자극분할형 동기전동기의 기본특성

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Basic Characteristics of Synchronous Motor with Divided Permanent Magnets per Pole

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Abstract - In this paper, we propose a new type of rotor construction in the permanent magnet synchronous motor. By using plural permanent magnets for one-pole of the rotor, it is possible not only to reduce space harmonics of air-gap fields but also to provide space for damper windings in the inter-pole space. The dimensions of the plural permanent magnets are derived by Fourier analysis. Based on the investigation by numerical analyses, we propose an optimal rotor construction in view of both the reduction of space harmonics and the damping effect.

KEYWORDS
permanent magnet synchronous motor, Space harmonics, Damper winding, Fourier analysis.

1. INTRODUCTION

The field system of the permanent magnet synchronous motor (PMSM) has generally a single magnet per pole of the rotor. In this study, we adopt plural permanent magnets having same polarity instead of the single magnet. One of the plural magnets is referred to as a sub-magnet hereafter. By using plural sub-magnets for a main-pole, we can reduce undesirable higher space harmonics in electric machinery. The appropriate dimensions of them for reducing specific space harmonics are determined by Fourier analysis[1]. Furthermore, by using such a sub-magnets scheme, the spaces for damper windings are provided between neighboring sub-magnets. The damper circuit is useful for hunting and stability problems, and the self-starting of the synchronous motor.

We numerically investigate the effect of the space harmonic reduction. It is analyzed by two-dimensional hybrid (coupled finite element and boundary element : FE-BE) method. And then, we propose an optimal rotor construction in view of the following : the magnitude of fundamental in air-gap flux distribution, the ratio of space harmonics to the fundamental component, the feasibility of manufacture, the hunting oscillations, and the induction starting.

2. REDUCTION OF SPACE HARMONICS

2.1 Dimensions of Sub-magnets

One spatial cycle of a two-pole synchronous motor is shown in Fig.1, which also includes the developed diagram of the rotor for simplicity in the following description. Fig.2 shows the several arrangements of sub-magnets investigated.

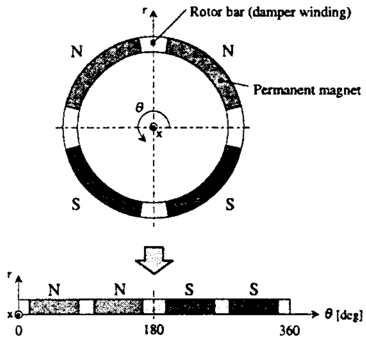


Fig.1. Construction of rotor.

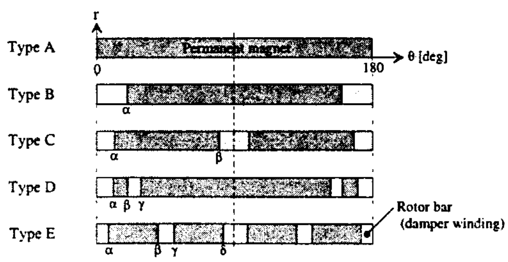


Fig.2. Arrangement of sub-magnets.

2.2 Fourier Analysis

By arranging the sub-magnets properly, we can eliminate some terms of Fourier coefficients as many as the number of sub-magnets per pole. For example, since the 5th space harmonic is eliminated by using 80 percents of magnet per pole, the α in Type B of Fig.2 becomes 9 mechanical-degree (deg). Furthermore, Type C is adopted for eliminating two kinds of space harmonics (e.g. 5th and 7th), and the air-gap flux harmonics are written as

$$B_{y5}(\theta)=\frac{4B_m}{\pi}\left\{\frac{\cos(5\alpha)-\cos(5\beta)}{5}\right\}\cdot\sin(5\theta)$$
$$B_{y7}(\theta)=\frac{4B_m}{\pi}\left\{\frac{\cos(7\alpha)-\cos(7\beta)}{7}\right\}\cdot\sin(7\theta) \quad (1)$$

where α and β (unknown constants yet) are related to the dimensions of the sub-magnets. By putting $B_{y5}=0$ and $B_{y7}=0$ in equation (1), α and β are determined by solving the simultaneous equations. In Fig.2, Type D is for eliminating three kinds of space harmonics and Type E for eliminating four kinds of them.

Table 1 shows the demensions of each type. Since the sub-magnet scheme reduces the magnitude of the fundamental in air-gap flux as well as the whole amount of permanent magnet per pole, we compare each type with same amount of PM. Because Type B is inferior in reducing space harmonics and Type D in manufacture of the magnets, we propose that Type C and E suit for practical use.

Table 1. Comparison of each type.

Type	$\alpha\ \beta\ \gamma\ \delta$ [deg]	harmonics/fundamental[%]					
		1	3	5	7	11	13
A		100.0	33.33	20.00	14.29	9.09	7.67
B	α=18.0000	100.0	20.61	0.00	8.83	9.09	4.75
C	α=15.4286 β=87.4286	100.0	29.93	0.00	0.00	5.04	12.45
D	α=14.0164 β=24.5044 γ=30.2875	100.0	16.01	0.00	0.00	0.00	7.64
E	α=19.1030 β=46.5359 γ=52.5812 δ=85.4505	100.0	25.98	0.00	0.00	0.00	0.00

3. HYBRID FE-BE ANALYSIS

The finite element method (FEM) suits for analyzing a complicated region including teeth, slots, and magnets, and the boundary element method (BEM) is for analyzing electromagnetic quantities caused by rotation without remeshing in the FEM. Taking account of the advantages in both methods, we apply the Hybrid method (3) to the motor.

3.1 Analysis Model

Figure 3 shows the analysis model and table 2 the specifications of experimental machine. In Fig.3, the spaces between the sub-magnets are filled with damper-bars made of solid copper.

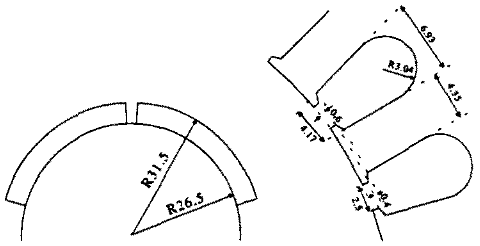


Fig.3. Dimension of experimental machine.

Table 2. Experimental specifications.

Item	Symbol	Value [Unit]
Diameter of stator	ϕ	0.065 [m]
Width of stator core	W_s	0.0365 [m]
Number of pole	p	2
Number of turn	N	64 [turns]
Number of slot	S	24
Width of magnet	W_m	0.0365 [m]
Air-gap	g	0.001 [m]

3.2 Analytical Results

To grasp the basic tendency of the motor, we analyze the static characteristics of the PMSM. Figure 4 shows the characteristics of reluctance torque, and Fig.5 the spatial distribution of magnetic flux density.

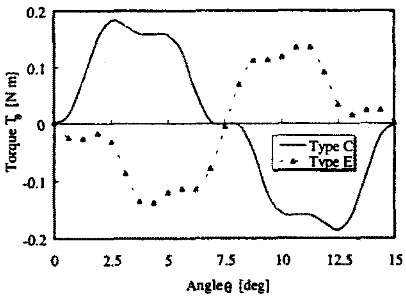


Fig.4. Characteristics of reluctance torque.

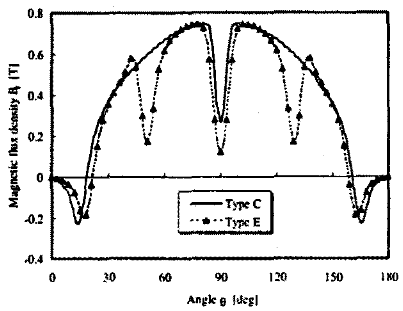
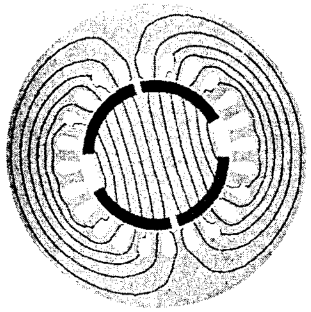
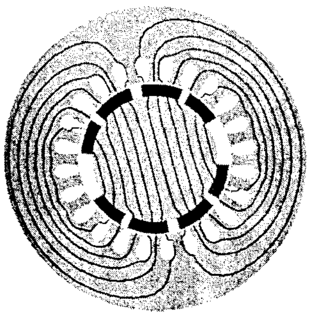


Fig.5. Distribution of magnetic flux density.

Figure 6 shows the distribution of equipotentials and Fig.7 the distribution of magnetic flux density in the cross section of the motor.

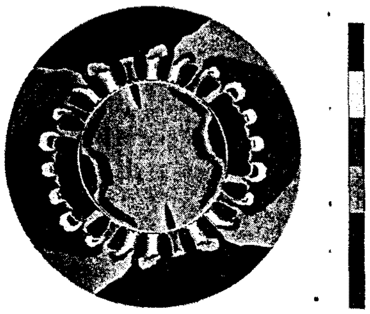


(a) Type C

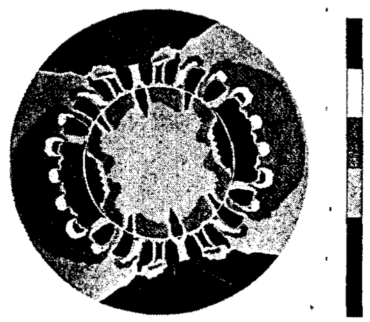


(b) Type E

Fig.6. Distribution of equipotentials.



(a) Type C



(b) Type E

Fig.7. Distribution of magnetic flux density.

4. CONCLUSION

The purpose of this paper is to derive an optimal rotor construction in the permanent magnet type synchronous motor (PMSM). By applying properly arranged plural permanent magnets for one-pole to the rotor, we can obtain both the reduction of higher space harmonics and the enhancement of damping effects.

From the analysis and experimental results, we recognize that the more number of permanent sub-magnets, the more higher space harmonics are reduced and the more damping effects are achieved. In view of the above advantages, we conclude that Type E is the most desirable construction among the investigated types.

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