BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LVIII No. 2 bis / 2006	295-300	Seria Tehnică

Analysis of Functional Stability of Permanent Magnet Bearings

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Abstract

This work is dealing with a comparative analysis of functional stability of passive magnetic bearings made out of permanent magnets from rare earth materials (Nd-Fe-B). Functional stability is studied both from the point of view of variation of forces density developed in bearings – on axial, respectively radial direction and from the point of view of variation of electromagnetic flux density in the air gap, with alteration of distance between magnets. The comparative analysis has kept a check on the behaviour of passive magnetic bearings for two classes of permanent magnets: anisotropic and isotropic.

Key words: *bearings, permanent magnet bearings, stability of magnetic bearings.*

Introduction

The use of principles in current production processes, such as flexibility and modularisation, require the implementation of new electric machines/devices, as well as new procedures of safety insurance and transmission of motion, which would eliminate friction and thus allow an increased action dynamics.

These new procedures of insuring the motion of a shaft without friction presuppose the lack of mechanical contact and the maintenance of the central position of the shaft within the bearing by means of electromagnetic field. Such bearings of electromagnetic type allow a rigorous control of the shaft position. But such bearings are relatively big-sized and need a power and command source of the excitation windings. Better performances may be achieved by using mixed bearings which include permanent magnets beside the excitation coils (command and control of the shaft position within the bearing).

The most reasonable solution would be to use only permanent magnets, as by coils removal, the power source would become useless, thus eliminating any additional losses and time constants innerent in such electric circuits. The main problems posed by thes solution would be the impossibility to control the shaft position within the bearing and the functional instability of such a system of levitation (Earnshaw's theorem).

A series of papers, [1], [2], [3], [4], set out the existence of distinctive configurations for permanent magnet bearings which allow a quasi-stable functioning. A simple configuration of central (co-axial) bearing made of Nd-Fe-B isotrope permanent magnets is analysed from the point of view of functional stability. In order to conduct this analysis, a modelling of the passive bearing was performed, determining the forces and rigidities of the bearing (built in the Laboratory of Electrical Machines – fig.1) based on the distribution of the magnetic field.

Fig.1 Permanent magnet bearing built in the Laboratory of Electrical Machines

The focus was mainly laid on the variation of the forces density developed within the bearing for distance oscillations between the two keepers – equiped with Nd-Fe-B permanent magnets - which constitute the structure of the characteristic configuration.

Modelling of permanent magnet bearings

In order to determine the distribution of the magnetic field and the forces density, it was used a mathematical model defined by the system (1), where:

$\overline{A} = \overline{A}(x, y)$ - the vector of the magnetic potential;

$\overline{B}$ - flux density;

$\overline{H}$ - the intensity of magnetic field;

$\overline{I}$ - the magnetic polarization (the interior induction - $\overline{I} = \mu \cdot \overline{M}$, $\overline{M}$ is magnetisation);

w_m - the specific magnetic energy (related to the volume unit of the structure);

f_x - the force density by x - axis;

f_y - the force density by y - axis.

$$\begin{cases} rot(rot\overline{A}) = 0 \\ \overline{A} = \overline{A}(x, y) \\ \overline{B} = rot\overline{A} \\ \overline{B} = \mu_0 \overline{H} + \overline{I} \\ \overline{n} \times \overline{A} = 0 \\ w_m = \frac{1}{2} B \cdot A \\ f_x = -\frac{\partial w_m}{\partial x} \\ f_y = -\frac{\partial w_m}{\partial y} \end{cases} \tag{1}$$

Additionally, the force density module developed within the bearing has been calculated using the formula:

$$f = \sqrt{f_x^2 + f_y^2}\ . \tag{2}$$

To solve the problem of electromagnetic field the PDE-ase [5] soft was used. The employed integration domain, due to the symmetry of the structure analysed, is shown in fig. 2.

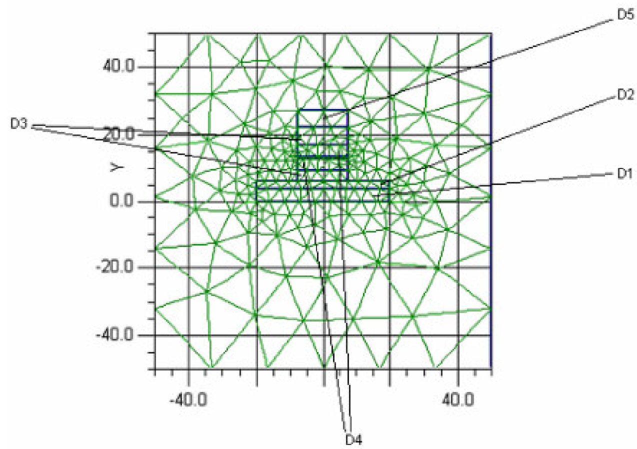


Fig. 2 Integration domain for permanent magnet bearings

where:

D1 – an air zone (the shaft being tube - shaped);
D2 – the wall of the pipe witch constitutes the shapt proper;
D3 – teflon cameras;
D4 – permanent magnets;
D5 – external keeper.

Results

Following the determination of field distribution (fig. 3 and 4), the variations of forces density by x - and y – axis were obtained (fig. 5 and 6). These variations are the result of use of anisotropic and, respectively isotropic permanent magnets (fig. 5,a and 6,a, respectively 5,b and 6,b), as the ones of the bearing built in the lab.

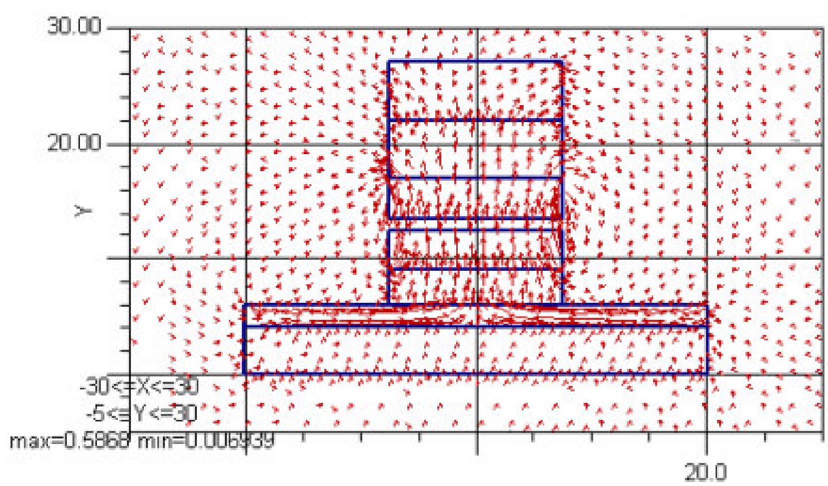


Fig. 3 The distribution of the flux density within the bearing for 1mm airgap

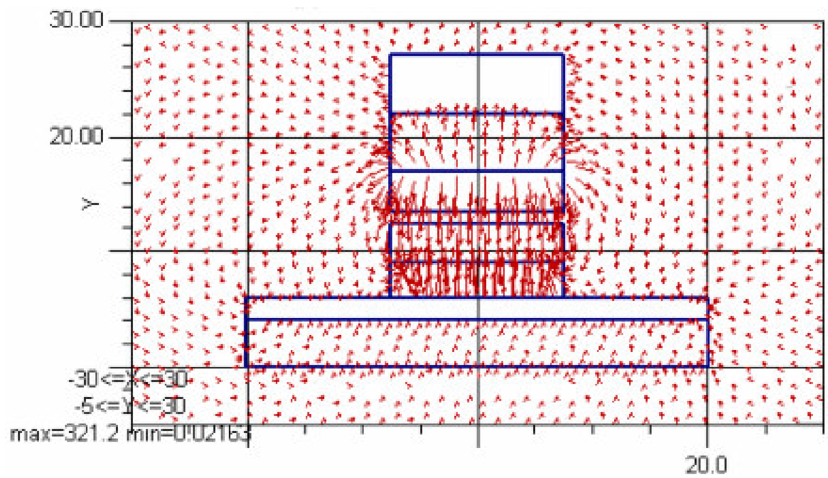
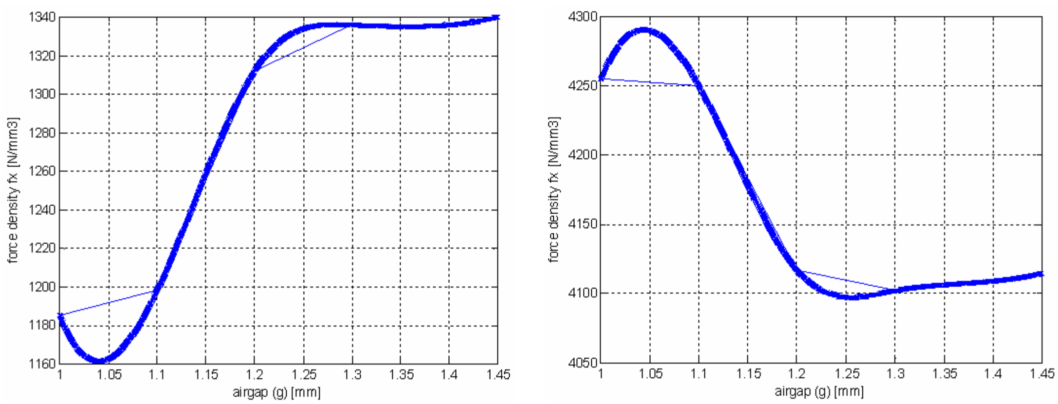
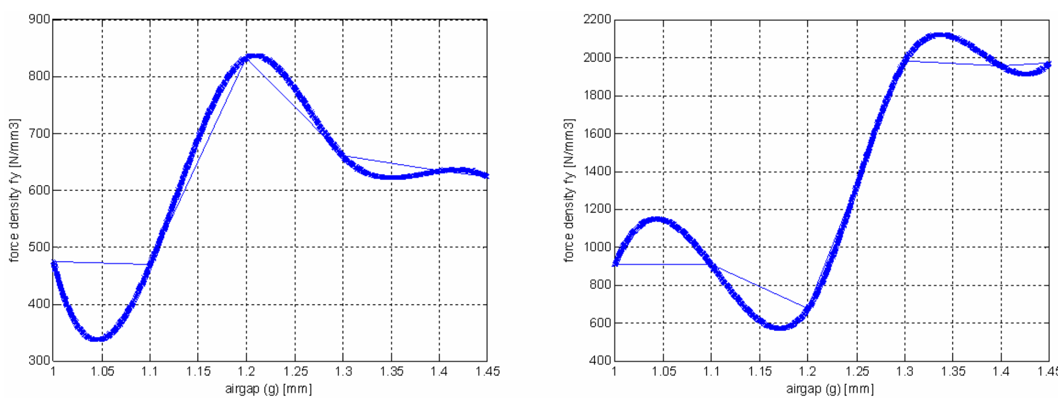


Fig. 4 The distribution of the magnetic field intensity within the bearing for 1mm airgap



a) b)

Fig. 5 Variation of force density module by x – axis for permanent magnets bearings:
a) anisotropic ($I_x = 0; I_y \neq 0$); b) isotropic ($I_x \neq 0; I_y \neq 0$).

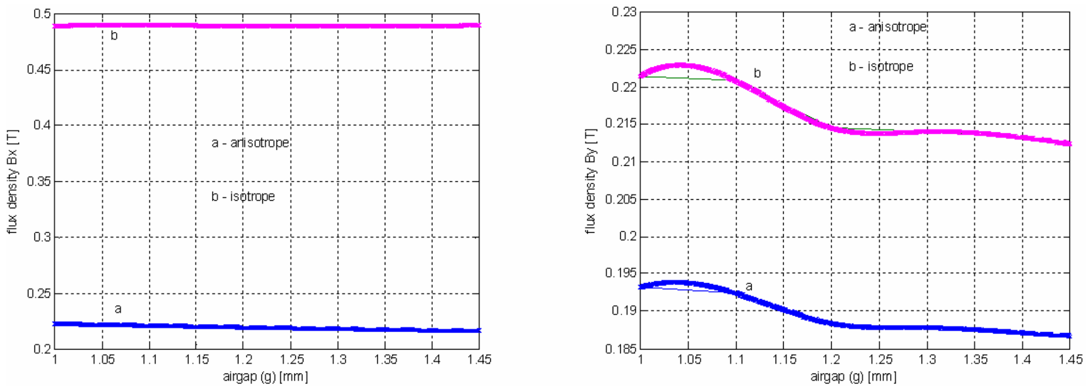


a) b)

Fig. 6: Variation of force density module by y – axis for permanent magnets bearings:

a) anisotropic ($I_x = 0; I_y \neq 0$); b) isotropic ($I_x \neq 0; I_y \neq 0$).

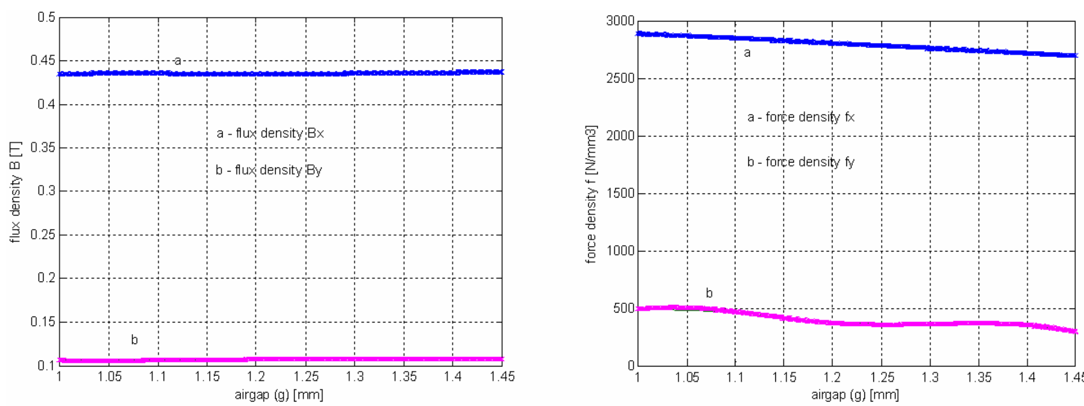
Fig. 7 shows variations of flux density by x - axis and, respectively y – axis (7,a, respectively 7,b) for two classes of permanent magnets used for comparative study: anisotropic and isotropic.



a) b)

Fig. 7 Variation of flux density for permanent magnets bearings:
a) by x - axis; b) by y – axis.

Fig. 8 shows variations of flux density (fig. 8,a), and force density module (fig. 8,b) with variation of distance between magnets, when the magnetic bearing would be made out of anisotropic magnets, but their magnetisation would be oriented by x – axis.



a) b)

Fig. 8 Variation of flux density and force density module for permanent magnets bearings when
($I_x \neq 0; I_y = 0$):
a) flux density; b) force density module.

Conclusions

As a result of this research, the following conclusions may be drawn:

1. Symmetrical structures of bearings with permanent magnets (of the anisotrope type) offer a good functional stability and a minimum rigidity by x - axis (the module of the force density displays a relatively small variation at the alteration of the distance between the keepers equiped with permanent magnets);

2. On the contrary, by y - axis (radial direction), the module of the force density also displays oscillations in these symmetrical structures with anisotrope magnets, thus reinforcing the idea that it is impossible to maintain the shaft in central position;

3. Flux density remains approximately constant by x – axis both for structures using anisotropic andisotropic permanent magnets, but displays oscillations and is diminished by y – axis;

4. For isotropic magnets (used to build the bearings shown in the paper), at the same symmetrical bearing structure there are oscillations of force, both axially (by x - axis) and radially (by y - axis), so functional instability for such inbuilt permanent magnets is maximal, and there can be critical values of the distance beween keepers (the airgap) witch may lead to resonance phenomena. Simulations prove that after such extreme phenomena, the axial direction forces decrease drastically, while the radial direction forces reach dangerous levels;

5. Notably, the case of anisotropic magnets (magnetised axially) where variation of force density module on radial direction displays insignificant oscillations compared to those occuring in bearings with radial magnetisation of magnets. Even though the amplitude of forces is lower than in case of radial magnetisation, bearing functional stability is much better.

References

1. E.P.Furlani, S. Reznik, A. Kroll – *A three dimensional field solution for radially polarized cylinders* – IEEE Trans. on Mag., vol 31, no 1, pp. 844-850, january 1995;
2. J. Delamare, E. Rulliere, J.P. Yonnet – *Classification and synthesis of permanent magnet bearing configurations* - IEEE Trans. on Mag., vol 31, no 6, pp. 4190-4192, november 1995;
3. Y.D. Yao, D.R. Huang, C.M. Lee, S.J. Wang – *Magnetic coupling studies beetwen radial magnetic gears* - IEEE Trans. on Mag., vol 33, no 5, pp. 4236-4238, september 1997;
4. F. Bancel, G. Lemarquand – *Three-dimensional analitycal optimization of permanent magnets alternated structure* - IEEE Trans. on Mag., vol 34, no 1, pp. 242-247, january 1998;
5. ***PDE-ase., *Reference manual tutorial handbook of demonstration*, SPDE, Inc., 1995.

Analiza stabilităţii funcţionale a lagărelor cu magneţi permanenţi

Rezumat:

In cadrul lucrării este prezentată o analiză comparativă a stabilităţii funcţionale a lagărelor magnetice pasive realizate cu magneţi permanenţi din pamânturi-rare (Nd-Fe-B). Stabilitatea a fost studiată atât din punctul de vedere a variaţiei forţelor specifice dezvoltate în cadrul lagărelor – pe direcţie axială, respectiv, radială – cât şi din punctul de vedere a variaţiei inducţiei magnetice din întrefier, la modificarea distanţei dintre magneţi. Analiza comparativă a urmărit comportarea lagărelor magnetice pasive pentru două clase de magneţi permanenţi: anizotropi, respectiv, izotropi.