Field Characteristics of Axial-Field Motor and 8-pole Impulsed Magnetizing Fixture for the Rotor Magnet using 2-D Model

Pill-Soo Kim

Daelim College, 526-7 Bisan, Dongan Anyang, Kyunggi 431-715, Korea

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This paper describes a method for field analysis inside the flat-type brushless DC motor and 8-pole magnetizing fixture for the rotor magnet using 2-D field simulator. Rigorous field analysis of two-kinds 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, a reasonable 2-D field distributions can be obtained.

Key words: 2-D field analysis, impulse magnetizer, magnetizing fixture, flat-type motor

1. Introduction

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 configuration 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 motor¹⁾. 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 motor²⁾.

On the other hand, various shape magnets such as multipole magnets are used in a variety of applications such as brushless DC motors and for various types of holding magnets. The required pole pattern is produced by placing the magnet in wire-wound fixture and discharging a large capacitor bank through the fixture³⁻⁴⁾. The problem of designing custom fixtures for magnetization fixtures has until recently been a "cut and try" process. It was common to literally blow up one or more fixtures before achieving the desired result. Finite element CAD package allow the design and analysis of such a fixture. This permit a rapid variation of many parameters without the necessity of fabricating and testing many prototypes. The use of such programs leads to an important reduction in development cost. 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. Two application examples (flat-type brushless DC motor and 8-pole magnetizing fixture for the rotor magnet of the motor) are cited. Finite-element analysis is also used as the analysis process.

2. Flat-type Brushless DC Motor and the Impulse Magnetizer

Figure 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 rotor magnet is magnetized by a impulse magnetizer shown in Fig.2⁵⁾. In Fig.2, a rotor magnet in wire-wound fixture is magnetized by the discharging current of capacitor C. Figure 3 shows an exploded view of the actual test fixture for magnetizing an 8-pole magnet. The material of fixture core is iron and each slots contains one-conductor of 1[mm] diameter wire of magnetizing coil.

Fig. 1 Flat-type brushless DC motor

Fig. 2 Circuits of impulse magnetizer

Fig. 3 Exploded view of 8-pole magnetizing fixture

3. 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). 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 and the magnetizing fixture. The 2-D surface for modeling is

(a) 2-D model of flat-type brushless DC motor

(b) 2-D model of 8-pole fixture (on half of one pole)
Fig. 4 2-D analyzed model

a cylinder cut at the mean diameter of the motor and magnetizing fixture, and unrolled into a flat plane. The 2-D modeling assumes that the volume extends to infinity in the Z direction (into the plane of the paper). The 2-D structure 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. Therefore, the 2-D analyzed model is shown in Fig.4. In case of Fig.4(a), the boundaries that form the top and bottom of the rectangle are bordered by a magnetic steel material (the flux return plates). For the sake of simplicity, it is assumed that this material has an infinite permeability ($\mu = \infty$). Consequently, the tangential component of the field vanishes along these boundaries.

4. Analysis Results

4.1 Simulation results

A series of 2-D FEA predictions were performed for a specified geometry. In case of flat-type brushless DC motor, 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.5. The resulting two-dimensional surface consists of one iron region containing 8 slots. The current runs through the slot which contain copper both into and out of page. The magnet to be magnetized is represented by the air gap. The relative permeability of magnetic materials such as ferrite is approximately unity both in the magnetized and unmagnetized states; therefore, the magnet can be represented as an air gap. If one were to model this entire region, the flux lines would surround each of the slots in an elongated elliptical fashion. An identical flux plot would be repeated at every slot. To model the entire region accurately would require a very large number of nodes in the finite-element model. The number of nodes can be reduced, however, by taking advantage of the symmetry in the problem. In fact, it is sufficient to model only one section of one pole as shown in Fig.4(b). In case of 8-pole magnetizing fixture, the iron is assumed to saturate at 12000[Gauss] and to have a relative permeability of 2000.

Fig. 5 Magnetic flux line of the flat-type brushless DC motor

A plot of the flux lines (prescribed flux density : 2400[Gauss]) is shown in Fig.6.

Fig. 6 Magnetic flux line of the 8-pole fixture (on half of one pole of 8-pole fixture)

4.2 Experimental results

In case of flat-type brushless DC motor, 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.7.

(a) above the center of one pole

(b) between neighboring poles
Fig. 7 Field versus gap length of flat-type brushless DC motor

It was found that the calculated magnetization was higher for smaller gaps and lower for wider gaps. In Fig.7(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.7(b), axial field is about 0[Tesla], at a series of gap lengths ranging from 0.5 to 6.5[mm]. The 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.

On the other hand, the experimental data from the 8-pole fixture are shown in Fig.8. The maximum flux density achieved is 2540[Gauss]. This measured maximum value shows very good agreement with the MAXWELL-calculated value. The discrepancy between measurement and calculation may be due to probe nonlinearity or probe placement within the fixture and numerical errors.

Fig. 8 Measured axial flux density at point Q of Fig.3(b) in case of 8-pole fixture (capacitor bank : 2800[μF], charging voltage : 650[V])

5. Conclusion

This study describes the field characteristics analysis inside the flat-type brushless DC motor and 8-pole magnetizing fixture for the rotor magnet of motor through 2-D finite element. Rigorous field analysis for the flat-type brushless DC motor and 8-pole magnetizing fixture entail 3-D analysis. However, this analysis are not often appropriate for system designs because of the time and cost involved. The field analysis used in this study represents a 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.

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