

STUDY ON RADIAL ACTIVE MAGNETIC BEARING FOR FLEXIBLE SHAFT

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Abstract

This paper presents the results of selected analysis realised for the flexible shaft with a solid rotor and 8 pole heteropolar active magnetic bearing designed for a such configuration. The calculations were realised with the support of COMSOL Multiphysics software. The 3D models allowed to expand previous analysis with eigenfrequencies and electromagnetic force calculated for a complete bearing as well for deviated rotor (as simulated orientation for flexible mode).

1 Introduction

The standard approach to calculate the electromagnetic force in the Active Magnetic Levitation system is based on the well known formula, which assumes the parallelism of the rotor-bearing surfaces, and axial symmetry of rotor and electromagnet. In recent years, thanks to the numerical analysis, the electromagnetic force is calculated numerically. One can find many papers in databases and from the recent ISMB symposia reporting electromagnetic force characteristics calculated for the particular configuration of the rotor-bearing systems.

The author's interest from the control point of view is focussed on the modelling and identification of rotor-bearing system for the control purposes. In this case, the electromagnetic force, as an active control component in the levitation system, plays a crucial role. Therefore the proper determination of the force characteristics is required for the future dynamics modelling and control study. A first author calculations were made with the support of FEMLab, many years ago. The research towards interdisciplinary modelling, including mathematical geometry modelling [1], and

virtual prototyping including controller action [5] shows, that the modern devices can be precisely designed with a support of complex models. The interdisciplinary methodology is proposed to perform a set of studies. This paper reports some results of the pending research.

2 Laboratory test-rig

The laboratory test-rig construction was designed in 2005 for the flexible shaft and AMB with three electromagnets [2]. Now, it is considered for the AMB with four electromagnets. The AMB (see Fig. 1.) located between ball bearings will be replaced.



Fig. 1: Laboratory test-rig with AMB3em

2.1 Mechanical configuration

The rotor-AMB system consists of the support base, two ball bearings at the end, AMB, and the drive. All bearings positions can be along the support to modify the system configuration. The rotor at the AMB is a double ring with internal joint to minimise its weight (see Fig. 2).

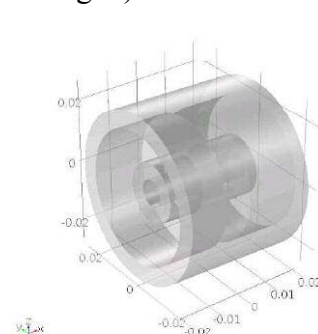


Fig. 2: Rotor configuration

2.2 AMB configuration

The AMB (see Fig. 3) was designed using mathematically based shape prototyping [1]. The selected parameters are summarized in Table. 1.

Parameter	value
radial airgap of magnetic bearing	300 μm
rotor diameter	51.2 mm
thickness of magnetic bearing	10 mm
load capacity	10 N

Tab. 1: Characteristics of the Compact Axial/Radial Magnetic Bearing

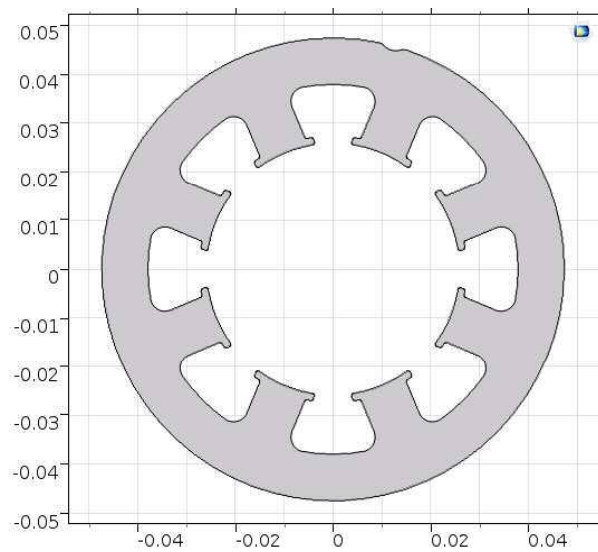


Fig. 3: Active Magnetic Bearing Stator

3 COMSOL models

Two COMSOL models were developed: one for eigenfrequency analysis and the second for electromagnetic force calculation. Both of them are true 3D models reflecting real geometrical and material properties.

3.1 Eigenfrequency study

The finite element method allows to investigate the eigenfrequencies with respect to shaft geometry and rotor position. in the case of laboratory test-rig the shaft is chamfered for an easy mount of the rotor. The comparison of the first four eigenfrequencies for an ideal and chamfered shaft-rotor is given in Table 2.

Eigenfrequency	cylindrical rotor	chamfered rotor
f_1	29.419	26.14
f_2	29.422	29.30
f_3	148.69	135.63
f_4	148.70	151.92

Tab. 2: Comparison of eigenfrequencies for both types of shaft-rotor configurations.

Table 3 presents the eigenfrequencies for three rotor positions (0.2, 0.3, 0.4) determined from the beginning of rotor . In Fig. 4 the shaft-rotor deformation is presented for the first three modes calculated for a chamfered shaft and rotor located at the shaft centre.

Eigenfrequency/ rotor position along shaft	0.2	0.3	0.4
f_1	35.11	28.07	26.14
f_2	39.31	31.47	29.30
f_3	97.55	117.04	135.63
f_4	109.33	131.18	151.92

Tab. 3: Characteristics of the Compact Axial/Radial Magnetic Bearing

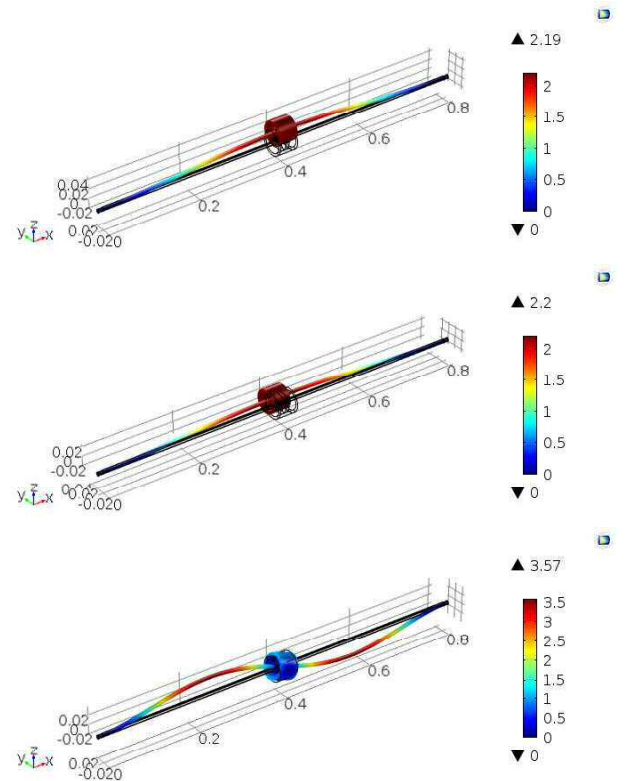


Fig. 4: Characteristics Field of the Radial Bearing Force

The numerical analysis allows to obtain a nearly realistic values of the calculated properties. Such analysis is valuable for control engineers for the modelling purposes and controller study. Values of the eigenfrequencies allows to adjust bearing position and designs a right controller for the selected operating modes.

3.2 Electromagnetic force study

The static magnetic field analysis was realised to obtain electromagnetic force characteristics. For this report a single upper electromagnet was supplied to calculate all three components of the electromagnetic force. The bearing is considered as solid and there exist cross-couplings between particular electromagnets. The designed model is helpful to determine such dependencies, but they will not be considered this time. A distribution of the magnetic field is given in Fig. 5.

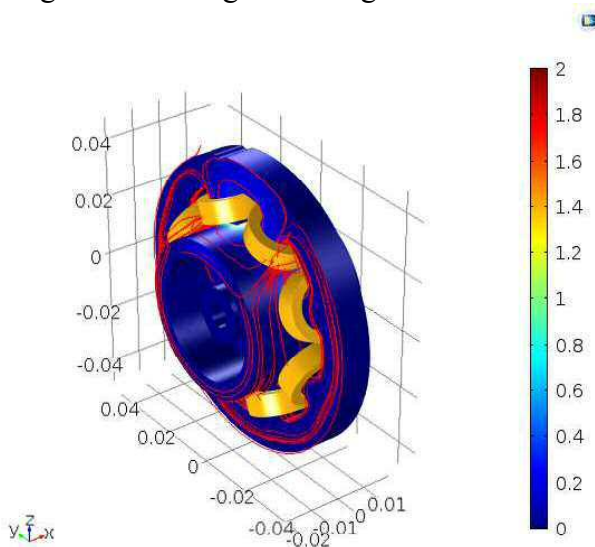


Fig. 5: Magnetic field distribution in AMB.

The calculated electromagnetic force characteristics for a coil current in a range of 0÷3A and rotor position in a range of 0÷200µm is given in Fig. 6. Excerpt from this characteristics is presented in Fig. 7.

The non-zero values of an electromagnetic force components in X and Y direction were observed what informs about cross couplings. The extended study of the electromagnetic force characteristics with respect to the supplied coils, rotor position and the mesh

density is required to determine the cross couplings characteristics.

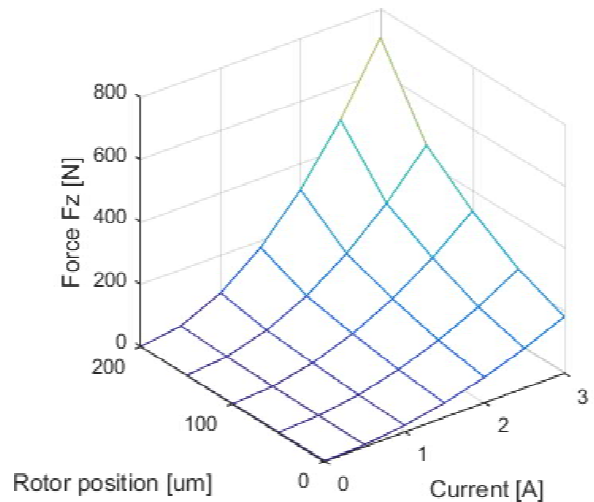


Fig. 6: Characteristics of the Radial Bearing Force component F_Z .

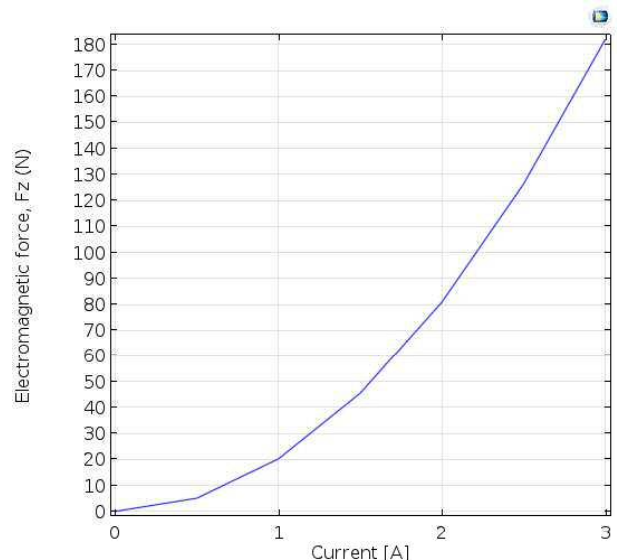


Fig. 7: Characteristics of the Radial Bearing Force F_Z vs. coil current for a rotor located at the bearing centre.

At this moment the attention was focussed on the electromagnetic force characteristics with respect to the shaft deflection and its result in the displaced rotor in the AMB. For three typical coil current $i_1=\{1, 2, 3\}$ A, the electromagnetic force F_Z was determined for the rotor located at the bearing centre and rotated vs. perpendicular axis to the bearing plane in a range of 0÷2 degrees (see Fig. 8). These calculations shows the growth of the electromagnetic force due to the rotor deviation. Such result is unobtainable by the typical force equation and 2D modelling. It opens a possibility to obtain a complete

electromagnetic force characteristics depended on the rotor displacement and deviation in all axes.

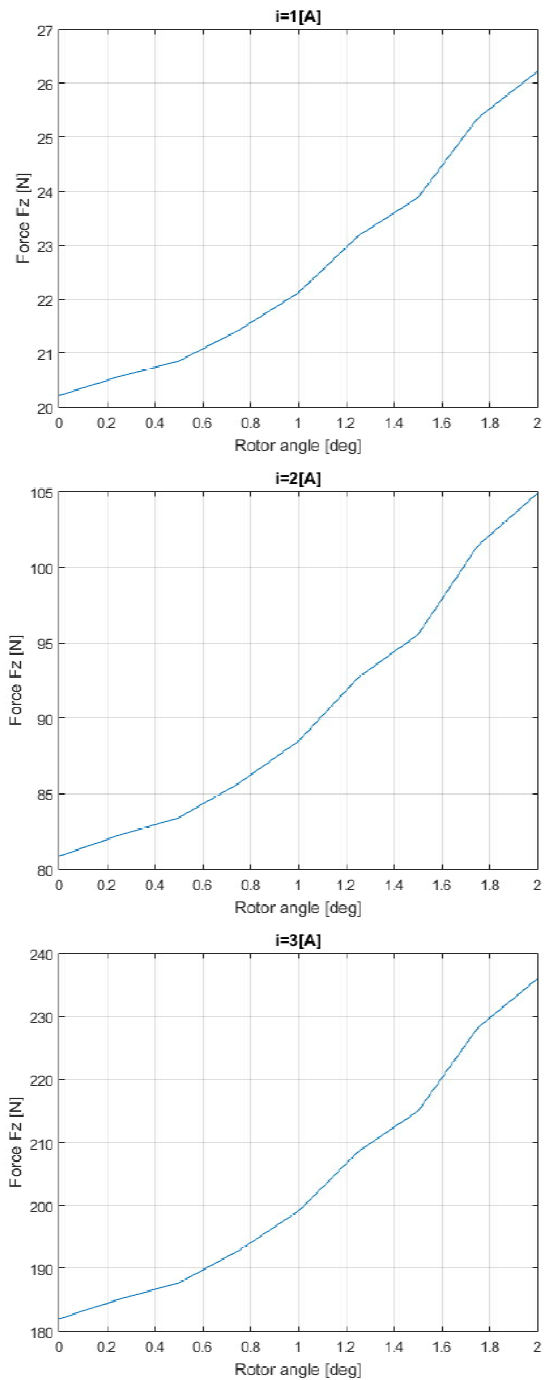


Fig. 8: Characteristics of the Radial Bearing Force component F_Z vs. rotor angular orientation.

The realised analysis confirmed the effort of 3D modelling. The initialized study shows that the complex rotor-bearing analysis require a 3D modelling and precise investigation prior the optimal design and prototyping.

4 Conclusions

Thanks to the mechanical analysis the possible flexible modes can be determined. Moreover, the vibration amplitude and rotor deflection was detected. It allowed to apply rotor position and orientation into AMB model to study the electromagnetic force dependencies. Thanks to these studies the knowledgebase about electromagnetic force characteristics versus rotor was expanded.

The developed shaft-rotor and AMB models in 3D space allowed to analyse dependencies existing in a such configuration, perform study on AMB parameters and look at the system from the target control point of view. The modern approach covering a complex study on the mechatronic device is nowadays the best way for the optimal machine design and controller study at the machine design stage.

The designed AMB is at the manufacturing stage and will be identified to compare results of simulation and experimental investigation.

References

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