Design of active magnetic bearing

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The paper deals with the analysis of an Active Magnetic Bearing system by the Finite Element Method and the magnetic vector potential formulation. This work proposes an optimal shape and dimensions of the legs of stator and air gap.

1. Introduction

The design of an Active Magnetic Bearing system has been started in the Laboratory of Electromagnetic Fields. The Active Magnetic Bearing (AMB) use electromagnets to hold the load stable. The AMB is a bearing without physical contact between the rotary and the stationary part. In this way the friction and losses of friction can be fully eliminated. Without this physical contact, higher operation speed can be reached, and the device requires less maintenance, and so the lifetime can be increased, too. Unfortunately, the AMB requires continuous power supply for the electromagnets, and for the controlling electronic.

2. Beginning

There is an increasing number of documents on the Internet about Active Magnetic Bearing systems, and after studying them, the design of an arrangement has begun. First, the design of the so called four pole bearing, which contains four electromagnets, has been started as a case study. However, the analyzed model does not proved to be the best solution. That is why, we have focused on the eight poles bearing, which seemed to be a good solution This setup contains eight electromagnets, and they work in pairs: there are four-four electromagnets in the dimension *x* and *y*. With this kind of setup the shaft could be positioned accurately. The layout of the AMB under design can be seen in Figure 1. In the center the „pipe" shaft can be seen surrounding it by the electromagnets [2,3,4].
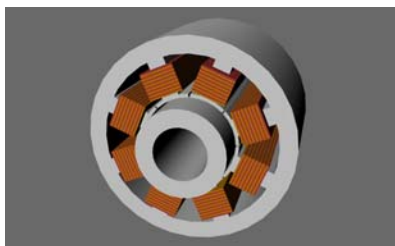

Fig. 1. Layout of the Active Magnetic Bearing (3D model)

3. Design

The basis of our design procedure was the two dimensional example by David Meeker, ie „Force of an Eight Pole Radial Magnetic Bearing", simulated in FEMM 4.0 [3]. This can be seen in Figure 2. At first, the same shape of the legs has been simulated in the COMSOL Multiphysics environment, and the results were equal. After that, the same sized AMB was used, but the shape of the legs was altered to gain greater holding force. This modified model can be seen in Figure 3.
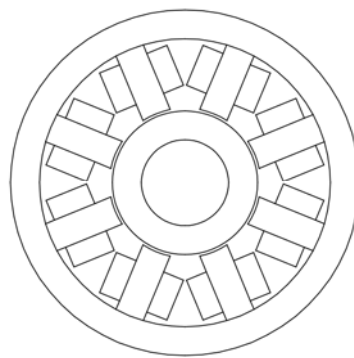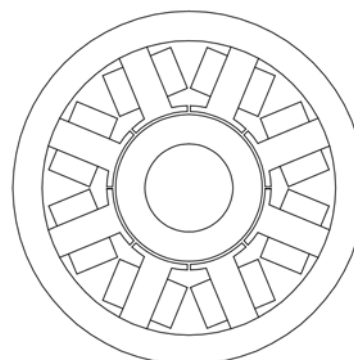

Fig. 2. Legs style from [3]

Fig. 3 Crown style legs

These data were used during the design of the shape of the AMB:

- outer diameter of the AMB is 121.92 mm,
- inner diameter is 101.6 cm,
- outer diameter of the shaft is 52.832 mm,
- inner diameter is 50.8 mm,
- leg thickness is 10.3124 mm,
- leg crown thickness 2 mm,
- air gap between the leg crowns is 1 mm,
- air gap between the legs and the shaft is 1 mm.

The calculation was done with a maximum of 12 A (DC), and 80 turns on each leg. In these simulations the turns and the current act like constant values, so they were not changed during the calculations. Like in the example in [3], the main goal was to determine the maximum holding force, i.e. the upper electromagnets in the y direction (vertical direction) got 12 A, and in the x direction (horizontal direction) the electromagnets on the left and on the right side got 6-6 A. During the simulations the lower electromagnets were turned off, i.e. it got 0 A.

Except these, there are three main things on which the holding force greatly depends. The first is the air gap length between the shaft and the legs, the thicker the gap the greater the force, as can been seen in Figure 4. The second is the depth of the apparatus in the z direction, twice depth gets twice force. At last but not least, the thickness of the crowns, the thicker crowns are used, the greater force can be generated. The main problem was to determine the maximum holding force in the y direction. After many calculations and probes, the simulated AMB can provide maximum 800 N as holding force over 1 mm thick air gap. The acting force can be seen on Figure 5.

Calculations were done with different shafts (bar and pipe), through different thick of air gaps (1mm-5mm), and different shape of the legs. The crown shaped legs proved to be better. Calculations were done in COMSOL Multiphysics, which program has a user friendly interface. After the correct shape of the device has been designed, and the correct physics has been added, the user has to choose the correct solver, and the program calculates the proper electromagnetic field quantities. The above proposed simulations take quite a long time.
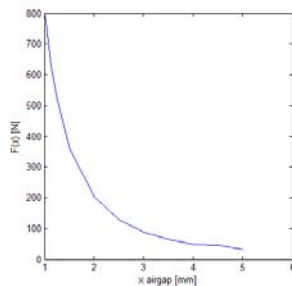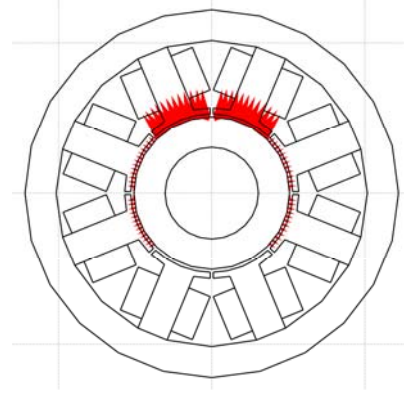

Fig. 4. Force-air gap dependency

Fig. 5. Direction of the holding force

4. The finite element model

The arrangement is working on DC that is why a static magnetic field problem has been analyzed by the Finite Element Method (FEM) [1]. The static magnetic field problem can be described by the following Maxwell's equations

$$\nabla \times \mathbf{H} = \mathbf{J}_0, \ \nabla \cdot \mathbf{B} = 0, \ \nabla \cdot \mathbf{J}_0 = 0, \ \mathbf{H} = \mathbf{B}/\mu, \ (1)$$

where $\mathbf{H}$, $\mathbf{B}$, $\mathbf{J}_0$, and μ are the magnetic field intensity, the magnetic flux density, the source current density, and the permeability, respectively. The permeability is supposed to be constant, $\mu = \mu_0$ in air, and $\mu = 4000\mu_0$ in the stator core and in the rotor.

The 3D problem has been solved by FEM applying the COMSOL Multiphysics software. The FEM mesh of the arrangement can be seen in Figure 6. The arrangement has been meshed by triangular elements in the x-y plane, and this mesh has been extruded in the z direction, i.e. prism elements are used.
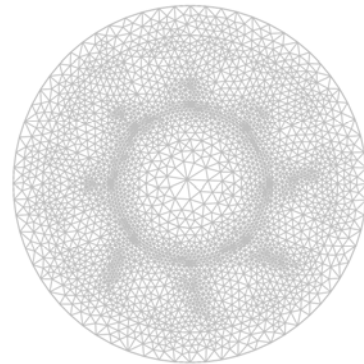

Fig. 6. The finite element mesh of the arrangement in the x-y plane

The edge shape functions have been used to represent the unknown magnetic vector potential [1]. According to the second equation in (1), the so called A-formulation can be used in the whole region, i.e. the magnetic flux density can be represented by the magnetic vector potential $\mathbf{A}$ as $\mathbf{B} = \nabla \times \mathbf{A}$. Using the magnetic vector potential and the constitutive relation in (1) leads to the linear partial differential equation

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \mathbf{A} \right) = \mathbf{J}_0 . \qquad (2)$$

The magnetic vector potentials have been represented by first order vector shape functions which divergence is equal to zero, and it is resulting divergence-free magnetic vector potential (Coulomb gauge),

$$\nabla \cdot \mathbf{A} = 0. \qquad (3)$$

It is supposed that the normal component of the magnetic flux density vanishes on the boundary, which can be prescribed by the boundary condition

$$\mathbf{A} \times \mathbf{n} = \mathbf{0}. \qquad (4)$$

After applying the Galerkin method and some mathematical manipulations, the following system of equations can be obtained

$$\int_{\Omega} \nabla \times \mathbf{W} \cdot \left(1/\mu \, \nabla \times \mathbf{A} \right) d\Omega = \int_{\Omega} \mathbf{W} \cdot \mathbf{J}_0 \, d\Omega \quad (5)$$

Here $\mathbf{W}$ is the vector shape function.

Fig. 7 shows the contour lines of the simulated magnetic vector potential when the acting force has maximum value.
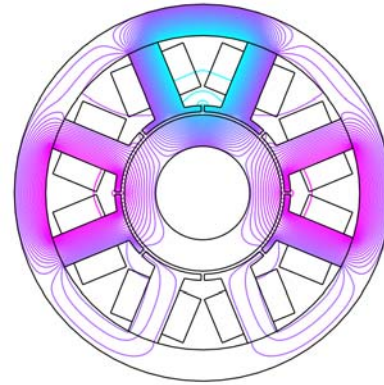

Fig.7. Contour lines of the magnetic vector potential

5. Conclusions

The future plan is to build the AMB, and to design a controller to operate the device properly. Before building the arrangement, further nonlinear simulations must be studied, the nonlinear characteristics of the stator and of the shaft will be taken into account by a simple inverse tangent type curve, and the nonlinear partial differential equation will be solved by the fixed point iteration technique [5].

References

[1] Bíró, O, Edge Element Formulations of Eddy Current Problems, Comput. Meth. Appl. Mech. Engrg. **169**, , 391 (1999).

[2] E. Maslen, MagneticBearing, Virginia, (2000)

[3] D. Meeker, Example: Radial Magnetic Bearing (Nonlinear Magnetostatics,) http://femm.foster-miller.net/wiki/Examples, (1999).

[4] G. Schweitzer, Active magnetic bearings - chances and limitation, Zürich.

[5] Hantila, I. F., A Method For Solving Stationary Magnetic Field in Nonlinear Media, Rev. Roum. Sei. Techn. Electrotechn. Et. Energ. **20**, 397 (1975).

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