# Three-Axis Active Control Magnetic Bearing with Asymmetric Structure for High-Temperature Machines

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**Recently, magnetic bearings with a five-axis magnetic levitation system have been developed. However, the supporting forces of the magnetic bearings are lower than those of mechanical bearings. In order to solve these problems, this paper proposes a new three-axis active control magnetic bearing with an asymmetric structure for a canned motor. Our proposed magnetic bearing can generate a large suspension force in one axial direction due to the asymmetric structure, because its rotor is attracted only in one axial direction due to a negative pressure of the fluid. The performances of our proposed magnetic bearing are computed through 3-D finite element analysis.**

***Index Terms*—Magnetic bearings, magnetic levitation, electromagnet, finite element method**

## I. Introduction

MAGNETIC BEARINGS realize high-speed rotation, long life, low noise and dust-free operation because of their contactless and oil-less constitution [1]-[3]. Because of these advantages, the magnetic bearings are practically used in turbomachinery and high-speed rotating machines. In order to support the rotating shaft using magnetic bearings, a five-axis control (3 translational axes, and 2 rotating axes except a rotating axis of the shaft) is needed. Generally, the stiffness of the magnetic bearings is lower than that of mechanical bearings. Therefore the system tends to become large and the critical rotation speed also tends to decreases. In addition, a flat disk in the magnetic bearing which generates thrust forces causes a complicated manufacturing process and decrease the rotation speed limit. Recently, triaxial active control magnetic bearings have been proposed [4]-[7] in order to increase the critical rotation speed and remove the flat disk, however, their supporting forces are not high enough. The increases of the size and coil turns are effective strategies for the increase of the supporting forces.

In this paper, we propose a new three-axis active control magnetic bearing with an asymmetric structure for a canned motor whose rotor is attracted only in one axial direction due to a negative pressure of the fluid. Our proposed magnetic bearing can generate a large suspension force in one axial direction due to the asymmetric structure. The performances of our proposed magnetic bearing are computed through 3-D finite element analysis, and its effectiveness is verified.

## II. Structure and Operating Principle

### A. Basic Structure

The sectional view of the proposed three-axis magnetic bearing is shown in Fig. 1. This magnetic bearing consists of a radial stator, three thrust stators and a rotor. The radial stator is axially sandwiched by the thrust stators z1 and z2, and a non-magnetic material is inserted between the thrust stators z2 and z3. The radial stator with 8 electromagnetic poles is formed by laminated silicon steel sheets, and has 8 radial coils. 2 adjacent radial coils are wound in the opposite direction with each other and are connected in series. Therefore, the radial coils consist of 4 circuits: positive and negative coils (x1, x2) for X-axis, and positive and negative coils (y1, y2) for Y-axis as shown in Fig. 2 (a). The thrust coils z1 and z2 are connected in series. The rotor consists of a magnetic material and 2 non-magnetic materials (A, and B) are inserted as shown in Fig. 1 (b). The non-magnetic material A leads magnetic fluxes from the rotor to the radial stator as shown in Fig. 2 (b). The non-magnetic material B controls magnetic fluxes so that the thrust force due to the thrust stator z2 in the positive direction of Z axis is not generated.

### B. Operating Principle

The operating principle of our proposed magnetic bearing is shown in Fig. 2. A radial suspension force is generated by the magnetic flux due to the radial coils. Similarly, a positive Z-axis thrust force is generated by the magnetic flux due to the thrust coils z1 and z2. A negative Z-axis thrust force is generated by the magnetic flux due to the thrust coil z3.

## III. Computed Result by 3-D FEM

We conducted 3-D FEAs to evaluate the supporting force of the proposed three-axis magnetic bearing, where its specification is shown in Table I. For conducting 3-D FEAs, we used JMAG Designer 15.1, and made a mesh model with about one million elements. Fig. 3 shows the analysis model.

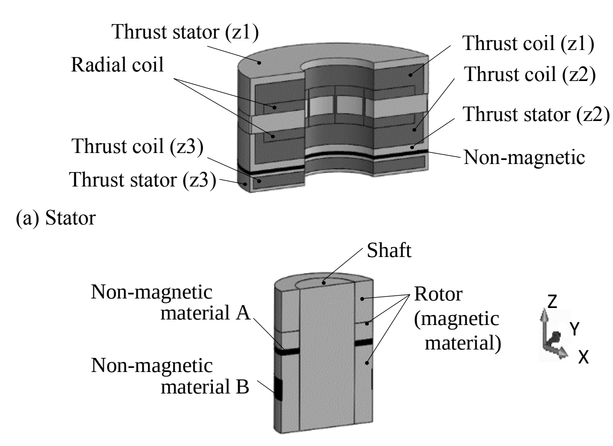
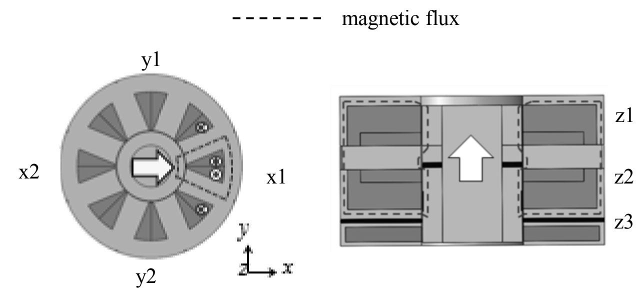



Fig. 1. New three-axis magnetic bearing with asymmetric structure.




(a) Radial force due to x1 coil

(b) Thrust force due to z1 and z2 coils.

Fig. 2. Operating principle.

Fig. 4 shows the computed suspension forces when the rotor position (displacement) and current density of the coils are changed. Fig. 4 (a) shows the computed positive Z-axis suspension force due to the thrust coils z1 and z2. As the displacement *z* increases, the suspension force decreases because of the decrease of the magnetic flux that contributes to a force generation in the axial edge of the rotor. Fig. 4 (b) shows the computed radial suspension force due to the radial coil x1. In this case, when the rotor moves in the positive X-axis, the radial air gap length decreases and the radial suspension force increases.

In all conditions, it is observed that the rate of the increase of the suspension forces decreases as the current density increases. This is because of magnetic saturations in the stator and the rotor.

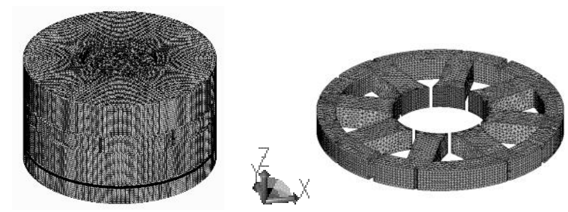
## IV. Conclusion

In this paper, we proposed a new three-axis magnetic bearing with an asymmetric structure for a canned motor to increase its thrust force. The performances of the proposed magnetic bearing were computed through 3-D FEA. The proposed magnetic bearing was able to generate large thrust forces in one axial direction and the effectiveness of the asymmetric structure was verified. In the final paper, the dynamic characteristics under control will be shown.

TABLE I

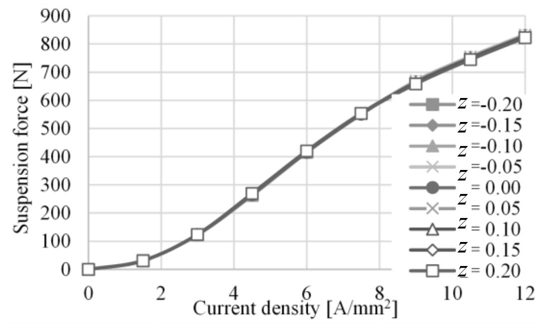
Analysis Specifications

| | | | |
|---|---|---|---|
| Dimension [mm] | Stator | Outer diameter | 130 |
| | | Inner diameter | 50.2 |
| | | Height | 75 |
| | Rotor | Outer diameter | 49.1 |
| | | Inner diameter | 29.5 |
| | | Height | 67.9 |
| | Radial air gap length | | 0.55 |

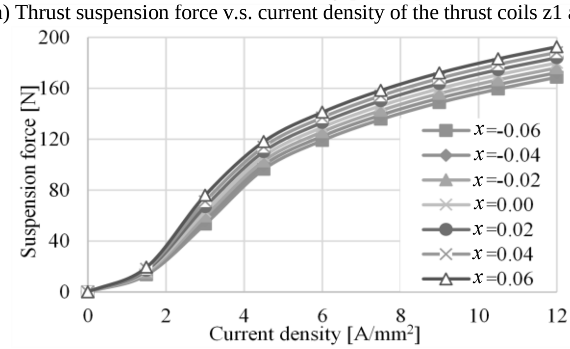



(a) Overview (b) Radial stator

Fig. 3. Analysis model.




(a) Thrust suspension force v.s. current density of the thrust coils z1 and z2.




(b) Radial suspension force v.s. current density of the radial coil.

Fig. 4. Static characteristics of the proposed magnetic bearing.

## References


[1] Gerhard Schweitzer, Eric H. Maslen, "Magnetic Bearings -Theory, Design, and Application to Rotating Machinery," Springer, 2009.

[2] A. Chiba, T. Fukao, O. Ichikawa, M. Oshima, M. Takemoto, and D. G. Dorrell, "Magnetic Bearings and Bearingless Drives," Elsevier, 2005.

[3] Takashi Saito, Toru Masuzawa, Naohisa Nakayama, "Development of a novel hybrid type magnetic bearing andapplication to micro centrifugal pumps for artificial hearts," The Society of Life Support Technology, Vol. 18, 2006.

[4] Kouji Sagawa, Eisaku Suzuki, Ryou Kondo, Youji Okada, "Development and Application of Parallel PM Type Hybrid Magnetic Bearing," Transactions of the JSME, vol. 73,2007

[5] Patrick T. McMullen, Co S. Huynh, Richard J. Hayes, "combination radial-axial magnetic bearing," Seventh International Symp. on Magnetic Bearings, 2000.

[6] Patrick T. McMullen, "magnetic bearing providing radial and axial load support for a shaft", USPatent5,514,924, May 7, 1996.

[7] Kouhei Tsuchida, Masatsugu Takemoto, Satoshi Ogasawara, "A Novel Structure of a 3-axisActive Control Type Magnetic Bearing With a Cylindrical Rotor", International Conference on Electrical Machines and Systems, 2010