STUDY ON ELECTROMAGNETIC FORCE IN CONICAL AXIAL MAGNETIC BEARING

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Abstract

This paper presents two models of a single coil cylindrical electromagnet with a conical shape. The point of interest is focussed on the electromagnetic force, features and limitations of a such models. The calculations were realised with the support of COMSOL Multiphysics software. The 3D models allowed to expand knowledgebase about the electromagnetic force components not visible in the 2D axisymmetry mode.

1 Introduction

The conical axial magnetic bearing are constructed in a form of four or three electromagnets and located at the end of the levitated shaft. The conical bearing plays a role of radial and axial stabilisation of the rotor. Moreover, recently the research covering self bearing rotors using conical magnetic bearings were shown. One can find a few ideas in e.g. [1-3]. This research was motivated by another approach and point of interest [5], as well a levitation of a slice type rotor and the successful modelling of the active magnetic suspension with cylindrical electromagnet [4]. In this case a complete virtual prototype was achieved - the complete numerical model based on finite element method and embedded control strategy (Fig. 1). The identification of the slice type rotor located in the radial magnetic bearing require a suspension of the rotor. It can be realised by the axial magnetic bearing or passive support with permanent magnets (Fig. 2). Therefore a new question was formulated: what are benefits of the modification of the cylindrical electromagnet to the conical shape? What values of electromagnetic force components are possible to reach? Is a such concept useful for rotating machinery? To find answers for the formulated questions the COMSOL Multiphysics software was used to perform magnetic field calculations.

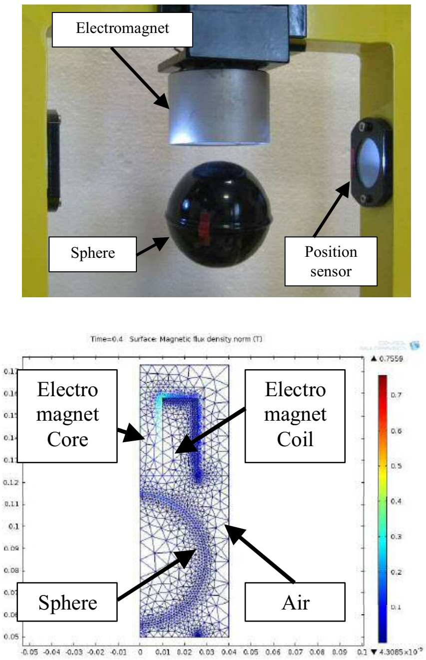

Fig. 1: Active Magnetic Suspension with cylindrical electromagnet: test-rig and COMSOL model.

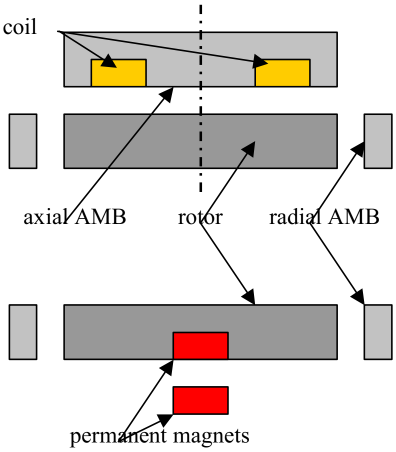

Fig. 2: Two types of axial suspension: active and passive to support radial magnetic bearing.

2 Conical magnetic bearing geometry

The conical active magnetic bearing (CAMB) in a considered concept consist of a single cylindrical electromagnet (Fig. 3) and acts as an axial magnetic bearing/magnetic suspension.

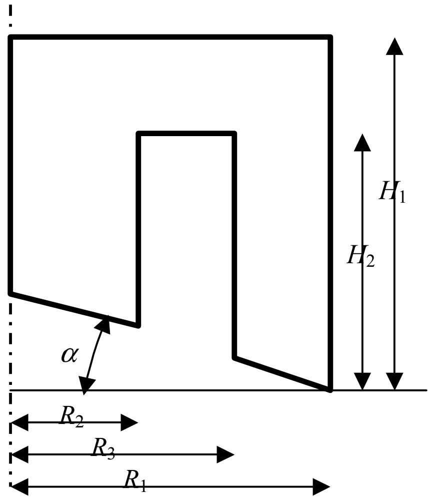

Fig. 3: Geometry

The considered rotor has a cone shape with a bottom radius R_1 and height determined by the angle α. The CAMB parameters are summarised in Table 1.

Parameter	value
R_1	0.03 m
R_2	0.015 m
R_3	0.025 m
H_1	0.04 m
H_2	0.03 m
α	variable
no of turns	100
steady current	1 A
coil diameter	0.6 mm

Tab. 1: Summary of cone electromagnet parameters

3 COMSOL models

Two COMSOL models were developed: one 2D axisymmetric mode and the second in 3D. The stationary magnetic field mode is used to realise calculations. The electromagnetic force is calculated for the conical rotor located 1mm below the electromagnet. It is assumed that the coil parameters like no of turns, coil current, coil diameter does not vary with respect to the changing cone shape. The calculation time vary with respect to the mesh density and with respect to the modification of a conical shape. The 3D model is much more time and memory consuming than 2D one. The comparison of solver results for i7core, 12GB RAM workstation is given in Table 2 for cone height of 10mm.

Parameter	2D	3D
DOFs	7 368	359 082
calculus time [s]	1	23
Fz	2.7809	2.7809
DOFs	83 890	2 218 066
calculus time [s]	2	134
Fz	2.8092	2.8018

Tab. 2: Comparison of computational effort

The realised research has shown again that active magnetic levitation systems are difficult to simulate due to the huge differences in the object vs. levitation gap dimension. Moreover, the discretisation stage and mesh density is crucial for the quality of the obtained results.

Please note, that the key point in the 3D modelling is the determination of coil length and cross section are.

With the 2D model it is impossible to achieve all three components of the electromagnetic force. The axial symmetry limits the possibilities of configuration analysis, the only axial rotor displacement is available. While, the 3D model allows freely to set the position and orientation of the conical rotor versus bearing shape.

3.1 Comparison of axial component of the electromagnetic force

The most important part of this research was to compare results of 2D and 3D models. The parametric study with a variable cone height (a respectively) was realised. The automatic reshaping adjust the mesh to the modified geometry. Table 3 presents the summary of degrees of freedom for the variable cone height. The results are presented in Fig. 4, while the error $e=F_{Z3D}-F_{Z2D}$ is given in Fig. 5. The error is about1.2% with respect to the obtained maximal force value.

Cone height	DOFs 2D	DOFs 3D
0.001	9 911	416 658
0.002	7 993	411 318
0.003	7 307	394 592
0.004	7 391	383 390
0.005	7 326	378 794
0.006	7 447	371 040
0.007	7 424	371 230
0.008	7 335	371 300
0.009	7 335	374 916
0.010	7 340	360 278
0.011	7 508	364 240
0.012	7 578	365 694
0.013	7 573	386 480
0.014	7 699	389 944
0.015	7 844	391 652
solution time	19 s	386 s

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

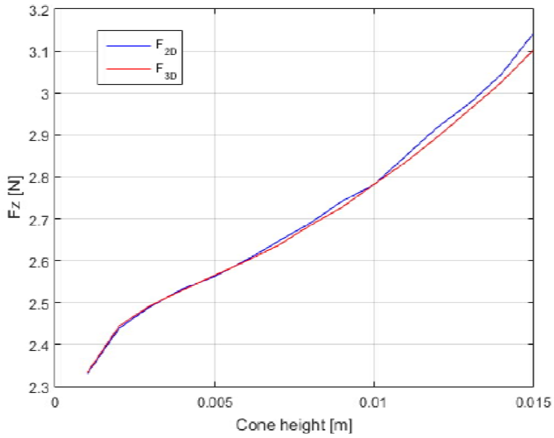

Fig. 4: Compison of axial component of the electromagnetic force calculated using both models.

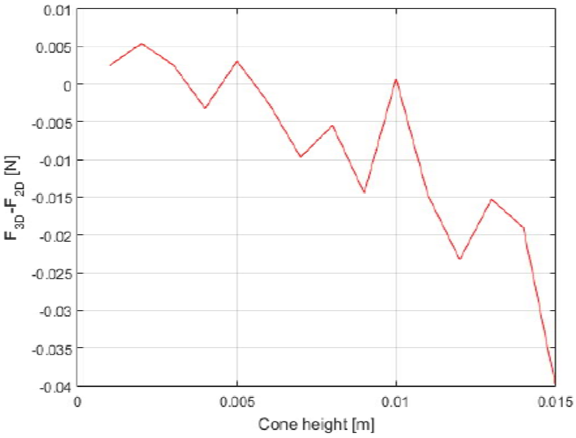

Fig. 5: Difference between computed force values.

Figure 6 presents the magnetix flux density computed in both cases for the cone height of 10mm and distance 1mm from the electromagnet surface. The difference of 0.008T in the maximal value can be observed.

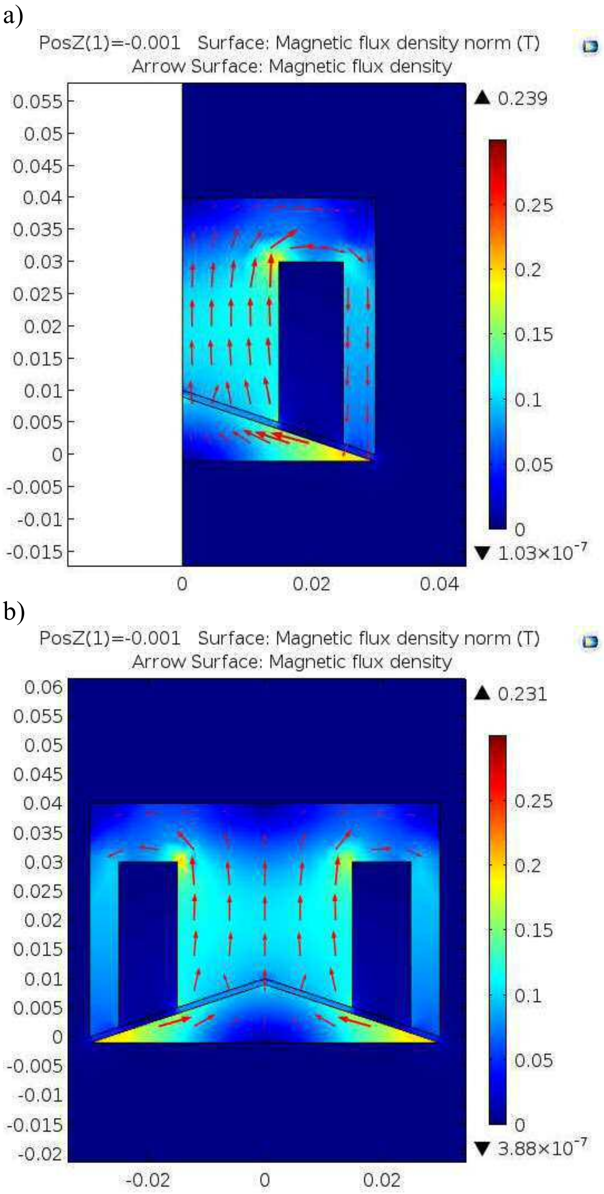

Fig. 6: Comparison of magnetic field for both models: a) 2D; b) 3D.

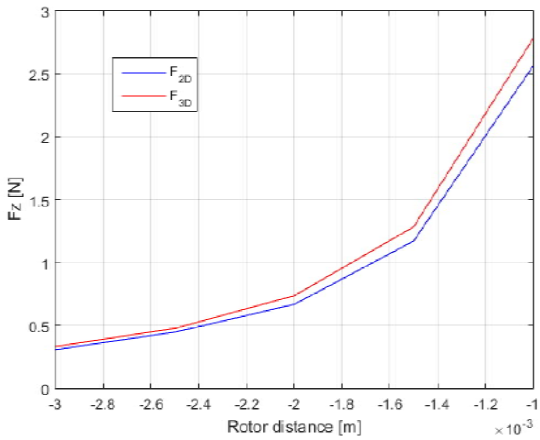

Fig. 7: Comparison of axial Fem for axial rotor displacement.

And finally, the 3D model is suitable to calculate all three components of the electromagnetic force, only. Therefore the tilt of the cone rotor of 1° around X direction was simulated and calculated for a variable distance from the electromagnet surface. A such simullation informs about forces requested forces to be generated by the radial magnetic bearing. The expected changes in the Y components are well visible (see Fig. 8), while X xomponent covers numerical errors.

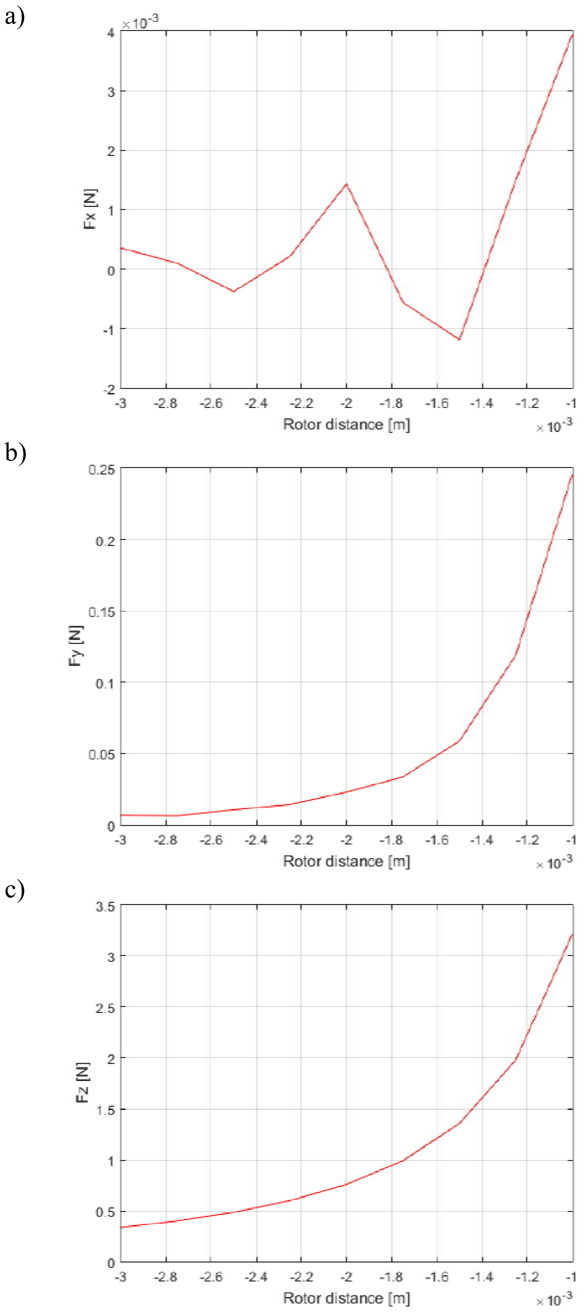

Fig. 8: Electromagnetic force components computed for tilted and displaced rotor.

4 Conclusions

The study on 2D and 3D models has shown that the for the axial operation the 2D model is satisfactory and allows to obtain proper results in a relatively short computational time. For the complex rotor-bearing analysis the 3D model is well suitable, although computational effort is huge. Moreover, the 3D model brings much more information and allows a complete study of the rotor-bearing system.

Please note that the source of main differences between comparable results is caused by the discretisation method (compare Fig. 4 and Fig. 7) as well in Tables 2 and 3.

The future research will cover the selection of appropriate variant with respect to the application and comparison with experimental test-rig manufactured on the basis on the designed conical electromagnet shape.

References

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