SOLUTION OF CONTACT–FREE
PASSIVE MAGNETIC BEARING

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The submitted paper deals with a simple method allowing easy calculation of static characteristics of passive radial or axial permanent magnetic bearings. There are two ways leading to an increase of the loading capacity: by asymmetrical arrangement of the bearing, or by its shielding with the help of a ferromagnetic jacket. The calculation algorithm is illustrated by numerical examples.

Key words: passive magnetic bearing, application of permanent magnets, magnetic levitation, stiffness of magnetic bearing.

1 INTRODUCTION

Progress in the development of high quality hard-magnetic materials allowed to carry out different technical applications of permanent magnets including magnetically levitated passive bearings. In comparison with traditional (sliding or roller) bearings they have remarkable qualities: they do not require any maintenance, they have a long operating life, there are no losses through mechanic friction and they do not heat, they are noiseless and there is no danger of contamination with lubricating oil near the bearing. Magnetic bearings can be used in extreme conditions, especially at high rotation speeds with a wide range of operating temperature and in chemically aggressive environment. Magnetic bearings are used for special purposes, such as turbo-compressors, vacuum pumps, gyroscopes, rotating accumulators of mechanical energy and can be also found in space engineering. Active magnetic bearings require complicated control hardware, such as digital signal processor amplifiers, digital-to-analog converters, analog-to-digital converters, and software. Passive magnetic bearings, unlike the active ones, are simple (and thus actually trouble-free), they do not have power consumption, they take up only little space and their price is low. Their disadvantage is a lower loading capacity and dynamic stiffness. Few studies have been performed on stiffness of passive magnetic bearings using permanent magnets.

The permanent magnet by itself is not able to keep the ferromagnetic body at free and stable levitation, as shown by Earnshow as early as 1842. To make the passive magnetic bearing stable, an additional mechanic bearing or a pair of magnetic bearings arranged according to Fig. 1 must be used. On the other hand a magnetic bearing can be stable if it is based on the principle of the Meissner effect (see eq [3]). The calculation of a passive bearing with permanent magnets, if done analytically, is quite troublesome (see eq [1]). In the submitted paper it will be shown that modern SW products can be used for the calculation of the magnetic bearing.

2 DYNAMIC STIFFNESS AND THE LOADING CAPACITY OF PASSIVE RADIAL MAGNETIC BEARING

2.1 Symmetrical bearing

From different variations of passive magnetic bearings (see eq [2]) we will consider a radial bearing with two ring permanent magnets according to Fig. 1, where the orientation of magnetization is indicated. The basic static characteristic of a magnetic bearing is its stiffness, it is the dependence of eccentricity of the axes of the stationary and rotational part of the bearing on load force \( F = f(\delta) \). The loading capacity is expressed as force \( F_m \) at which the eccentricity is just \( e = r_1 - r_3 \). In Fig. 2 the levitation area \( L \) of the bearing is marked. The inner ring is repelled from the outer one. If the bearing is not loaded \( (F = 0) \), \( e = 0 \) and area \( L \) is in the annulus.

The magnetic field between the rotational and the stationary part of the bearing is 3D. In cylindrical coordinates this field changes with co-ordinate \( \delta \) only slowly, it is thus possible to solve it approximately like a 2D field. An air gap inter leaves with the circle with centre \( O(0, e/2) \) and diameter \( (r_1 + r_3)/2 \). Force \( F_d \) acts on the angular element. We solve the magnetic field between two long rectangular parallelepipeds from permanent magnets (we get them by unrolling both rings of the bearing, thus for \( r_1, r_3 \rightarrow \infty \); the distance between them is \( \delta \)). Then we define the force (per unit length) with which both parallelepipeds repel each other. A general
relation is valid (see eg [5]):

\[ F = \frac{1}{2} \int_S [(r \times H)(n \cdot B) + (r \times B)(n \cdot H) - (r \times n)(H \cdot B)]dS \quad (1) \]

where \( S \) is the surface of the body on which force \( F \) operates (in our case it is the surface of one of the parallelepips per length unit) and \( n \) is outer unitary normal vector. Numerical solution of the magnetic field of permanent magnets and then defining force \( F \) can be easily done by a SW product for magnetostatic field analysis.

The static curve characteristic of bearing (it is the stiffness of bearing) \( F = f(e) \) can be obtained by the following algorithm:

- Choose eccentricity \( e \in (0, r_1 - r_3) \).
- Choose various values \( \alpha \in (0, \pi) \).
- For these values \( \alpha \) calculate the corresponding air gap \( \delta \), according the relation (see Fig. 2)

\[ \delta = \sqrt{R_1^2 - \left(\frac{e}{2} \sin \alpha\right)^2} - \sqrt{R_2^2 - \left(\frac{e}{2} \sin \alpha\right)^2} - e \cos \alpha \quad (2) \]

- For calculated \( \delta \), determine the magnetic field between unrolled rings of permanent magnets and then calculate force \( F \) according to eq. (1).
- The total force operating on the rotating part of the bearing is then

\[ F = 2 \int_0^\pi F(\alpha)d\alpha \quad (3) \]

- Repeat the calculation for different values of eccentricity \( e \) to get the course of \( F = F(e) \), ie the stiffness of bearing.

2.2 Radial/axial bearing

It is possible to obtain the stability of the magnetic bearing (according to [1]) by the fact that the air gap of an unloaded bearing is in the shape of a conical jacket. Then it is necessary to use a pair of these bearings arranged according to Fig. 3. Calculation of the characteristic of the radial component of force \( F_x = F_x(\delta) \) and of the axial component of force \( F_y = F_y(\delta) \) is in fact the same as described in Section 2.1.
2.3 Asymmetrical bearing

In devices that have a stationary position when working it is possible to improve the qualities of the magnetic bearing by asymmetrical arrangement of the fixed part. Let us suppose that the radial bearing is in its function loaded by force $F \geq 0$, that does not change its direction. The outer magnetic ring of the bearing is divided into two segments, top and bottom according to Fig. 4. It is possible to increase the loading capacity if we make the top segment from a material with a lower magnetic remanence than the bottom segment. We label the force repelling the rotating part of the bearing in the area of bottom segment as $F_1$ and in the area of top segment as $F_2$. Then for $e = 0$ will be $F_1 = -F_2$, but for $e = -e_{\text{max}}$ must be $F_2 = -F_1$. If this condition is not met, there will be a mechanic contact between the rotational and stationary rings of the unloaded bearing.

The stiffness of the bearing can be examined by algorithm given in Section 2.1 with the difference that eccentricity is chosen in the interval $e \in \langle -(r_1 - r_3); r_1 - r \rangle$.

2.4 Bearing with magnetic shielding

Another way of increasing the load caring capacity of bearing dwells in its magnetic shielding. By lowering the reluctance of the paths of the magnetic flux outside the bearing we can cause an increase of magnetic flux density in the air gap and so an increase of loading capacity of the bearing. Shielding is made of a soft ferromagnetic material with high permeability. Fig. 5 shows the arrangement of the bearing.

3 NUMERICAL EXAMPLES

3.1 Radial symmetrical bearing (Fig. 1)

We examine the stiffness of the bearing with dimensions shown in Fig. 6. The stationary and rotational parts of the bearing are made of hard ferromagnetic material RECOMA 25 (based on cobalt-rare earth magnets). The demagnetization curve of this material is in Fig. 7a. The magnetic field was calculated using the programme Quick...
Field for eccentricity $e = 0, 0.5, \ldots, 3$ mm. In Fig. 8, distribution of magnetic lines of force is drawn for $e = 0$. The examined characteristic of the bearing $F = f(\delta)$ is in Fig. 9, the loading capacity being $F = 120$ N.

### 3.2 Radial/axial bearing (Fig. 3)

Calculation of the characteristic of the bearing was done for stationary and rotational rings with dimensions shown in Fig. 10. Distribution of the magnetic field is in Fig. 11. In Fig. 12 there is the dependence of the radial loading force on eccentricity.

### 3.3 Radial asymmetrical bearing (Fig. 4)

Calculation of the characteristic of the bearing was done for stationary and rotational rings with dimensions shown in Fig. 6. The demagnetization curve of the bottom segment is in Fig. 7a, demagnetization curve of the top segment is in Fig. 7b. Distribution of the magnetic field is in Fig. 13. In Fig. 14 there is course of $F_2$ from the top segment, then the course of $F_1$ from the bottom segment and the course of the final force $F$. It is evident from the graph that for zero load the eccentricity $e = -2.4$ mm, for load $F = 130.2$ N the eccentricity is zero and loading capacity of the bearing is $F = 340$ N.
3.4 Magnetic bearing with shielding (Fig. 5)

Dimensions of the bearing and its shielding jacket are in Fig. 15. Both the stationary and rotational part are made of material whose demagnetization part of the hysteresis curve is in Fig. 7a, relative permeability of the shielding jacket is \( \mu_r = 750 \). Distribution of the magnetic field is drawn in Fig. 16. Calculated characteristic of the bearing is in Fig. 17; loading capacity of the bearing is \( F = 460 \text{ N} \).

4 CONCLUSION

The aim of the submitted paper was to show that using professional programmes for magnetic field analysis it is possible to solve magnetic bearings effectively. Then two ways in which it is possible to improve the qualities of magnetic bearing were pointed out. The first way dwells in asymmetrical arrangement of the stationary part of the bearing. The second one is the magnetic shielding of the bearing. The first way can only be used when the bearing is part of a device that is stationary. From the given numerical examples it is evident that the loading capacity of the bearing increased considerably for both ways. For asymmetric bearing it was by 283\%, and for shielded bearing by 383\%.

Acknowledgements

The authors are grateful to the Grant Agency of the Czech Republic for funding the research work within the project no. 102/01/1401.

References


Received 29 October 2003

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