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스테이터 구조에 의한 마그네틱 베어링의 전자장해석

(Electromagnetic Field Analysis of Magnetic Bearing due to Stator Structure)

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요 약

본 연구에서는 스테이터 구조에 의한 마그네틱 베어링의 전자장해석을 수행하였으며 AMB 시스템의 설계 기준을 얻기 위하여 3가지 방식의 구조에서 전기적 특성을 구하였다. FEM 기법을 이용하여 AMB의 3가지 방식을 시뮬레이션한 결과, 1, 2, 그리고 3번 방식은 N극에서 S극으로 많은 자속선 벡터가 이동하는 것으로 나타났으며, 이 자속선들은 로타로 전달되고 있다. 이 선들은 로타가 회전하는 것을 도와주고 있다. 따라서, 이러한 전기적 특성 자료는 마그네틱 베어링 설계자료로 이용되고, 설계 기준을 만드는데 도움이 될 것이다.

Abstract

In this study, it carried out Electromagnetic Field Analysis of Magnetic Bearing due to stator structure and it got the electrical characteristics of 3 structure types of AMB(Active magnetic bearing) systems to get optimal design criteria. The results of simulation in three types of AMB, using FEM method, type 1, 2, and 3 had many paths to move magnetic flux vectors from N pole to S pole and magnetic flux lines are transferred to rotor as a shaft. The paths help to rotate the rotors. So, their data of electrical properties carry out design of magnetic bearing system and the data help to make design criteria.

Keywords : 마그네틱, 베어링, 스테이터, 전자장

Ⅰ. Introduction

Active magnetic bearing(AMB) systems are well known in the field of mechanical and electrical engineering. These systems have a stationary component known as a stator and a rotating or translating component known as a rotor and there is one such pair combination in the motor frame. The stator that is one is comprised of multiple pole pieces, each of which has a coil wrapped around it to generate a magnetic field that passes between the stator and the rotor. The current through the coils is able to provide motor shaft displacement and may be adjusted by the control system by measurement and feedback[1~3].

It is important to establish an ideal system for motor control. Especially, it is essential to suspend and control angular orientation, position, and rotational speed of an object with minimal or without any physical contact to eliminate wear or frictional effect. This kind of a suspension and control system would have very important use and application in high-speed rotating devices[3].

Conventional mechanical bearings which is used well

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commonly have limitations of limited lifetime and maintenance, needs for lubrication, and performance limitations due to nonlinear frictional characteristics. Hydrodynamic bearings provide a dramatic improvement over such mechanical bearings, but present problems in terms of the needs to maintain the fluid within the bearing gap. Therefore, magnetic bearings have been considered as a solution to these problems.

Magnetic bearing technology is widely used in electrical rotate machine. That is a collection of electromagnetics used to suspend a machine shaft via feedback control. It is offered many advantages rather than conventional bearings such as lower rotating losses and higher speed by noncontact motion control, external lubrication, no mechanical maintenance, and longer life[1~2].

In this study, it designed 3 types of magnetic bearing system due to stator structure and it analyzed the electrical characteristics to get optimal design criteria.

Ⅱ. Design of Three types in Magnetic Bearing System

There are a number of prior art magnetic bearings, one of them shown in Figure 1. In Figure 1 the principle of the radial magnetic bearing system has been used. This conventional magnetic bearing consists of a stator element and rotor element. The stator element is fixed in a housing, not shown in this figure, and the rotor is fixed in the shaft respectively. The Figure shows a rotor with NSNS type structure and a stator section. The rotor and their shaft assembly are rotatable or axially translatable relative to the stator and their housing assembly[4].

The poles are arranged in pairs, which each pair occupying a quadrant of the bearing. Each pole has a coil wrapped around stator teeth. Each coil is also arranged in pairs and generates magnetic flux by a current feed. Flux of each coil follows only one path,

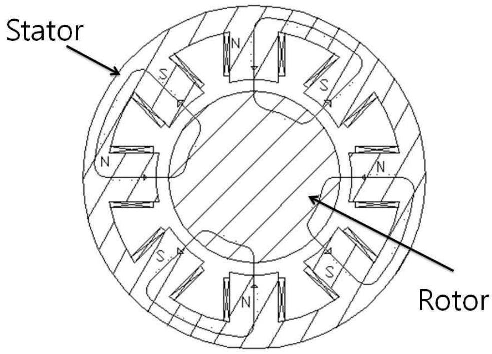
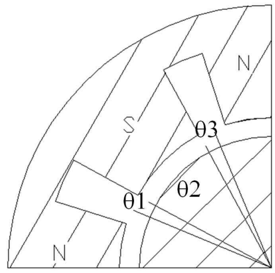
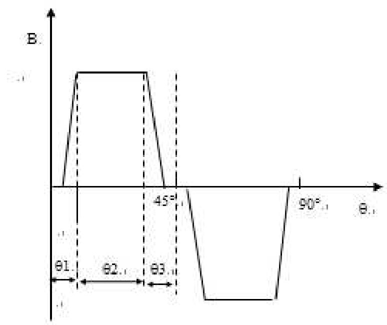


그림 1. 1번 방식의 보기
Fig. 1. View of type 1.



(a)



(b)

그림 2. 1번 방식의 확대도
Fig. 2. Enlarged view of type 1.

the flux in staor is included in the top quadrant of the bearing and this flux traverses across air gaps. The flux provides a net outward radial force on the rotor. The flux generates a force proportional to the area of the pole, and in the direction from the center of the rotor to the center of the pole. The resultant tangential force is zero due to symmetry and cancellation. No net radial force is generated on the rotor near the coil slot, nor by the horizontal poles. The amount of flux in any path like figure 1 is proportional to the magnetomotive force driving the flux through the path and inversely proportional to the reluctance of the path.

The magnetic flux density distribution has been approximated to be sinusoidal and their periodic function has a close resemblance to a rectangular wave or a trapezoidal wave generally. The magnetic flux distribution along the circumference (angle of rotation) of the electromagnet is shown in Figure 2. The magnetic flux distribution in the interval of 0 to 90 degrees is analyzed. It is theoretically known that the density is almost 0 in the interval of the slot width q_1 or q_2 as shown in Figure 2(a). The magnetic density waveform somewhat loses its edges due to the influence of leakage flux, the chamfer angle of the rotor inner surface edge portion of the electromagnet, and other factors.

Figure 3 shows type 2(Extended toes of stator) of magnetic bearing system. The magnetic bearing system also consists of a stator element and a rotor element. The structure of stator and rotor is very similar to the previously described magnetic bearing system. Four north poles and four south poles of rotor are alternately arranged in the circumferential direction. In this case, with regard to one magnetic pole, there is a perfect circle portion, in which the gap between the rotor and each magnetic pole is uniform. The magnetic flux density distribution of the electromagnet is shown in Figure 4(b). With regard to the shape of electromagnet of Figure 4(a), the slot width is set to be very small, which is smaller than the shape of the radial bearing for normal use similar

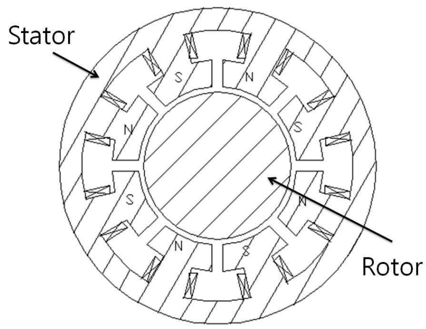
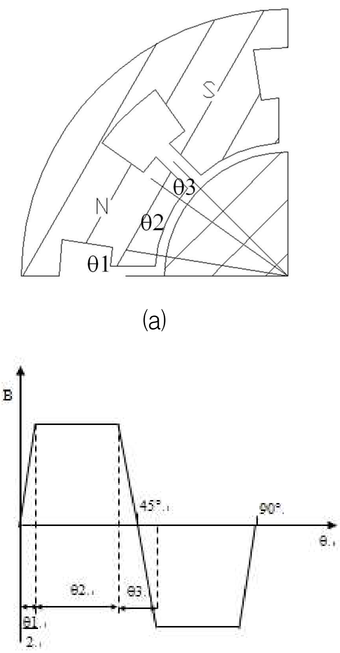


그림 3. 2번 방식의 보기
Fig. 3. View of type 2.



(a)

(b)

그림 4. 2번 방식의 확대도
Fig. 4. Enlarged view of type 2.

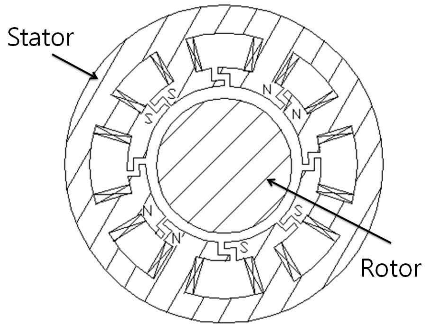
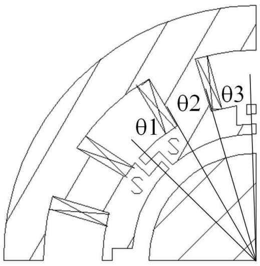


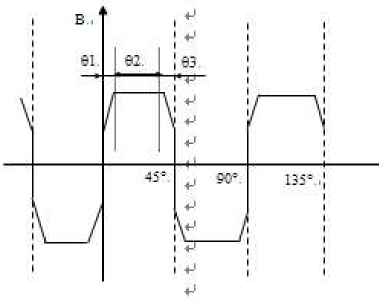
그림 5. 3번 방식의 보기
Fig. 5. View of the structure 3.

to the aforementioned magnetic bearing system. So it is known that magnetic flux density distribution of the electromagnet of Figure 3 are dotted in Figure 4(b).

Figure 5 shows type 3(zigzag style of stator) of magnetic bearing system. The bearing consists of a stator element and rotor element like conventional type. The stator element is fixed in a housing, not shown in this figure, and the rotor is fixed in the shaft. A rotor with NNSS type structure and a stator section is shown. The rotor and the shaft assembly are rotatable or axially translatable relative to the stator and their housing assembly. As shown in



(a)



(b)

그림 6. 3번 방식의 확대도
Fig. 6. Enlarged view of type 2.

Figure 5 it can be realized that the stator structure is different from other bearings. Each stator has the zig-zag style gap between pole and pole of stator and the magnetic flux due to each stator are superposed. The reason for this design is to avoid a magnetic flux density distribution of zero approximately. If magnetic flux density distribution is zero, levitation of the shaft may not be fixed instantaneously. So to avoid their condition we designed new stator. Figure 6(a) is an enlarged view of the electromagnet of Figure 5, q_1, q_2, and q_3 of Figure 6(a) are similar to general motors, but the force of q_1 and q_3 in this present invention is different than other motors. The zig-zag style gap between a pole and a pole are stacked up with each other and magnetic flux density distribution are flowed from N pole to S pole continuously.

Ⅲ. Computer Simulation

It performed computer simulation to three types(1, 2, and 3) for electrical analysing. To simulate it can be used finite element method and the method provides a greater flexibility to model complex geometries than finite difference and finite volume methods do. It is widely used in solving structural, mechanical, heat transfer, and fluid dynamics problems as well as problems of other disciplines. So, it can be decided to analysis each types of AMB.

Ⅳ. Results and discussion

The simulation results based on the electrical effect, which are carried out by using derived finite element method. All types are same conditions (material, poles, voltage, current, size, and air gab size), but there are just different from structure of stator. First, it applied NI(wound and current) of 100 to stator coils and we got different results from each types.

In case of type 1, in figure 7, there are many paths to move magnetic flux vectors from N pole to S pole and magnetic flux lines are transferred to rotor as a shaft. The paths help to rotate the rotors.

In case of type 2, in figure 8, also there are many paths to move magnetic flux vectors, but their almost vectors of magnetic flux are not move to rotor because

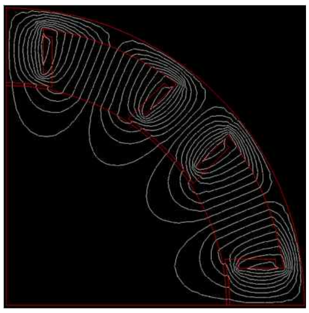


그림 7. 1번 방식의 자속선
Fig. 7. Flux lines of type 1.

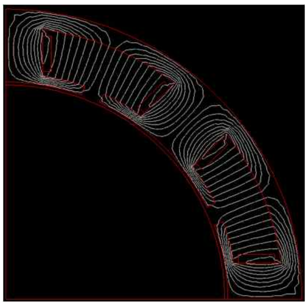


그림 8. 2번 방식의 자속선
Fig. 8. Flux lines of type 2.

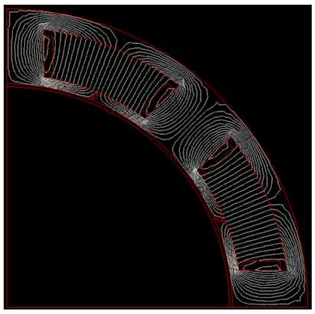
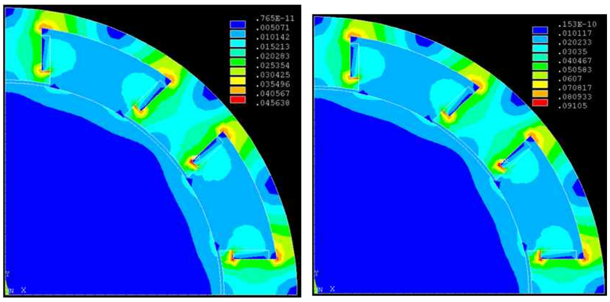
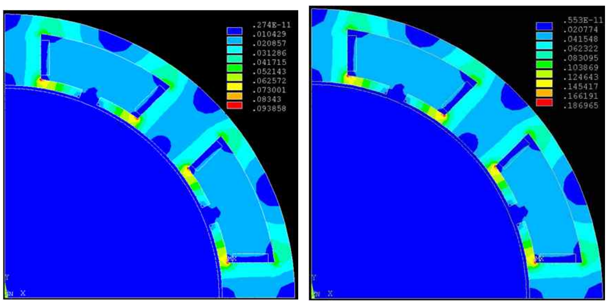


그림 9. 3번 방식의 자속선
Fig. 9. Flux lines of type 3.



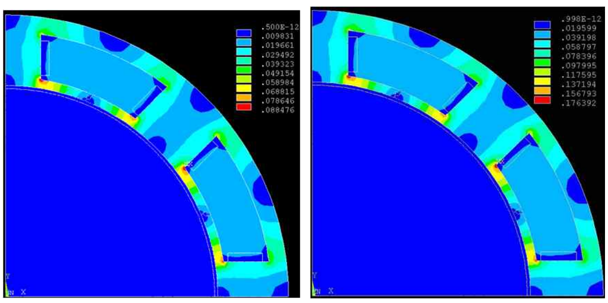
(a) 100[A] (b) 200[A]

그림 10. 1번 방식의 자속분포
Fig. 10. Flux Distributions of type 1.



(a) 100[A] (b) 200[A]

그림 11. 2번 방식의 자속분포
Fig. 11. Flux Distributions of type 2.



(a) 100[A] (b) 200[A]

그림 12. 3번 방식의 자속분포
Fig. 12. Flux Distributions of type 3.

of stator′s lengths. So, the paths can not help to rotate the rotors.

In case of type 3, in figure 9, also there are many paths to move magnetic flux vectors, but the paths are so small by contrast with type 1 and 2. Their almost vectors of magnetic flux are not move to rotor because of stator′s lengths and zigzag style. So, the paths can not help to rotate the rotors.

The reason of difference of electrical properties are their different structures(type 1, 2, and 3) and gab′s lengths of each poles, if the gab is so wide, magnetic flux lines move to another pole. If the gab is so narrow because of long length, magnetic flux lines can not go to another pole very well. So, the structure of type 1 is common and conventional structure and it has good electrical properties rather than type 2 and 3.

But, in figure 10 to 12, it applied NI(wound and current) of 100 and 200[A] to stator coils and it got different Flux Distributions results from each types. It′s Flux Distributions are large at type 2. That is reason of the structure of extended toes in stator.

Ⅴ. Conclusion

In this study, it analyzed Electromagnetic Field Analysis of Magnetic Bearing due to Stator Structure and it got the electrical characteristics of 3 types of AMB(Active magnetic bearing) systems to get optimal design criteria.

The results of simulation in three types of AMB, using FEM method, type 1, 2, and 3 had many paths to move magnetic flux vectors from N pole to S pole and magnetic flux lines are transferred to rotor as a shaft. The paths help to rotate the rotors. But, the structure of type 1 is common and conventional structure and it has good electrical properties rather than type 2 and 3. Also, it′s Flux Distributions are large at type 2 That is reason of the structure of Extended toes in stator. So, their data of electrical properties carry out design of magnetic bearing system and the data help to make design criteria.

Reference

[1] Jong-Moon Kim and Young-Kiu Choi, "A Design and Control of an Active Magnetic Bearing System",KIEE Trans. Vol 53B, No. 2, p.82-89, Feb. 2004.

[2] Chang-Hwa Kim, .Byung-gun Jung, and Joo-Ho Yang,"A Study on the Robust Control of Horizontal-Shaft Magnetic Bearing System Considering Perturbation", Journal of the Korean Society of Marine Engineering, Vol. 734, No 1., pp. 92~101, 2010.

[3] Korea Electrotechnology Research Institute, "Development of a Horizontal High-speed Active Magnetic Bearing System", 1996.

[4] US Patent, " Magnetic Bearing", US 6194800B1, 2001.

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