. Only elements with free electron on last shelf have got magnetic property. If magnetic moment sets parallel electrons move in the same direction. The moving electron in magnets is a quasi-current. A resultant current inside magnets is equal zero. The current is different than zero only in the wall of magnet.

The next parameter which characterizes magnet is surface current in the active wall. The surface current is as follows:

$$\mathbf{K} = \mathbf{M} \times \mathbf{n} \quad (2)$$

where: K – surface current, M – magnetization vector, n – normal vector.

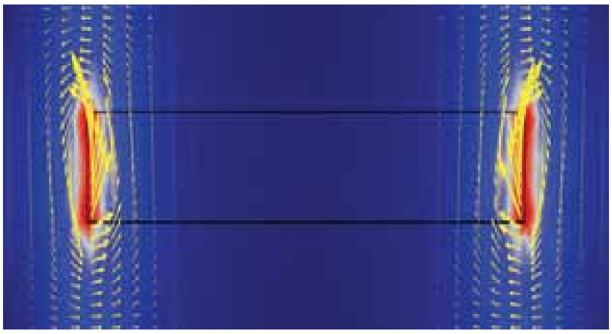

Fig. 2. Magnetic flux density around active wall of magnet
Rys. 2. Indukcja magnetyczna wokół aktywnej ściany magnesu

Figure 1 presents disc shaped magnet. There is magnetization M_z. Distribution of magnetic flux density was obtained as isosurfaces. Thus, we can see magnetic flux around wall and this wall is parallel to direction of vector of magnetization. Magnetic field does not occur inside disc. The equation (2) confirms phenomena showed in fig. 1.

If we consider hypothesis about the current in the active wall as a magnet model, we can use Biot-Savart law, Lorentz forces and Ohm's law to design the passive magnetic bearing.

The notion used above is "active wall". This notion signifies wall of magnet which is parallel magnetization vector. This wall has got normal vector perpendicular to magnetization of magnet (equation (2) and figure 2).

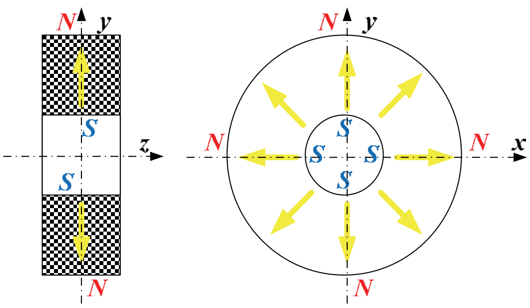

Fig. 3. Ring shaped magnet with radial orientation of magnetization
Rys. 3. Magnes pierścieniowy z promieniową orientacją wektora magnetyzacji

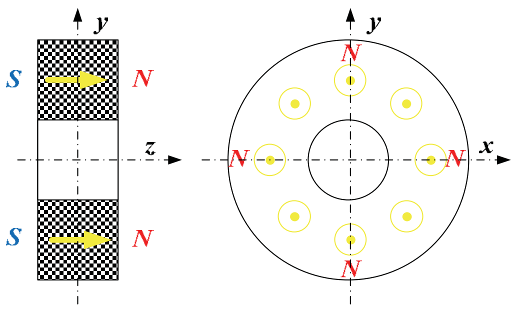

Fig. 4. Ring shaped magnet with axial orientation of magnetization
Rys. 4. Magnes pierścieniowy z osiową orientacją wektora magnetyzacji

3. Magnets of passive magnetic bearing

Ring shaped magnets are used in the passive magnetic bearing. Magnets with radial orientation of magnetization vector are used to curry radial forces and magnets with axial orientation of magnetization are used to curry axial forces.

Figures 3–4 present magnets and theirs orientation of magnetization. Also, the main geometric relation in the magnet with radial and axial orientation of magnetization is presented.

Figure 5 presents surface current in the active wall of magnet with axial orientation of magnetization. There are two active walls. The first is outside wall; it has diameter D and height h. The second is inside wall and it has got diameter d and height h.

Figure 6 presents surface current in the ring shaped magnet with radial orientation of magnetization. There are two active walls. There is left and right wall.

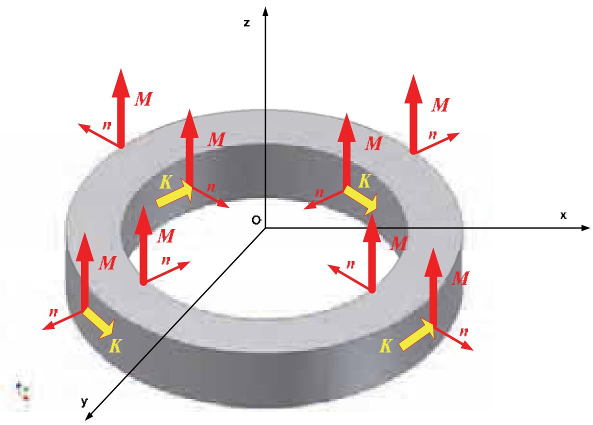

Fig. 5. Surface current in axial magnetized ring
Rys. 5. Prąd powierzchniowy w osiowo namagnesowanym pierścieniu

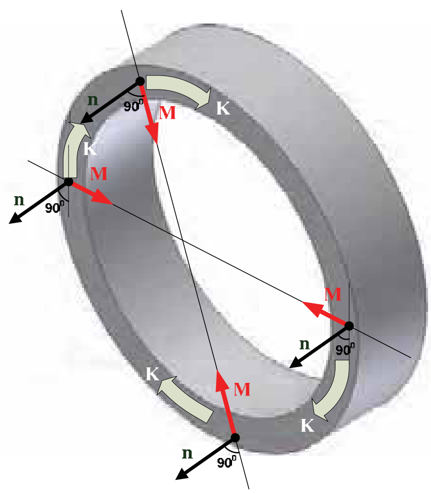

Fig. 6. Surface current in radial magnetized ring
Rys. 6. Prąd powierzchniowy w promieniowo namagnesowanym pierścieniu

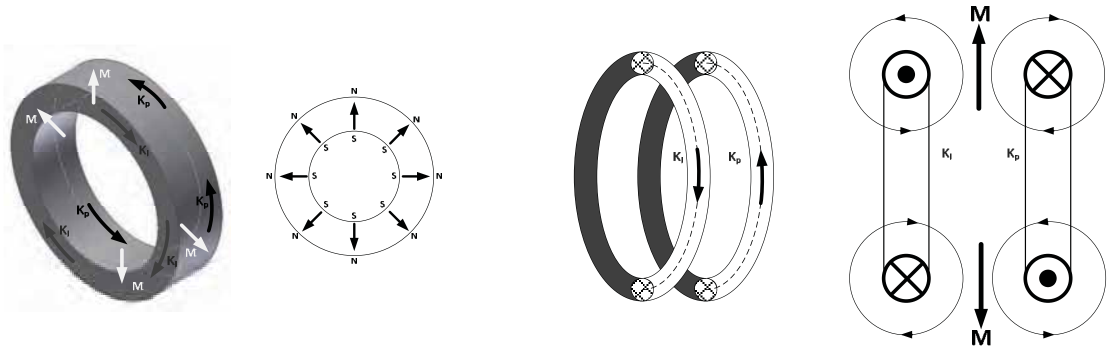

Fig. 7. The ring shaped magnet with radial orientation of magnetization
Rys. 7. Magnes pierścieniowy z promieniową orientacją wektora magnetyzacji

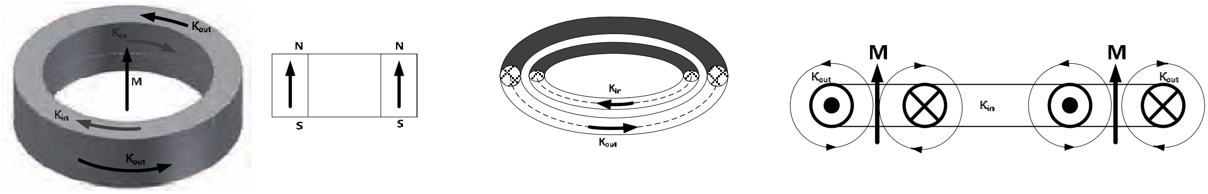

Fig. 8. The ring shaped magnet with axial orientation of magnetization
Rys. 8. Magnes pierścieniowy z osiową orientacją wektora magnetyzacji

A magnet presented in fig. 4 has got magnetization:

$$\mathbf{M} = \begin{bmatrix} 0 & 0 & M \end{bmatrix} \tag{3}$$

The normal vector for outside wall:

$$\mathbf{n_{out}} = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 \end{bmatrix} \tag{4}$$

And inside wall:

$$\mathbf{n_{in}} = \begin{bmatrix} -\cos\varphi & -\sin\varphi & 0 \end{bmatrix} \tag{5}$$

The surface current in the outside wall is equal:

$$\mathbf{K_{out}} = \begin{bmatrix} -M\sin\varphi & M\cos\varphi & 0 \end{bmatrix} \tag{6}$$

And inside wall:

$$\mathbf{K_{in}} = \begin{bmatrix} M\sin\varphi & -M\cos\varphi & 0 \end{bmatrix} \tag{7}$$

Magnet with radial magnetization has got magnetization vector (fig. 3):

$$\mathbf{M} = \begin{bmatrix} M\cos\varphi & M\sin\varphi & 0 \end{bmatrix} \tag{8}$$

The normal vector for left wall:

$$\mathbf{n}_l = \begin{bmatrix} 0 & 0 & -1 \end{bmatrix} \tag{9}$$

And right wall:

$$\mathbf{n}_p = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \tag{10}$$

The surface current in the outside wall is equal:

$$\mathbf{K}_l = \begin{bmatrix} -M\sin\varphi & M\cos\varphi & 0 \end{bmatrix} \tag{11}$$

And inside wall:

$$\mathbf{K}_p = \begin{bmatrix} M\sin\varphi & -M\cos\varphi & 0 \end{bmatrix} \tag{12}$$

If we compare equations (11) and (6) or (12) and (7) we have got the same formula for magnets with different orientation of vector of magnetization. This is significant property of magnets, which uses in the construction Halbach's array.

4. Loop with molecular current as a model of magnet

The conclusion from previous point is used to obtain the model of magnet as a loop with molecular current

In fig. 7 is presented ring shaped magnet with radial orientation of magnetization. The magnet is replaced by two closed loops with current. There is left and right rings. The surface currents K_l and K_p flowed by the closed loops. Magnets with axial orientation of magnetization can be approximated by two coaxial closed loops with surface molecular current.

The active wall of magnet can be approximated by several loops. In fig. 9 is presented ring shaped magnet with axial magnetization approximated by loops.

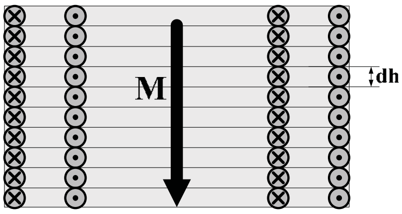

Fig. 9. The magnet approximated by several loops

Rys. 9. Magnes aproksymowany przez kilka pętli

Loops have got an altitude dh. The current in the loop is equal:

$$\mathbf{I} = \mathbf{K} \cdot dh \tag{13}$$

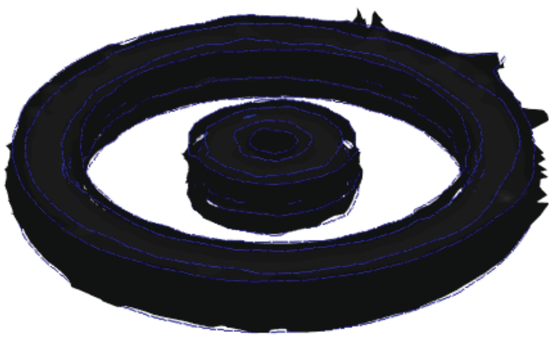

Fig. 10. The magnetic flux density around ring shaped magnet with axial orientation of vector magnetization

Rys. 10. Pole magnetyczne wokół magnesu pierścieniowego z osiową orientacją wektora magnetyzacji

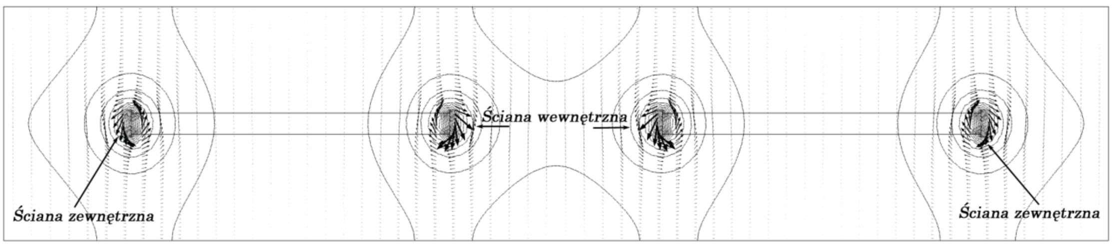

Fig. 11. The cross section by the thin magnet

Rys. 11. Przekrój przez cienki magnes

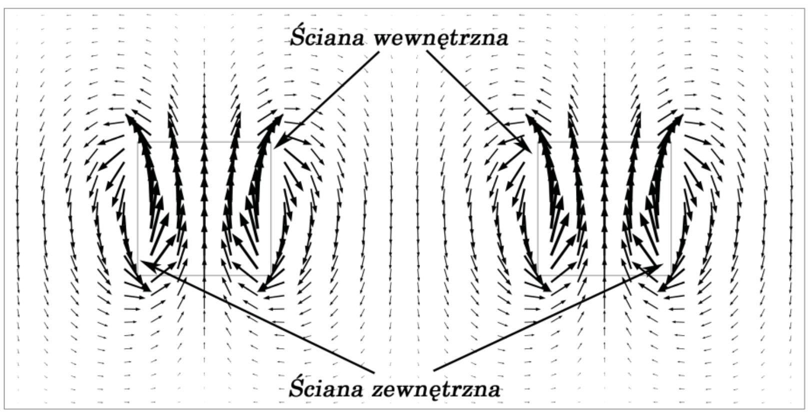

Fig. 12. The cross section by the tall ring shaped magnet

Rys. 12. Przekrój przez wysoki magnes pierścieniowy

Figure 10 presents magnetic flux density around the ring shaped magnet. Here the magnetic flux density is concentrated around the inside and outside wall.

In figs. 11–12 two rings shaped magnets is compared with axial orientation of vector of magnetization. There is one discrepancy. The magnet shown in fig. 12 is taller than magnet from fig. 11. Moreover, the magnet from fig. 11 is very thin.

The magnetic flux density presented in fig. 11 is like to magnetic flux density around two coaxial wire rings. The contours of magnetic flux density lay as a circle. If an altitude of wall of magnet increases distribution magnetic flux density changes. If the proportion between the altitude of wall and diameters takes:

$$h/D \ll 1 \tag{14}$$

Contours of magnetic flux density are similar to circle.

5. Summary

There is presented model of magnet as a loop with surface molecular current. Here a magnet is approximated by loop or set of loops. The current is a result of magnetization. The ring shaped magnets are used in the passive magnetic bearing. The most of applications use magnets where the proportion (14) maintains. However, coefficient of wall will be recommended to estimate. The coefficient will be taken into consideration a deformation field around wall for different proportion (14).

The model of magnet as loop with molecular current can be used to analyze, design and test passive magnetic bearing and electrodynamics passive magnetic suspension.

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Pętla z prądem molekularnym jako model magnesu

Streszczenie: W artykule zaprezentowano model magnesu. Model ten zakłada występowanie prądu molekularnego w aktywnych ścianach. Prąd powierzchniowy jest wynikiem uporządkowania atomów w materii. W artykule przedstawiono model matematyczny i analizy metodą elementów skończonych.

Słowa kluczowe: magnes, pasywne łożysko magnetyczne, aktywna ściana, prąd molekularny

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