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2-D Field Analysis of Flat-type Motor

평판형 전동기의 2차원 자계 해석에 관한 연구

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Abstract

This paper describes a method for field analysis inside the flat-type brushless DC motor using 2-D field simulator. Rigorous field analysis entail 3-D analysis. However, this analysis is not often appropriate for system designs because of the time and cost involved. For field analysis in this study, the 3-D problem is reduced to a 2-D boundary value problem by introducing a cylindrical cutting plane at the mean radius of the magnets. Independent of sizes and shapes of systems, the exact 2-D field results can be obtained with reasonable predictability.

요 약

본 연구에서는 2차원 자계 해석 프로그램을 이용하여 평판형 브러시레스 직류 전동기의 자계 해석을 위한 방법을 제시하였다. 정확한 자계 해석을 위해서는 3차원 자계 해석이 필요하지만 많은 시간 및 비용이 요구되는 단점이 있다.

따라서 본 연구에서는 자계 해석을 위하여 3차원 문제를 해당 자석의 평균 반지름에 대한 원통방향의 단면으로 해석하여 2차원 경계치 문제로 축소시켰다. 본 방법을 이용할 경우 시스템의 크기 및 형태에 관계없이 정확한 2차원 자계해석 결과가 합리적으로 얻어지게 된다.

Keywords : Flat-type Motor, 2-D Field Analysis, Impulse Magnetizer

I. Introduction[1]

Flat-type brushless DC motors have been widely used recently in the wide range of low-torque electrical machinery and speed control applications. A typical configuratioin for its motor consists of a set of coils that are fixed below a flat multipole magnet with flux return plates (= stator yoke and rotor yoke) above the magnet and below the coils. In order to miniaturize a brushless DC motor and to decrease its torque ripple, it is necessary to know accurately the flux distribution in the motor[1]. The flux distribution in the rotor magnet, however, was unknown, because the analysis of 3-D magnetic field in a magnetizer for the rotor magnet was difficult. Therefore, the precise analysis of magnetic field could not be anticipated. Moreover, the shape of the coil in the motor is generally 3-D, and interlinkage flux of the coil varies with the rotation of the rotor magnet. In this case, the Finite Element Method (FEM) is used to analyze the magnetic field of the magnetizer and the motor[2-11].

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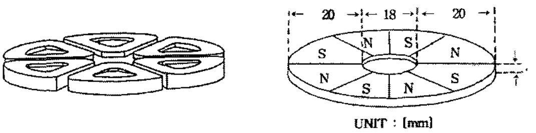
A 2-D field analysis has been demonstrated that this solution yields field values that are reasonably accurate over a substantial portion of the radial expanse of the magnet. But, the analysis which is based on a 2-D model of the geometry, would normally be limited to motors with relatively thin magnets, narrow gaps, and large numbers of poles.

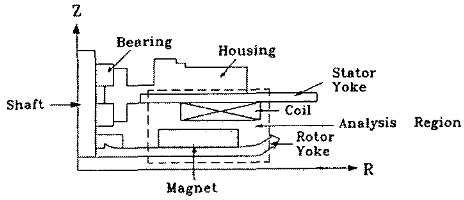
In this paper, the 3-D problem is reduced to a 2-D boundary value problem by introducing a cylindrical cutting plane at the mean radius of the magnets. An application example (flat-type brushless DC motor) is cited. Finite-element analysis is also used as the analysis process.

II. Flat-type brushless DC motor and the impulse magnetizer

Fig.1 shows the analyzed flat-type brushless DC motor. The motor has six coils and is driven by a three-phase switching circuit. During normal operation, the coils are energized in a synchronous fashion as they pass under the transition region between adjacent poles and the field that they produce imparts a torque to the magnet. The rotor magnet is made of a ring-shaped ferrite which is magnetized in the z-direction in 8 poles. The yoke of the rotor is made of soft iron. In this case, a size of the flat-type brushless DC motor abbreviated because of conventional use of Floppy Disk Drive (FDD), etc.



(a) configuration of coil and magnet



(b) cross-section of motor

Fig.1 Flat-type brushless DC motor

III. A method for 2-D field analysis

Eight north-south alternating magnetic pole are arranged in pie-shaped zones with vertical magnetization over each zone. In this study, the field analysis was performed by using a finite element analysis program (MAXWELL 2-D field simulator). The magnetic field inside the application examples is modeled by using Meshmaker and Magnetostat (abbreviated as MESH and MS, respectively) from Answers Unlimited. Since the programs are designed for 2-D analysis, it is necessary to choose a cutting plane or surface through it that will approximate the average behaviour of the fields in the motor. The 2-D surface for modeling is a cylinder cut at the mean diameter of the motor, and unrolled into a flat plane. The 2-D modeling assumes that the volume extents to ±infinity in the Z direction (into the plane of the paper). The 2-D geometry in shown in Fig.2.

This 2-D geometry can be reduced further by exploiting the symmetry that results from the repeating magnetic structure. Especially, the field is symmetric about the vertical center lines of each pole. The stage of general field analysis using MAXWELL is[12]

- 1st step : Decision of configuration
- 2nd step : Generation of the mesh
- 3rd step : Definition of a nominal flux for the magnet regions and the boundary condition
- 4th step : The problem is solved
- 5th step : Plots of the magnetic vector potential, magnetic flux density, estimation of **B** field

The procedure described above is the most general approach to 2-D field analysis. Therefore, the 2-D analyzed model is shown in Fig.3.

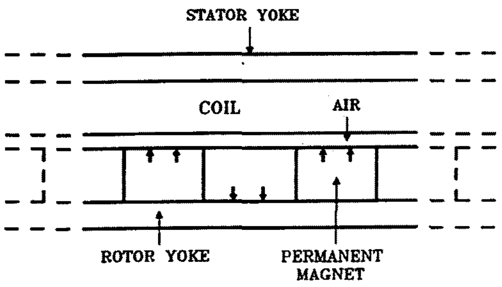


Fig.2 2-D geometry of flat-type motor

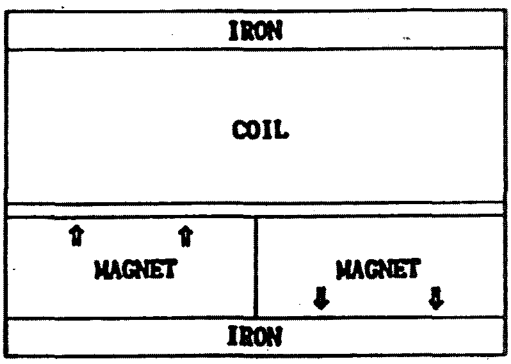
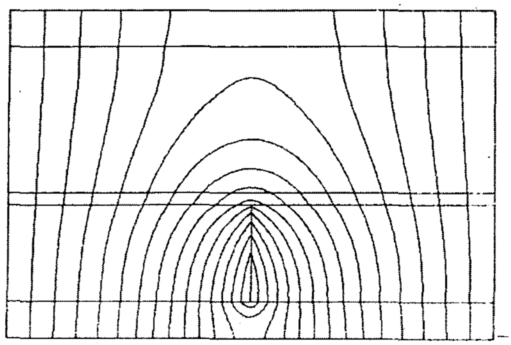


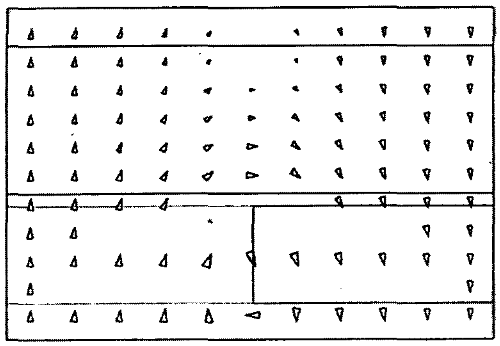
Fig.3 2-D analyzed model of flat-type motor

IV. Analysis results

A series of 2-D Finite Element Analysis (FEA) predictions were performed for a specified geometry. The required symmetry is forced by specifying the boundry conditions when running the Magnetostat program as Neumann or Dirichlet. In case of flat-type brushless DC motor, the actual finite element mesh created by the program MESH and the magnetic field inside the motor is found by running MS. The iron is assumed to saturate at 12000[Gauss] and to have a relative permeability of 2000. A plot of the flux lines (prescribed flux density : 1500[Gauss]) is shown in Fig.4(a). Also, Fig.4(b) shows the magnetic vector potential.

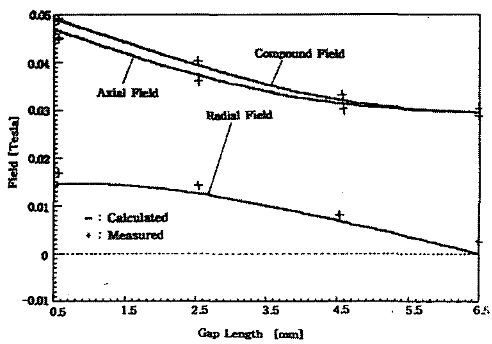


(a) magnetic flux line

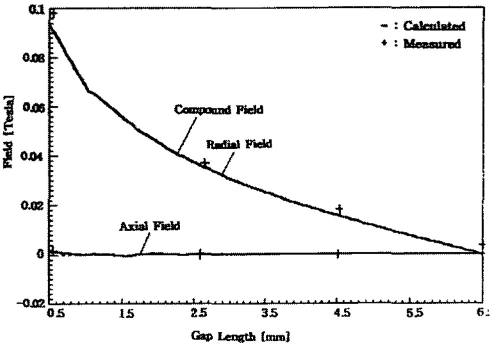


(b) magnetic vector potential

Fig.4 Magnetic flux line and magnetic vector potential of the flat-type brushless DC motor



(a) in case of above the center of one pole



(b) in case of between neighboring poles

Fig.5 Field versus gap length of flat-type brushless DC motor

For measurements of field versus gap length were made using the 8-pole magnet described above. This magnet was placed in an equivalent magnetic circuit (between stator yoke and rotor yoke) and field values were measured with a hall probe in the center of one of the poles and between neighboring poles. Measurements were taken for a series of gap lengths ranging from 0.5 to 6.5[mm]. The resulting field predictions are shown in Fig.5. It was found that the calculated magnetization was higher for smaller gaps and lower for wider gaps. In Fig.5(a), axial field undoubtedly higher than radial field. Especially, in case of gap length 6.5[mm], radial field is about 0[Tesla] and axial field is about 0.032[Tesla]. Also, resultant field and axial field are in close agreement. In case of Fig.5(b), axial field is about 0[Tesla], at a series of gap lengths ranging from 0.5 to 6.5[mm]. Radial field and resultant field are 0.092[Tesla] at gap length 0.5[mm], about 0[Tesla] at gap length 6.5[mm], respectively. Table 1 shows the field values of flat-type brushless DC motor.

On the other hand, Fig.6 is an enlarged view of axial field of Fig.5(b). In this case, maximum flux density is about 12[Gauss]. Note that there is good agreement for all value.

Table 1 Field values of flat-type brushless DC motor

Values (Compound Field)	Calculared [G]			Measured [G]			Errors [G]		
GabLength[mm] / Cases	2.5	4.5	6.4	2.5	4.5	6.5	2.5	4.5	6.5
Above the center of pole	401	322	302	415	332	311	14	10	9
Between neighbor poles	353	175	12	364	194	25	11	19	13

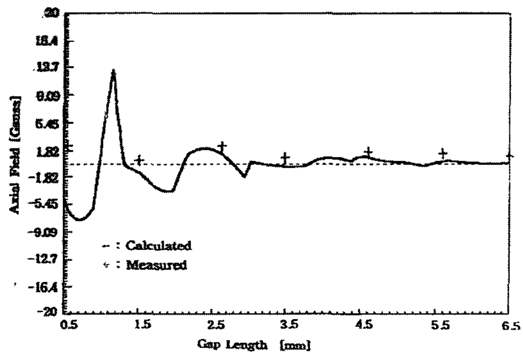
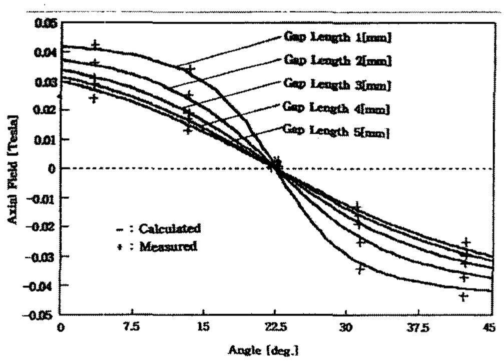
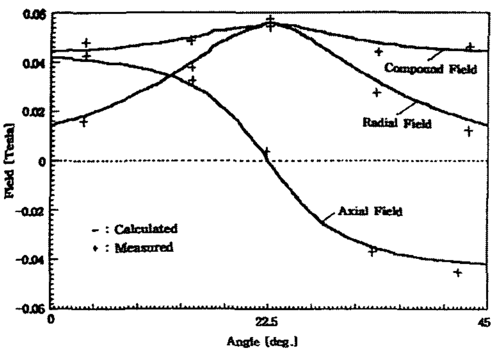


Fig.6 Axial field in case of between neighboring poles of flat-type brushless DC motor



(a) axial field versus angle for five different gap settings



(b) field versus angle at gap setting of 1[mm]

Fig.7 Field versus angle

Also, field values were measured at three different gap settings of 1, 2, 3, 4, and 5[mm], respectively. The measurements were made using a hall probe located 0.5[mm] under the stator yoke and directively above the center of a pole. Value was taken as the magnet rotated from the center of one pole to that of the neighboring pole (45[degrees]). The caculated and measured value are compared in Fig.7. Good agreement between caculated and measured has been achieved. Also, various field values at gap setting of 1[mm] is presented in Fig.7(b) and the radial field shows the maximum flux density (0.058[Tesla]).

V. Conclusion

This study tested the field characteristics inside the flat-type brushless DC motor using 2-D finite element analysis (MAXWELL 2-D field simulator). Rigorous field analysis for the flat-type brushless DC motor entail 3-D analysis. However, this analysis are not often. appropriate for system designs because of the time and cost involved. Namely, Such a 3-D approach may be extended to other systems in which the geometry although simple needs the use of 3-D programs, noticeably more difficult to handle an run than 2-D package. The field analysis used in this study represents an analytical 2-D field calculations and is ideally suited for rapid field characteristic calculation. Independent of sizes and shapes of systems, the rigorous field can be obtained with reasonable predictability. Good agreement between calculated and measured has been achieved.

References

[1] T. Nakata, N. Takahashi and K. Uehara, "Analysis of Magnetic Characteristics of a Brushless DC Motor taking into account the Distribution of Magnetization", IEEE Trans. on Magnetics, vol.22, no.5, pp.1084, 1986.

[2] E. P. Furlani, "A Method for Tredicting the Field the in Axial Field Motors", IEEE Trans. on Magnetics, vol.28, no.5, pp.2061, 1992.

[3] J. K. Lee, "The Analysis of Magnetizing Fixture for a Multipole Nd-Fe-B Magnet", IEEE Trans. on Magnetics, vol.24, no.5, pp.2166, 1988.

[4] J. K. Lee and E. Furiani, "The Optimization of Multipole Magnetizing Fixtures for High-Energy Magnets", Journal of Appl. Phys., vol.67, no.3, pp.1570, 1990.

[5] Pill-Soo Kim and Soo-Hyun Baek, "Design and Analysis of Capacitor Discharge Impulse Magnetizer-Magnetizing Fixture System", Proc. of the 5th International Energy Conference (ENERGEX'93), pp.473, 1993.

[6] Pill-Soo Kim, et al, "2-D Field Analysis of Flat-type Brushless DC Motor", Proc. of the 2nd Chinese International Conference on Electrical Machines (CICEM'95), pp.613, 1995.

[7] Pill-Soo Kim, et al, "2-D Field Analysis of Magnetizing Fixture for Stator Magnet of Air-Cleaner DC Motor", Proc. of the ISPMM'95, pp.1154, 1995.

[8] Pill-Soo Kim, et al, "Computer Simulation of a Capacitor Impulse Discharging Circuit", Proc. of the International Symposium on Power Electronics (ISPE'92), pp.365, 1992.

[9] Pill-Soo Kim, et al, "Efficient Design of Capacitor

Discharge Impulse Magnetizer System for 8-Pole Magnet", Proc. of the ISPMM'95, pp.1149, 1995.
[10]Pill-Soo Kim, et al, "Thermal Modeling of Capacitor Discharge · Impulse Magnetizng Fixture System", Proc. of the International Power Electronics Conference (IPEC'95), pp.259, 1995.
[11] Pill-Soo Kim and Yong Kim, "Thermal Modeling of Capacitor Discharge Impulse Magnetizer", the Trans. of the IEE of Japan, vol.116-D, pp.397, 1996.
[12] *Maxwell 2-D Field Simulator User's Guide*, Ansoft Co., Pittsburgh PA U.S.A, 1994.

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