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3차원 유한요소법을 이용한 축방향 자속형 브러시리스 DC 전동기 최적 설계

(Optimal Design of Axial Type Brushless DC Motor Using 3-D FEM)

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요 약

본 연구에서는 희토류 자석편을 이용한 이중 회전자를 갖는 축방향 자속형 브러시리스 DC 전동기를 설계한다. 이러한 종류의 전동기는 반경방향 자속형에 비해 축방향 길이가 짧고 조립이 용이한 장점이 있다. 충분한 토크를 얻기 위해서 NdFeB 자석이 이용되며 생산 비용을 고려하여 자석은 세그먼트로 만들어 진다. 이 전동기를 설계하기 위해 자기 등가회로 모델이 이용되었고, 정확한 파라미터를 얻기 위해 3차원 유한요소법을 이용하여 공극 자속밀도를 구하였다. 최적화된 설계 변수들은 유전 알고리즘을 이용하여 구하였다. 시뮬레이션결과로부터 자석에 따른 설계의 지침과 타당성을 확인하였다.

Abstract

Abstract - In this paper, an axial type brushless DC motor which has double rotors using rare-earth magnet pieces is designed. This kind of motor has shorter axial length and is easier to assemble than the radial type motors. To get enough torque, NdFeB magnet is used and for the cost of production, the magnets are segmented to rectangle or disk shape. To design this motor, a equivalent circuit is adopted and the air-gap density is calculated using 3D finite element method to get exact parameters. The design variables are optimized with genetic algorithm. From the results of the simulations, the reference of the axial type BLDC motors can be obtained.

Key Words : Optimal design, Axial BLDC motor, Genetic Algorithm, 3D FEM

1. Introduction

Axial type brushless DC motors are widely used to video cameras, VCR, DVD etc. which need small volume and especially short axial length[1,2]. The structure of axial type brushless DC motor consists of rotor and stator which usually have

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donut type permanent magnet and magnetic wires located under the magnet. Thin steel plates cover the magnet and coils outsides to make the flux paths. One merit of these type motors is not to have cogging torque[2] because it does not use magnetic cores. The other merit is that this motor can be relatively thin because the thin magnet and coils are parallel. However, the effective air-gap is large because these motors do not have magnetic cores and it makes difficult to make the air-gap flux density high. The solution of this problem is to use rare-earth magnet or large volume of the ferrite magnet. Single block rare-earth magnet, or doughnut ring magnet is too expensive and ferrite magnet becomes to have large volume[3] to make it have enough flux.

In this study, 100[W] output axial double rotor type brushless DC motor is designed. Small pieces rare-earth permanent magnet are used to get high air-gap flux density and to make the production cost to be low. The used rare-earth magnet is NdFeB. While the single block doughnut type magnet can not be applied to produce these kind of motors for its high price, the small pieces of magnets are much cheaper than ring magnet. Another advantage of this type is that there is no core loss because the magnet yokes rotate with the magnets so that there is no alternating flux in the cores. Another special feature of this motor is that it has double rotors to enhance the stability of rotation and torque. The important parameter in calculating the motor characteristics is the flux density in the air-gap. The leakage factor is evaluated using 3-D finite element method to calculate the exact torque and other characteristics with the equivalent circuit. To optimize this motor whose object function is efficiency, the genetic algorithm is used[4,5]. By comparing the simulation results with the experimental ones, good agreements are obtained. This motor is applied to the fan motor of which speed needs to be controlled like air conditioners and makes it have good performances.

2. Motor Structure

Fig. 1 shows the cutting face of the double rotor type axial brushless DC motor. In the figure, the upper and lower yokes where the magnets are attached are included in the rotor, therefore DC flux flows in the rotor yokes and there are no core losses. As we can see in the figure, the rotor has symmetric structure centered with coils, and the stator does not have iron core so that there is no cogging torque. The coils in the middle part which becomes stator are fixed by molding. The thin plate under the coils is PCB plate for wire connection and its thickness is within 0.4[mm].

Fig. 2 shows the half structure of the rotors in the case of containing 12 poles. In the figure, the magnets have disk or rectangular shape to reduce the motor cost.

Although the characteristics for donut shape are a little better than those for these shapes, it is almost impossible to make a donut shape magnet with rare-earth magnet because its price of making the magnet 1 bulk block becomes extremely expensive.

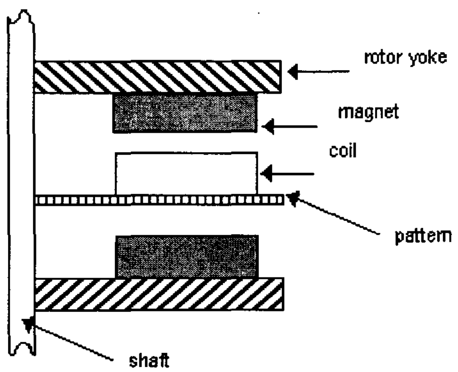

Fig.1. Structure of double rotor type axial motor

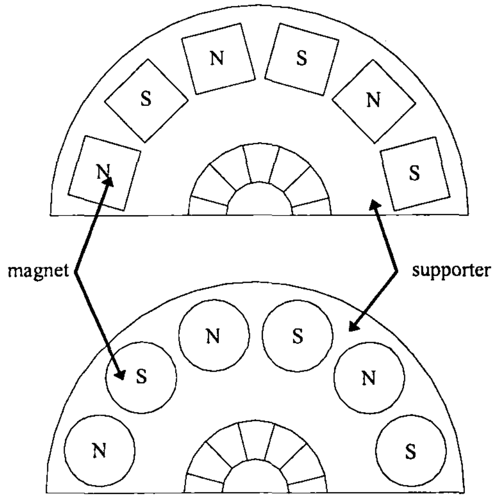

Fig. 2. Rotor part(for 12 poles)

Because the magnets are segmented, the surface area also becomes smaller than that of donut magnet and the flux becomes reduced. Therefore the effective air-gap flux density should be calculated exactly and we could get the exact value using 3D FEM. From this result, the leakage factor is calculated.

As we can see in the figure 1 and 2, the motor structure is very simple. There is stator part which molds the stator coils and PCB pattern for electric wiring and it is made just 1 block. The second part is rotor and the segmented magnets are fixed by bonding them to the iron yoke. Iron yokes are also molded by plasticization. These two parts are just assembled by inserting them in the shaft. For the yokes are parts of the rotor, there are no core losses and no axial magnetic force which becomes the load to the bearing in the case of single rotor type brushless motor.

3. Genetic Algorithm and Efficiency Optimization

Genetic algorithm(GA)[4,5] is a optimization algorithm based on the principle of survival of fittest and natural selection which is the natural evolution law made by Darwin. GA uses binary strings rather than real values of design variables. These kinds of strings have discrete characteristics and are efficient for the mixed optimization problem including integers or discrete design variables. Because GA is also a direct searching method which uses only the object function and constraints and does not need the differential values or other information, it is appropriate for rotor design which is complex structure and has various environments. GA is subject to modify the program cause from the variance of basic model.

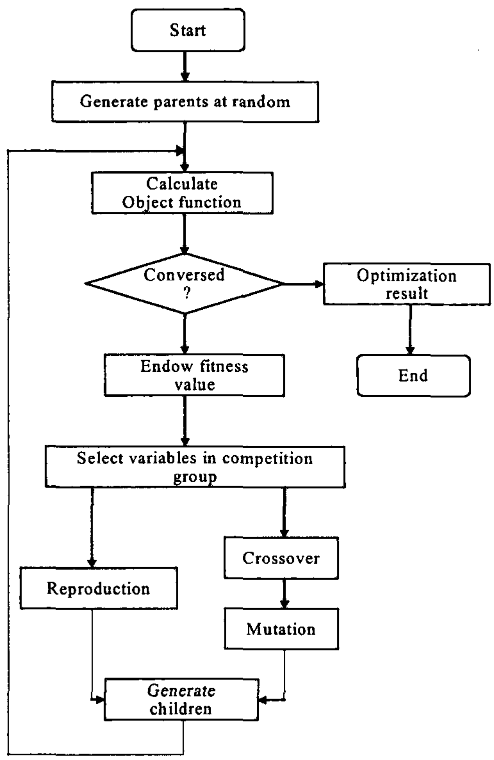

Fig. 3. Flow chart of GA

In this study, the object function is the motor efficiency. The design variables are number of turn of the coil, coil thickness, coil width and magnet thickness. The magnet area is dependent on the motor diameter. Fig. 3 shows the flowchart for the GA.

4. Simulation and Results

To get the air-gap flux density, the motor is analyzed by 3D finite element method. The used package is Maxwell 3D. Fig. 4 shows the rotor part diagram of the motor which has 16 magnet poles. Fig. 5 shows the flux density for a cutting plane of the motor. From these results, the flux density in the air-gap can be acquired and the average air-gap flux density can be calculated.

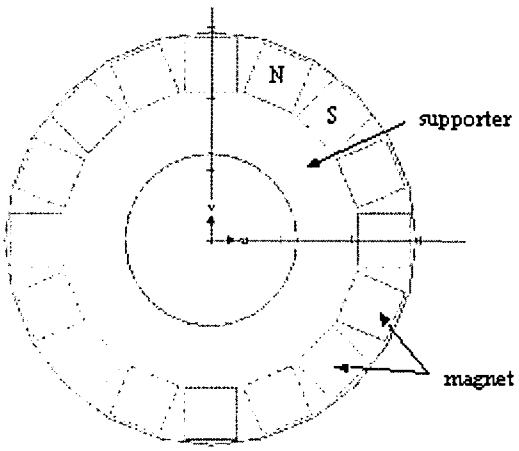

Fig. 4. Rotor with magnet

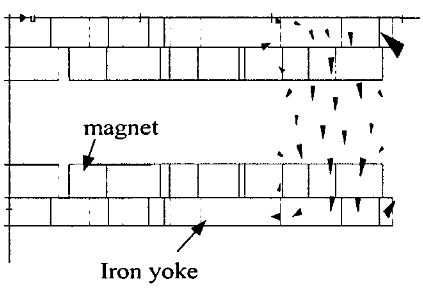

Fig. 5. Flux Density Distribution per half pole

Fig. 6 shows the 3 dimensional air gap flux density distribution of the one pole of the rotor. As we can see, the flux density under the magnet is not flat and it varies according to magnet and machine structure. For the optimization using GA, we used equivalent circuit and it needs the leakage factor to consider the linkage between the flux and the stator coil. Because the flux distribution is known by the 3D FEA, the average flux density can be calculated and the leakage factor is derived.

Fig. 7 shows the distribution of the flux density along the circumferential direction. The magnitude of the flux density of the doughnut or ring type magnet is a little larger than the that of rectangular piece magnet because the donut magnet has larger effective surface than the rectangular segmented magnet has. However the rectangular magnet is adopted for this study because the magnet is much cheaper that the ring type magnet and difference of flux density between the donut magnet is very small which is shown in Fig. 7.

Table 1 shows the designed results. The value of the leakage factor in the table is not so different with ring type motor. The efficiency of the assembled motor is over 68[%]. To increase the efficiency, larger volume of the magnet is needed and the efficiency of wide magnet is better than that of thick magnet if the volume is constant.

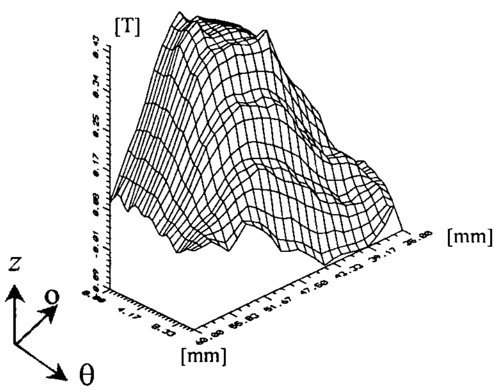

Fig. 6. Distribution of flux density in the airgap

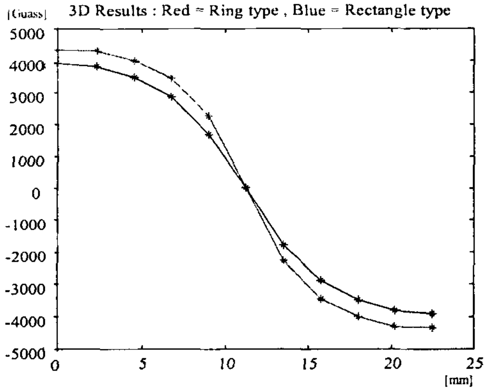

Fig. 7. The air-gap flux densities

Table 1. Motor Specification

Coil height	7.0[mm]	Coil width	5.8[mm]
No. of turn	660	Leakage factor	1.20
Coil resistance	51.2	Magnet thickness	3.5[mm]
No load speed	1212[rpm]	Load current	0.61[A]
Load Speed	870[rpm]	Output	112[W]
Wire size	0.26[mm]	Voltage	285[V]

5. CONCLUSION

In this paper, a axial type brushless DC motor which has double rotor using rare-earth magnet is designed. The rotor has 16 poles and the stator has 12 coils. This type of motor has the merits that the axial length is shorter and easier to assemble than the radial type motor is. To reduce the axial length, NdFeB magnet is used and for the cost of production, the magnets are segmented to rectangle or disk shape for commercial goods. To design this motor, a equivalent circuit is adopted and the air-gap density is calculated using 3D finite element method. In the study, we have known that the efficiency of wide magnet is better than that of thick magnet if the volume is constant. This motor was fabricated and applied to a fan and we could get good performance. This kind of motor shape can be expanded more large motor which can be applied to lots of fields.

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