Design and Analysis of an Electromagnet Biased Integrated Radial-Axial Magnetic Bearing

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Abstract

The theory for a new electromagnetically biased diskless combined radial and axial magnetic bearing is developed. A typical magnetic bearing system is composed of two radial magnetic bearings and an axial magnetic bearing. The axial magnetic bearing with a large axial disk usually limits rotor dynamic performance and makes assembling and disassembling difficult for maintenance work. This paper proposes a novel electromagnet biased integrated radial-axial magnetic bearing without axial disk. The axial magnetic bearing unit in this integrated magnetic bearing utilizes reluctance forces such that the axial disk can be removed from the bearing unit. The 4-pole homopolar type radial magnetic bearing unit is also designed and analyzed. 3-D flux analysis are also provided to illustrate the novel diskless integrated magnetic bearing.

1 Introduction

Active Magnetic bearings (AMB) are commonly used in high speed and high performance applications since they have advantages over rolling element bearings. In general AMB consists of a pair of radial magnetic bearings and an axial magnetic bearing. These three magnetic bearings placed along the rotor shown in Fig. 1 (a) may result in a long flexible rotor which decreases the critical speed. Conventional axial magnetic bearings consist of a solid axial disk sandwiched between a pair of facing axial bearing stators. In this axial bearing structure, assembling and disassembling for maintenance work become more difficult. The high tip speed of the solid axial disk also limits the maximum rotating speed due to the material stress limit.

In order to remedy these problems many researchers have attempted to develop AMBs with a compact and simple structure in which radial and axial magnetic bearing are integrated in one bearing unit. A permanent magnet biased integrated radial-axial magnetic bearing shown in Fig. 1 (b) was developed by McMullen et. al [1]. This integrated magnetic bearing utilizes permanent magnets to provide homopolar type bias flux to both radial poles and axial poles. However, this integrated radial-axial magnetic bearing also make assembling and disassembling difficult since it still require a small axial disk to generate axial Maxwell forces. An integrated radial-axial magnetic bearing with Lorentz force type axial actuator was developed by Kim and Lee [2]. This integrated radial-axial magnetic bearing utilizes Lorentz axial forces as well as Maxwell radial forces. The axial disk is removed from this bearing structure so that assembling and disassembling makes easy. However, there exists some flux coupling between the radial and axial bearing units, which results in stiffness coupling. The feed-forward control should be used to compensate for this coupling effects. A permanent magnet biased axial magnetic bearing without axial disk was developed by Hijikata et. al [3]. They used a cylindrical rotor core without the large axial disk to generate the reluctance force for the axial magnetic bearing.

A permanent magnet biased integrated radial-axial magnetic bearing shown in Fig. 1 (c) was proposed by Na [4]. The radial magnetic bearing unit in this integrated magnetic bearing utilizes conventional homopolar type radial magnetic bearing while the axial bearing unit utilizes reluctance forces so that the axial disk can be removed from the bearing unit. Figure 2 shows the cut view of the integrated magnetic bearing . The 4 permanent magnets, sandwitched between the axial stator and the radial stator, provide the bias flux to both radial poles and axial stator. The radial control coils are wound in a manner such that control fluxes can flow through the opposing pole pairs. The axial coils also provide the axial control fluxes to the non-uniform axial gaps of the axial stators. The highly magnetized left axial stator and left rotor iron produces reluctance forces.

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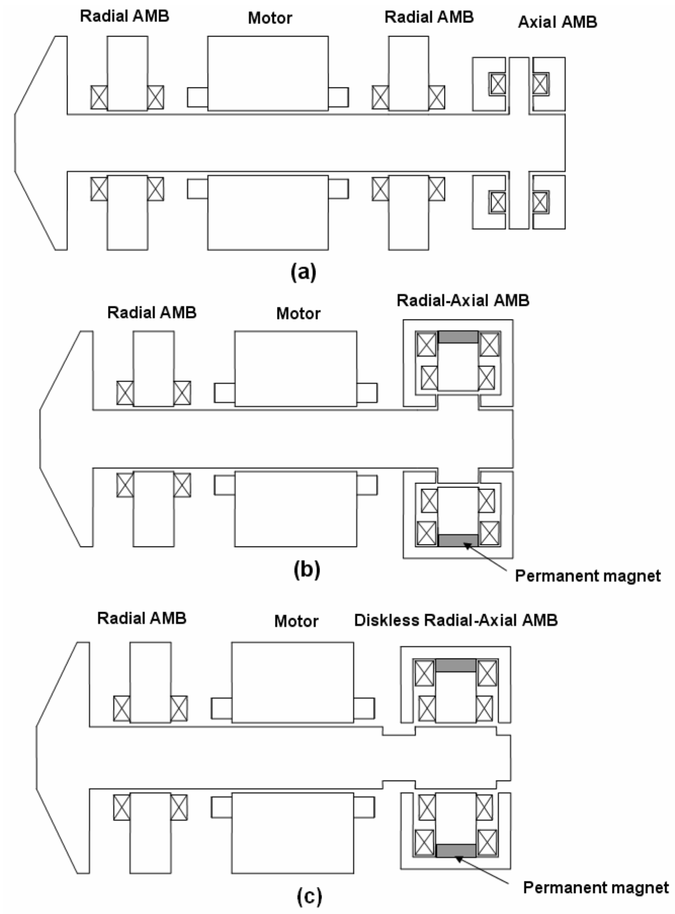


Figure 1: Magnetic bearing systems. (a) conventional AMB. (b) Radial-axial AMB (McMullen et al [1]). (c) Permanent Magnet Biased Diskless Radial-axial AMB (Na [4])

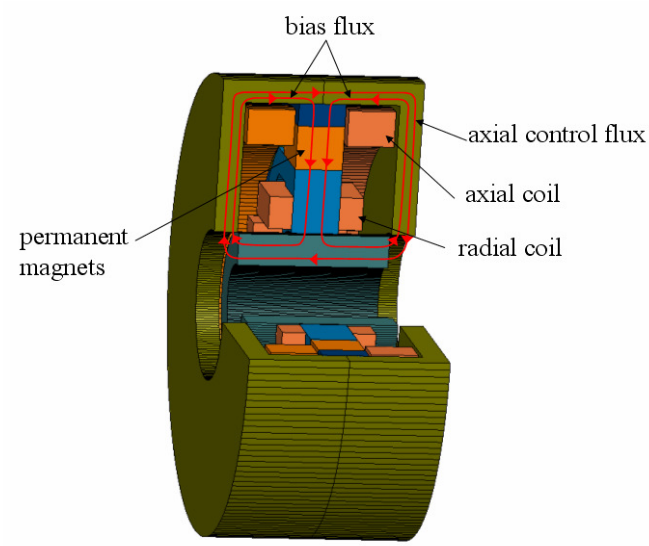


Figure 2: Cut view of the permanent magnet integrated radial-axial magnetic bearing (Na [4])

This paper extends the works of the integrated radial-axial magnetic bearing in Na [4]. An electromagnet biased integrated radial- axial magnetic bearings is proposed in this paper. The principle of this magnetic bearing is explained to show the feasibility of this novel magnetic bearing.

2 Principle of a New Integrated Magnetic Bearing

Schematic of a new electromagnet biased integrated radial-axial magnetic bearing is shown in Fig. 3. The integrated magnetic bearing shown in Fig. 1 (c) is modified such that permanent magnets are removed from the bearing unit.

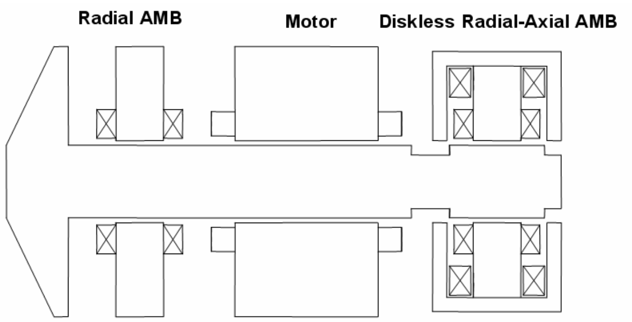
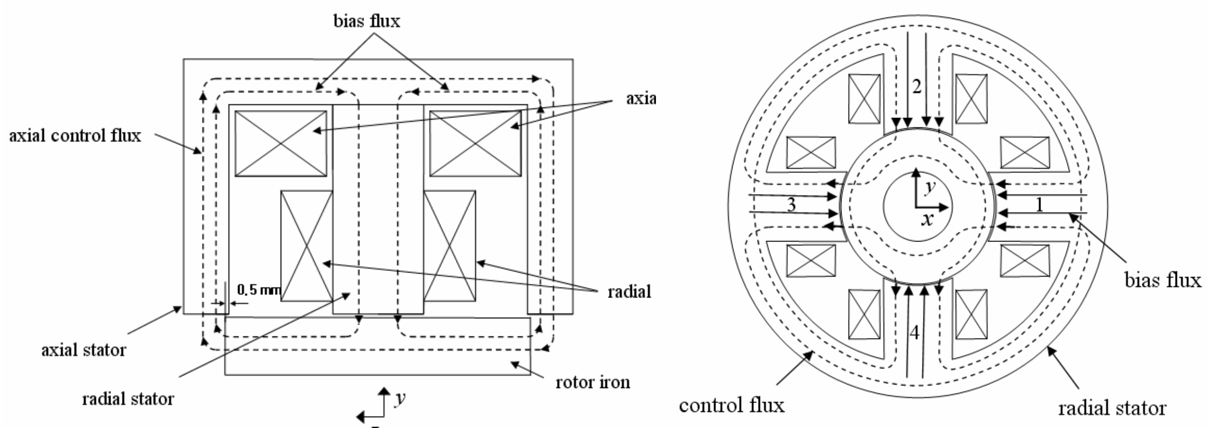


Figure 3: Electromagnet biased diskless radial-axial AMB

The detailed schematic drawing of the electromagnet biased integrated radial-axial magnetic bearing is shown in Fig. 4. This magnetic bearing consists of a C-core axial stator assembled and a radial stator iron. The rotor iron is extended up to the end of inner ring of the axial stator. Two axial coils are independently controlled and located between the axial stator and the radial stator to supply bias flux through the radial stator, the rotor iron, and the axial stator. The unique feature of this magnetic bearing unit is to share the same bias flux through the radial air gaps and the non-uniform axial air gaps. The independently controlled axial coils also provide axial control flux through the axial stator and the rotor iron such that C-core axial control flux can be preserved. The axial control flux is added to the bias flux at the left side of the axial stator while it is subtracted from the bias flux at the right side of the axial stator. This superimposed magnetic flux results in the axial reluctance force on the rotor iron.



axial magnetic bearing unit radial magnetic bearing unit

Figure 4: Schematic of the electromagnet biased integrated radial-axial magnetic bearing

Figure 5 shows the cut view of the electromagnet biased integrated axial-radial magnetic bearing.

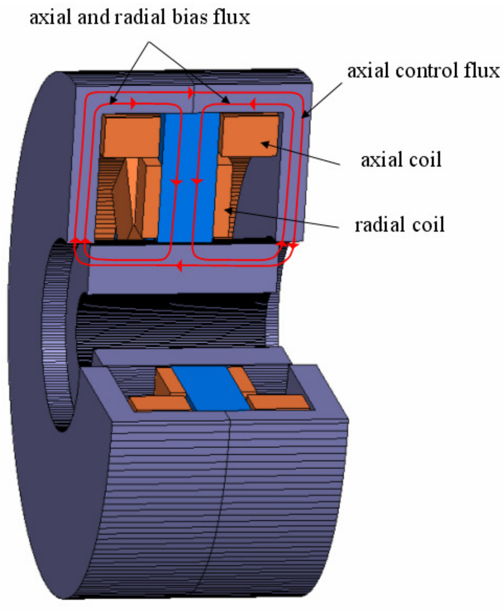


Figure 5: Cut View of the new integrated radial-axial magnetic bearing

3 3-D Finite Element Magnetic Analysis

The following examples illustrate the 3-D magnetic flux analysis and the resulting magnetic forces for the designed integrated radial-axial magnetic bearing. The designed integrated magnetic bearing has bearing parameters, pole face area a_0 (0.00028 m^2), nominal radial air gap g_0 (0.0005 m), radial coil turn n (70 turns), and axial coil turn n_a (200 turns). The B-H curve of the axial stator, radial stator, and rotor iron is shown in Fig. 6.

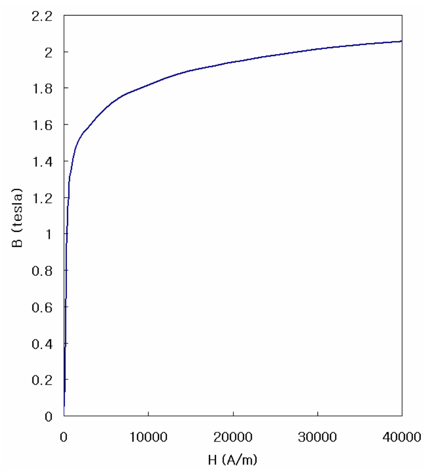
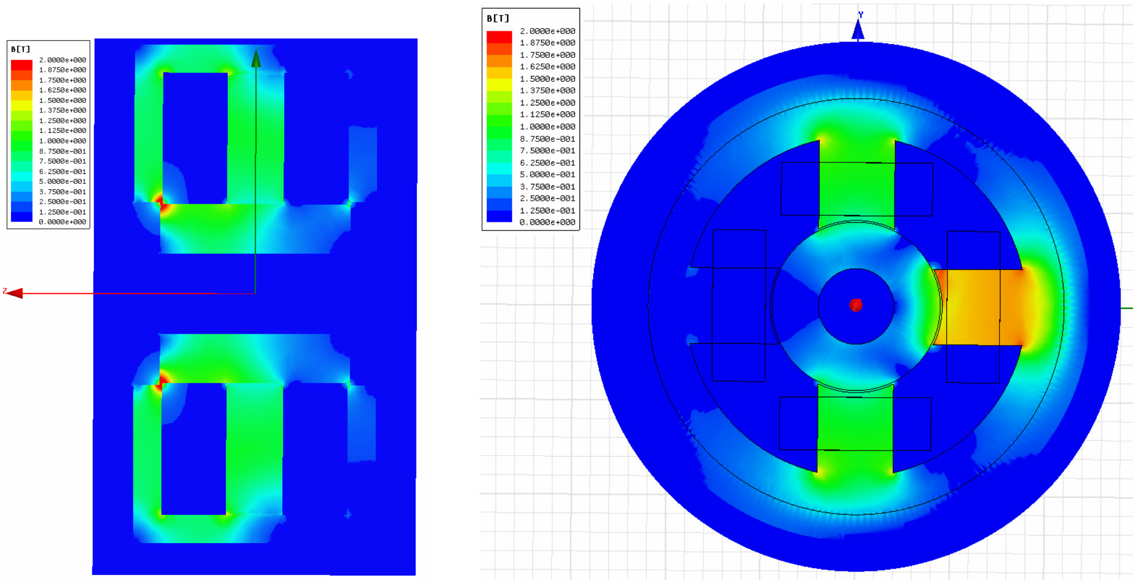


Figure 6: B-H curve of the magnetic bearing material

A commercial magnetic field software (MAXWELL3D) is used to model the integrated magnetic bearing. The radial and axial magnetic forces are calculated using 3-D finite element model. Firstly, the maximum axial magnetic force is calculated for the integrated magnetic bearing using 3-D finite element method. Figure 7 (a) shows the flux density distribution for the axial magnetic bearing unit when $i_{z1} = 7A$,and $i_{z2} = 0A$ are applied to the axial coils and no radial control currents are applied. It is evident that the flux density of the left side of the axial stator is maximized while the flux density of the right side of the axial stator is minimized. The maximum axial force of 186 N is generated. Secondly, the maximum radial magnetic force is calculated for the integrated magnetic bearing. Figure 7 (b) shows the flux density distribution for the radial magnetic bearing unit when currents, $i_{cx} = 4A$, $i_{cy} = 0$, $i_{z1} = 3.5A$, $i_{z2} = 3.5A$ are applied. The flux density in the air gap of radial pole 1 is maximized while the flux density in the air gap of radial pole 3 is minimized. Only bias fluxes are flown through radial pole 2 and radial pole 4. The maximum radial force of 168 N is then generated.



(a) (b)

Figure 7: Flux density distribution for magnetic bearing unit

Current dependent magnetic forces are calculated for both radial and axial bearing units at the rotor center position as shown in Fig. 8 when radial and axial control current is increased. It is interesting to see that both radial and axial current forces are increased linearly. Position dependent magnetic forces are also calculated for both radial and axial bearing units as shown in Fig. 9 when radial and axial displacements of the rotor iron are increased. It is notable that the axial position forces are negligibly small. No axial position forces may help to increase the axial load capacity as well as increase of the axial control stability margin.

4 Conclusion

A new electromagnet biased integrated radial-axial magnetic bearing is developed. The principle of this magnetic bearing is explained to show the feasibility of this novel magnetic bearing. The axial disk is removed from the design such that assembling and disassembling makes easy. 3-D finite element analysis is provided to calculate the fluxes and magnetic forces. This diskless axial bearing unit may be helpful in some applications with frequent maintenance work

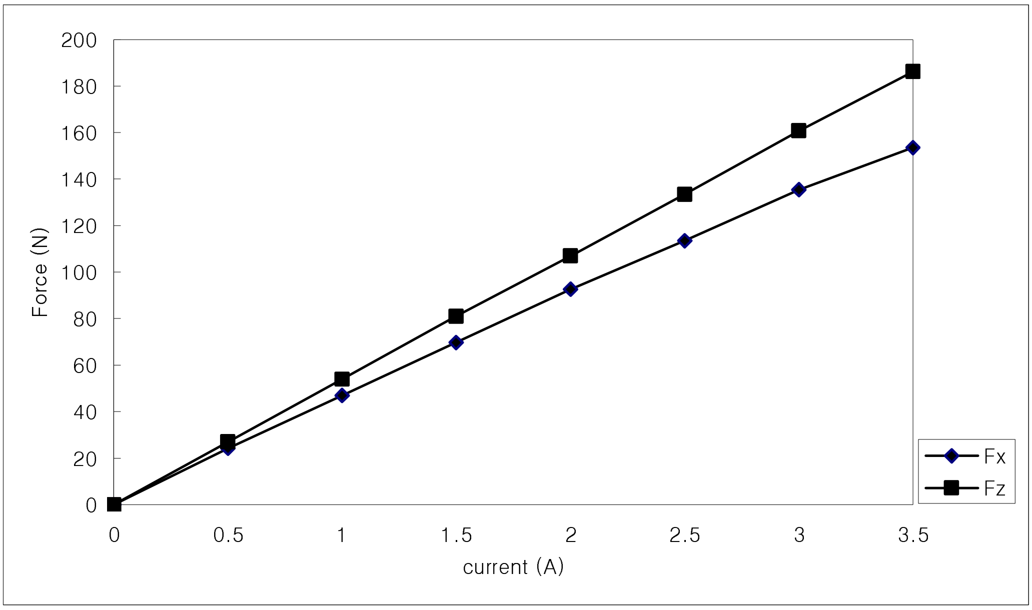


Figure 8: Current forces with respect to the current

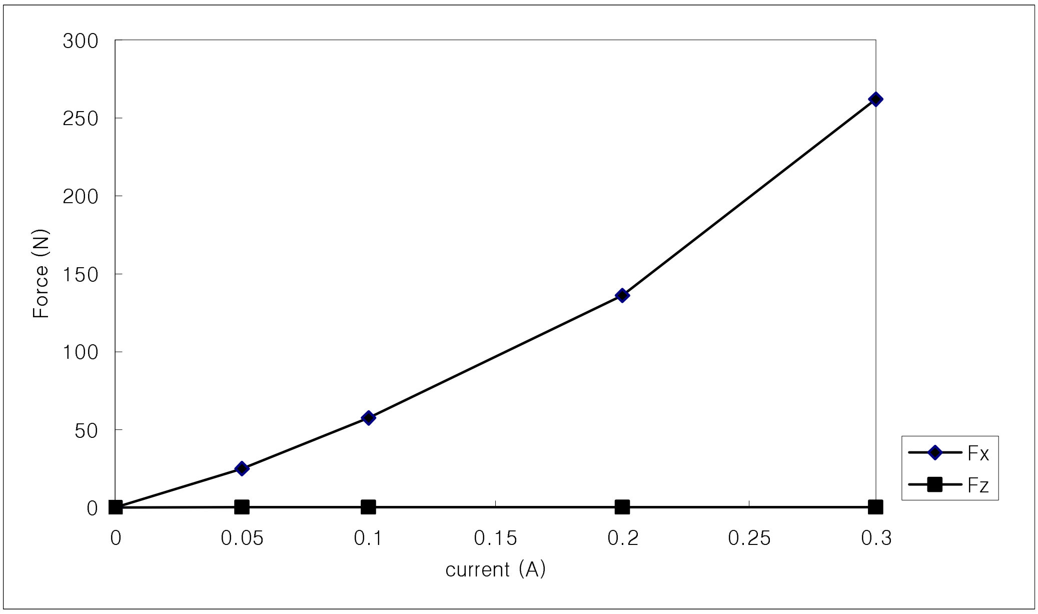


Figure 9: Position forces with respect to the current

References

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