

## The Numeric Evaluation of The Magnetic Field Produced by a Rotor With Alternating Poles

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**Abstract:** The magnetic field produced by a rotor with alternating magnetic poles in a magnetic fluid hydrostatic bearing is numerically evaluated. There has been used a 3D program based on the finite element method (3D-FEM).

**Keywords:** Magnetic Field, Magnetic Fluid, 3D-FEM, Magnet 5.0.

### 1 Introduction

The cylindrical bearing with magnetic liquid represents one of the applications of the second order magnetic levitation.

The bearing with magnetic fluid, alternating magnetic poles on the stator, and nonmagnetic rotor has been presented in [1] and analytically investigated in [2, 3]. A numerical computation of the force that acts on the rotor, using a 2D-FEM program under the hypothesis of a magnetic field with plane meridian symmetry, can be found in [4].

The bearing with magnetic fluid, alternating magnetic poles in rotor and nonmagnetic stator has been analyzed analytically in [5, 6].

In the present paper, the magnetic field is evaluated numerically in a bearing with magnetic fluid, alternating magnetic poles in rotor and nonmagnetic stator. It has been used Magnet 5.0, a 3D program based on the finite element method (FEM).

The sketch of a bearing with magnetic fluid and alternating magnetic poles placed in rotor is presented in Fig. 1, where we have denoted:

- 1 – the rotor (the shaft) of  $r_1$  radius and  $\mu_0$  permeability;
- 2 – the magnetic poles with  $h_p$  height, supposed to have a radial permanent magnetization  $M_p$  of zero divergence and  $\mu_m = \mu_0\mu_{rm}$  permeability;
- 3 – magnetic liquid that fills the space between the rotor and stator, considered as a linear medium of permeability  $\mu_1 = \mu_0\mu_{r1}$ ; and

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4 – the nonmagnetic stator of  $\mu_0$  permeability.

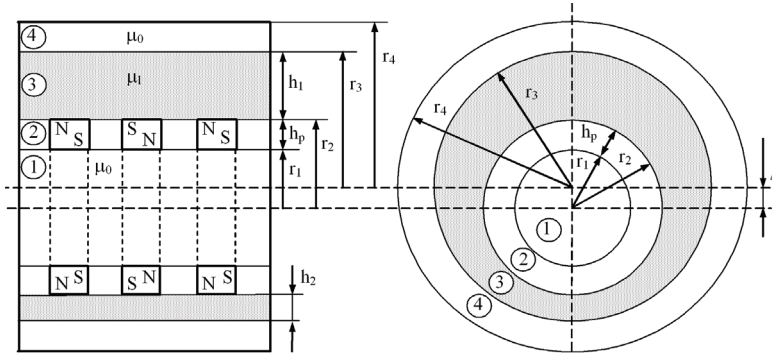


Fig. 1 – The sketch of a bearing with alternating poles in rotor.

The displacement between the rotor axes and stator axes will be denoted by  $\Delta$ . Because of the displacement  $\Delta$ , the magnetic field has not a radial symmetry, and on the rotor acts a magnetic force in the direction to bring the rotor in equilibrium (when it is centered in the bearing). The levitation force depends on the displacement  $\Delta$ , the magnetic properties of the magnetic liquid, the permanent magnetization of the magnetic poles and on the geometrical design of the bearing. To evaluate numerically the levitation force, we need to know the magnetic field distribution produced by the magnetic poles.

## 2 Magnetic Field Equation and Finite Element Formulation

The bearing that will be analyzed is considered to have a long extension along  $z$ - axes, Fig. 2.

The length of the 3D model has been denoted  $\lambda/2 = l_p + l_0$ , a half of wavelength. It represents the length between two orthogonal planes on the  $z$  axes that pass through the middles of two consecutive poles, Fig. 3. The radial extension of the 3D model, a cylinder of  $r_{\text{ext}}$  radius, has been adopted so that the magnetic field is considered to vanish outside the model.

The Dirichlet condition  $\mathbf{A} = 0$  has been considered for the boundary of the 3D model.

In all domains of the 3D model, Fig. 3, the magnetic potential vector  $\mathbf{A}$  satisfies a Laplace equation:

$$\nabla^2 \mathbf{A} = 0$$

as  $\text{div } \mathbf{B} = 0$ ,  $\text{curl } \mathbf{H} = 0$ ,  $\text{div } \mathbf{M}_p = 0$  and,  $\mathbf{B} = \mu \mathbf{H} + \mu_0 \mathbf{M}_p$  in the magnetic poles,  $\mathbf{B} = \mu_l \mathbf{H}$  in the magnetic liquid and  $\mathbf{B} = \mu_0 \mathbf{H}$  in the shaft, stator and outside the bearing.

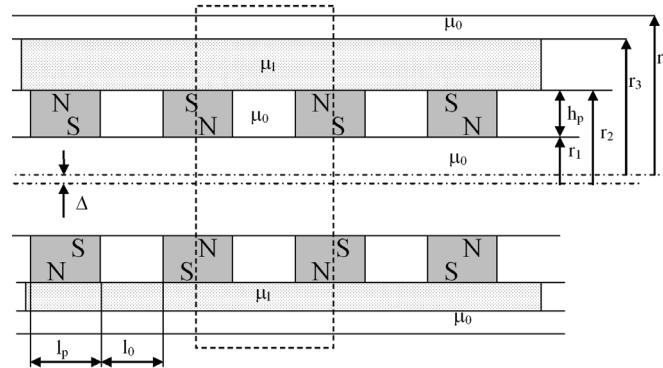


Fig. 2 – The bearing heaving a long extension on z axes.

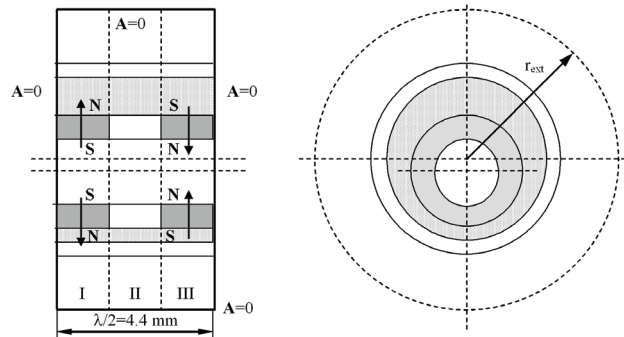


Fig. 3 – The geometrical model used in 3D-FEM analyzes.

The 3D-FEM program MagNet 5.0 of the Infolytica was used to solve numerically the field problem. The version 5.0 of the program doesn't allow defining a radial permanent magnetization. To simulate the radial magnetization of the permanent magnets has been used the model in Fig. 4. The toroidals magnets has been divided in 20 domains,  $ba, bb, \dots, bt$ , each of them having a constant permanent magnetization, as shown in Fig. 4.

The geometry and the finite elements in a orthogonal plane on the z axis of the model, generated by the MagNet is presented in Fig. 5.

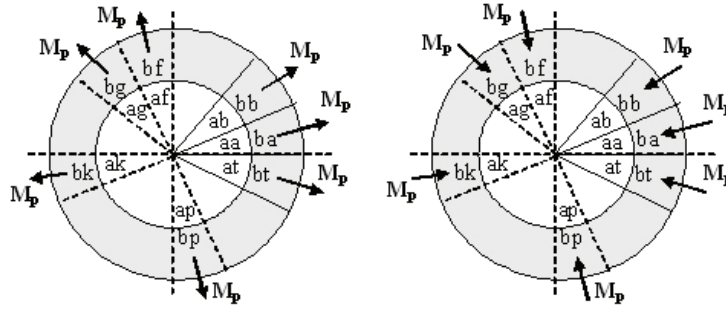


Fig. 4 – The model adopted for simulating a radial magnetization.

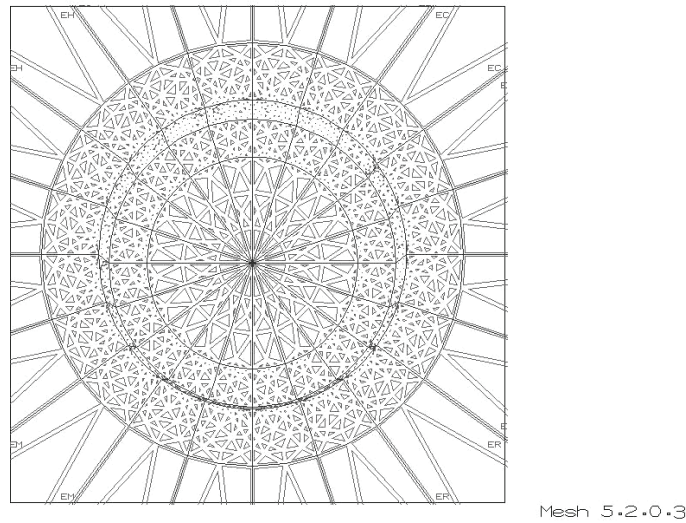


Fig. 5 – The finite elements in a plane orthogonal on the z axis.

To generate the 3D model, has been used the extrusion principle.

The first order tetrahedrons were used in all the regions of the model except the region of the liquid where second order tetrahedrons have been used. In the analysed cases there has been used a number of 25000-30000 nodes and 130000-150000 tetrahedrons.

The values of the geometrical quantities used in the numerical simulation, are:  $r_1 = 10 \text{ mm}$ ,  $r_2 = 13.57 \text{ mm}$ ,  $r_3 = 14.57 \text{ mm}$ ,  $l_p = 2.93 \text{ mm}$ ,  $l_0 = 1.466 \text{ mm}$ ,  $\lambda = 8.8 \text{ mm}$ ,  $\delta = 1 \text{ mm}$  and  $r_{\text{ext}} = 100 \text{ mm}$ , where  $\delta$  represents the maximum displacement.

### 3 Results and Conclusions

The results are presented in a graphical form.

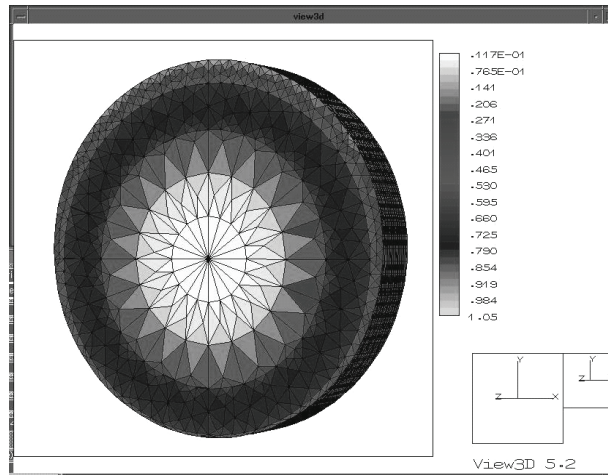


Fig. 6 – The magnetic flux density distribution in the bearing.

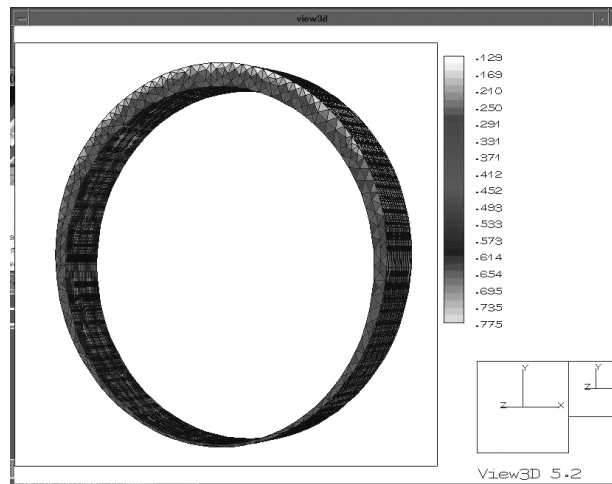
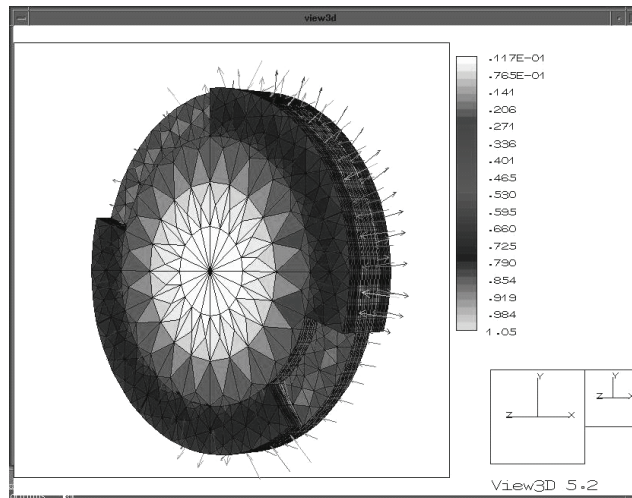


Fig. 7 – The magnetic flux density distribution in the liquid.

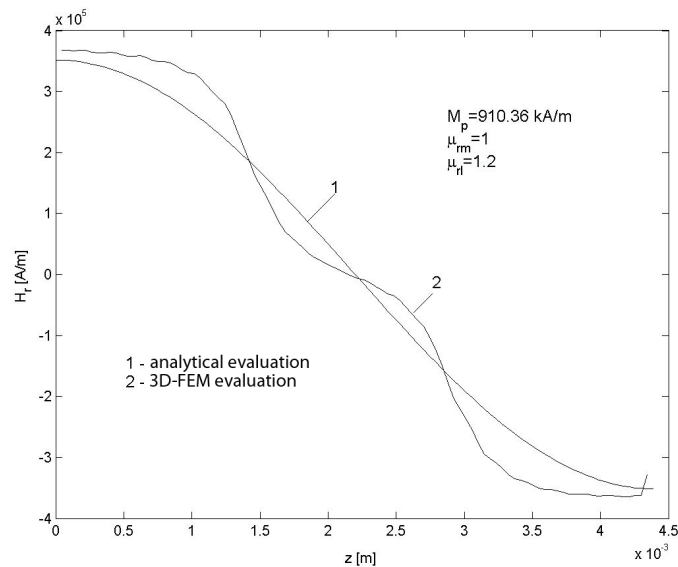
In Fig. 6 the magnetic flux density distribution in the bearing (in Tesla) is presented, using a Nirodium-Fer permanent magnet with  $M_p = 910.36 \text{ KA/m}$ ,  $\mu_{rm} = 1$  and a liquid with  $\mu_{r1} = 1.2$  for a displacement  $\Delta = 0.8 \text{ mm}$ . The mag-

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netic flux density distribution in the magnetic liquid and in the rotor (with magnetic poles), for the same quantities, is presented in Figs. 7 and 8. The higher values of the flux density in the liquid take place where the liquid layer is the thinnest (the bottom part of the liquid). In the rotor, the higher values of the flux density are placed in the magnetic poles and immediately around them.



**Fig. 8** – The magnetic flux density distribution in the rotor.



**Fig. 9** – The radial component of the magnetic field strength versus  $z$  axes.

In Fig. 9 there has been presented the radial component of the magnetic field strength versus  $z$  axis for the analysed model and  $\Delta = 0.8$  mm. The magnetic field strength has been considered in the points of the magnetic liquid placed on the interface surface between the magnetic liquid and rotor, where the displacement has a maximum value (the upper part of the bearing, Fig. 3). The  $z$  component of the magnetic field strength versus  $z$  axis, for the same points as in Fig. 9, is presented in Fig. 10. The results obtained from the 3D-FEM model, trace 2, are compared with the corresponding analytical results obtained in [6] where has been used a plan-parallel model for the field evaluation, trace 1. In the both cases, the curves resulting from 3D-FEM (curves 2) match quite well with the curves 1 obtained by analytical approximation.

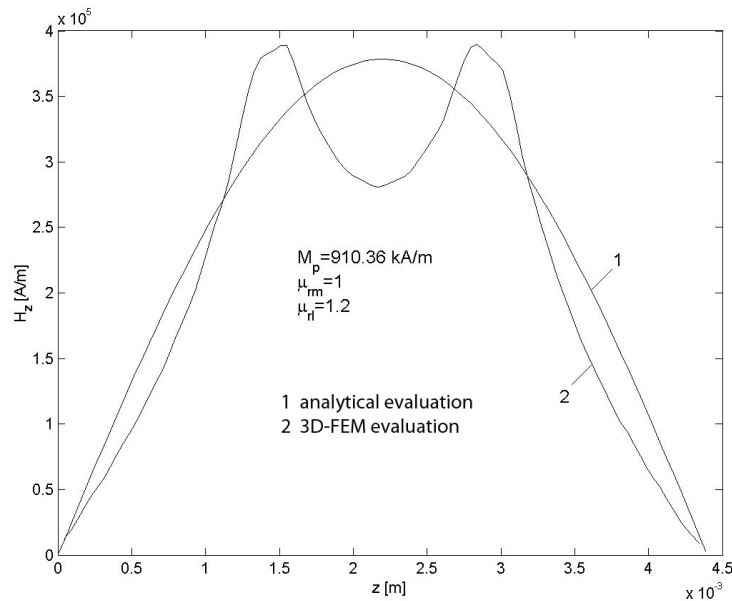


Fig. 10 – The  $z$  component of the magnetic field strength versus  $z$  axes.

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