# Characteristic Analysis on PMSMs with Three Types of Diametrically Magnetized Rotors under Magnetic Circuit Construction Conditions

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**Abstract — This paper deals with the comparison and analysis on the characteristics of high speed permanent magnet synchronous machines (PMSMs) with diametrically magnetized rotors according to the magnetic circuit construction conditions, and the analytical method is adopted to predict the magnetic field distribution and to calculate the electrical parameters. In addition, the three types of PMSMs with diametrically magnetized PMs are suggested, and with those models, not only the analysis on the magnetic field distribution and the estimation of electrical parameters but also their comparison with finite element analysis (FEA) is performed. From the analysis, the real model is manufactured and the validity of this paper is demonstrated by experiment with showing which model is the most appropriate to apply.**

## I. INTRODUCTION

Due to their high efficiency, small size, light weight and good reliability, high speed electrical machines are likely to be a key technology for the many future applications of motion control and drive systems. In order to facilitate the design and accurate dynamic modeling of the high speed machines, various techniques can be employed to predict magnetic field distribution [1]-[5]. In particular, the transfer relation theorem (TRT) proposed by Melcher is more useful than the existing space harmonic method, because it reduces the analytical burdens. Even though the analytical method cannot offer exact solutions for the characteristic analysis on electrical machines, it can reduce the analysis time. Therefore, if both the FEA (Finite Element Analysis) and analytical method are suitably used by taking advantages each other, it can get big benefit for the analysis. Therefore, this paper adopts the analytical method to predict the magnetic field distribution and to calculate the electrical parameters of permanent magnet synchronous machines (PMSMs) by using transfer relation theorem (TRT). In addition, the three types of PMSMs as shown in Fig.1 are suggested in this research. With those models, the analysis on the magnetic field distribution and electrical parameter derivation are performed, and the FEA is applied to confirm the analysis.

## II. ANALYSIS ON THREE TYPES OF HIGH SPEED PMSMS WITH DIAMETRICALLY MAGNETIZED ROTORS

The analysis models are divided to open circuit field and armature reaction field, and it is assumed that the current is distributed in an infinitesimal thin sheet in terms of armature reaction field for the simplicity of analysis.

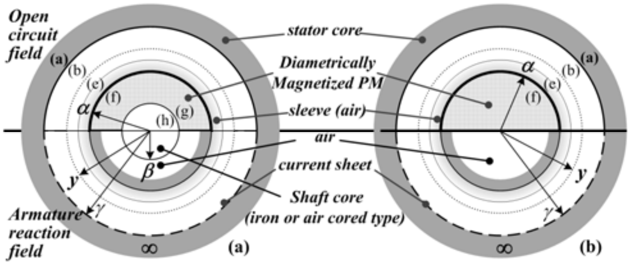


Fig.1. Analysis model : (a) Iron or air cored type, (b) Full-ring magnet type.

### A. Open Circuit Field

Based on the Maxwell's equations, the transfer relation matrix for open circuit field can be derived, and the boundary conditions of three types of PMSMs are obtained by considering the characteristics of each region. By using TRT with those boundary conditions, each of the magnetic vector potential of three types in the boundary (e), which is essential to calculate the radial and tangential components of flux density in the boundary, is derived. Fig. 2 shows the comparison of the results of radial components of flux density by the FEA and the analytical method, and it is noticed that they are well corresponded.

### B. Armature Reaction Field

For the characteristic analysis of the simplified analysis model for armature reaction field, it is assumed that the relative recoil permeability of the PMs is unity. Similar to the process of the open circuit field, the governing equation and the transfer relation matrix for this model are obtained. Especially, the current density modeling is performed by considering the sheet current. Here, the flux density components can be obtained as open circuit field.

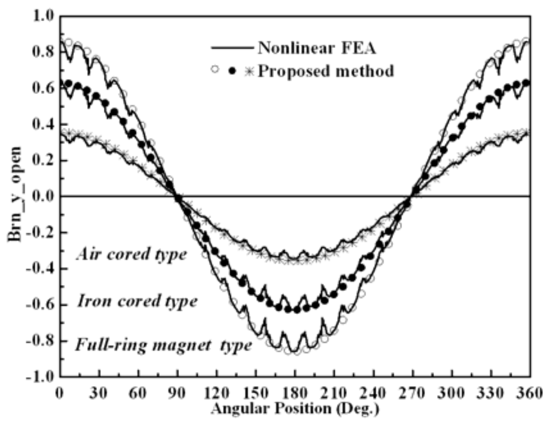


Fig.2. Radial component of flux density in open circuit field.

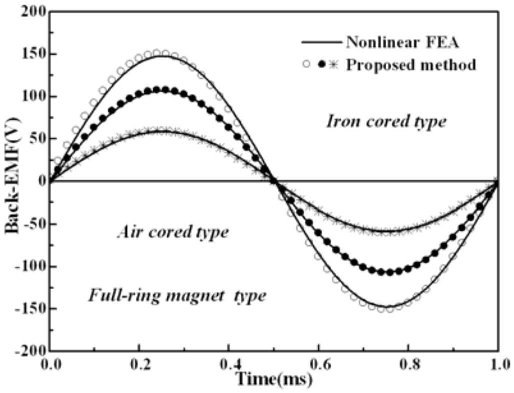


Fig.3. Back-EMF comparison according magnetic circuit conditions.

### C. Electrical Parameter Derivation

In addition to the magnetic field analysis, this paper also obtains the electrical parameters such as back-EMF constant, inductance and torque constant. The comparison of back- EMF for each type is shown in Fig. 3. Among the three types of PMSMs analyzed in this paper, the full-ring magnet type is determined to manufacture. In addition, Table 1 shows the inductance calculation results from FEA and TRT. Those results have approximately 95% of agreement, so it is demonstrated that the proposed method is valid. As shown the table, the iron cored type has the highest value of inductance for both self and mutual inductance. Besides, the torque constant is obtained, and the analysis result will be presented in later full paper. The torque constant can be calculated according to current values, and it will be noticed that the full-ring magnet type shows the highest value.

### D. Electromagnetic Losses

In a high-speed machines, the power losses can be split into core loss in the stator core, copper loss in the armature winding, rotor loss in the sleeve and PM and all of them can

Table 1. The inductance results of both FEA and TRT

| Inductance | FEA($\mu$H) | | | TRT($\mu$H) | | |
|---|---|---|---|---|---|---|
| | Full | Iron | Air | Full | Iron | Air |
| Self | 96.8 | 199 | 96.8 | 91 | 187 | 91 |
| Mutual | 48.4 | 99.5 | 48.4 | 45.5 | 93.5 | 45.5 |

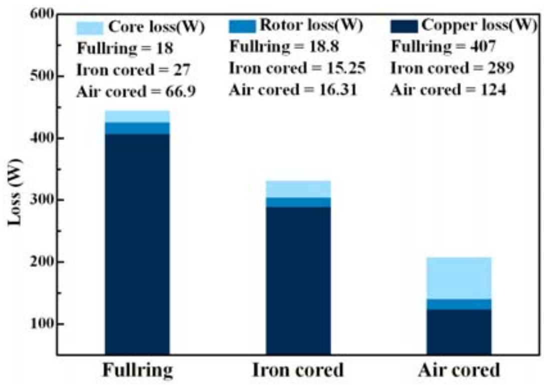


Fig.4. Electromagnetic Losses.

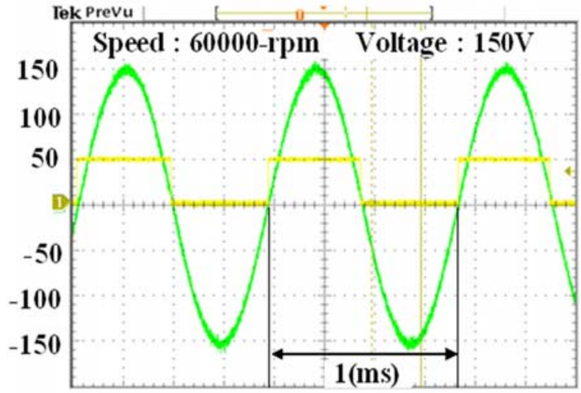


Fig.5. Experimental result of back-EMF (full-ring magnet type).

be calculated analytically as shown in Fig. 4. Here, the mechanical losses are ignored in this paper. The figure shows that full-ring magnet type has the highest losses in comparison with others. Consequently, it is demonstrated that air cored type is the most efficient in identical size of motor. However, to obtain required back-emf, the full-ring magnet type is determine to manufacture,

## III. CONCLUSION

The manufactured model, which is full-ring magnet type, has the specification of 7.5[kW] of rated output power and 60000[rpm] of rated speed. Fig. 5 shows the experimental back-EMF result. By the comparison with the results of the analytical method suggested above, its validity is demonstrated. In conclusion, three types of PMSMs based on the suggested analytical approach, which is the electromagnetic transfer relations theorem (TRT), is dealt with in this paper, and the magnetic field distribution and electric parameters are derived, such as back-EMF constant , inductance and torque constant are analytically derived. Moreover, power losses are estimated. The proposed method is validated in that each of results show great agreement with FEA and experiment, so this paper will have been attributed to the precise decision of choosing required rotor type.

## IV. REFERENCES


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