Design and Analysis Method of Alternate Rotor Core for Concentrated Flux–type IPMSM

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Motors for automotive chassis components require compact size due to space constraints. Therefore, a rare earth permanent magnet synchronous motor (PMSM) is mainly used as the motor applied to the chassis system. The magnetic concentrated flux-type PMSM with the ferrite magnet is likely to be used as a motor for the chassis system because it can increase the air magnetic flux density as the rare earth PMSM. The most important thing for the design of concentrated flux-type motor is to reduce the flux leakage. In order to reduce the leakage flux, it is necessary to increase the reluctance of main leakage path in the rotor core. Increase in magnetic reluctance of flux path is necessary to reduce the flux leakage. Accordingly, a new rotor structure with a 3-dimensional (3D) magnetic circuit that can reduce leakage flux is proposed in this paper. In order to easily analyze three - dimensional complex magnetic circuits, an equivalent 2D-3D model was applied to analyze the characteristics.

***Index Terms*— Concentrated flux-type IPMSM, Equivalent 2D-3D model, Ferrite magnet, Finite element analysis**

I. Introduction

RECENTLY, development of concentrated flux-type interior permanent magnet synchronous motor (IPMSM) using ferrite magnet is being conducted actively due to unstable supply of rare-earth material resource. The most significant advantage of the concentrated flux type IPMSM is that high magnetic flux density and output power can be obtained through the magnetic flux concentration effect of two adjacent PMs. By using these characteristics, it is possible to design a Concentrated flux-type IPMSM with ferrite magnet at a lower cost than an IPMSM using a rare earth magnet.

Despite of these advantages described above, some issues still exist for the concentrated flux-type IPMSM with ferrite magnet. Mostly, leakage flux around the rotor inner circumference significantly affects motor performance. Several studies have been done to solve this problem. The most common method is to apply the shaft as a non-magnetic material [1]. This method effectively reduces leakage flux. In this case, however, manufacturing process is complicated and increases the price.

An alternate rib type rotor core combined with a ferromagnetic shaft was applied to minimize the leakage flux and manufacturing cost of the rotor. The rib design of the rotor is not only important to reduce leakage flux in the rotor core bus also affects the mechanical stiffness of the rotor core due to centrifugal force [2]. Therefore, mechanical considerations are required along with magnetic circuit analysis.

In this paper, we propose an equivalent 2-dimensional (2D) model for analyzing an alternate rib rotor core with a complex 3-dimensional (3D) magnetic circuit. The equivalent 2D model is derived from the equivalent magnetic circuit (EMC) method and is used for parameter and characteristic analysis.

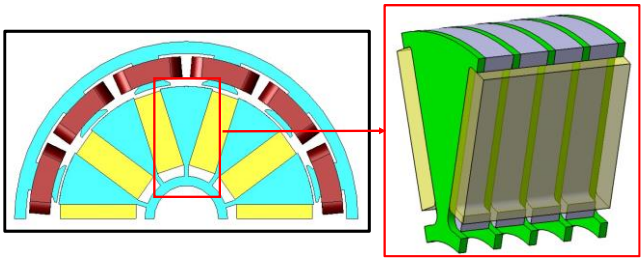

Fig. 1. Alternate rib rotor core.

TABLE I
MAIN PARAMETER OF CONCENTRATED FLUX TYPE IPM MODEL

Parameter	Unit	Value
Stator slot / rotor pole	-	12 / 10
Stator outer diameter	mm	75
Stator inter diameter	mm	57
Lamination axial length	mm	18
Air-gap length	mm	0.5
PM size	mm	16 / 6
PM residual magnetism (20 ℃)	T	0.41
Magnet material	-	Ferrite
Winding turn per series phase	-	34

II. Electro-Magnetic Designs

Concentrated flux-type IPMSM has high torque density. Therefore, it has been researched for high torque application. It is possible for concentrated flux-type ferrite magnet motor to achieve air-gap flux as high as a rare-earth magnet motor [3].

The concentrated flux motor can effectively improve the air gap flux density by the concentrated flux effect. However, the leakage flux around the inner circumference of the rotor should be effectively reduced for actual products. In order to reduce the leakage flux, it is necessary to eliminate the leakage path. The most effective way to reduce leakage is to remove ribs of rotor core. However, if the ribs are removed, the shape of the

rotor core assembly cannot be maintained. In order to overcome this problem, an alternate rib was applied as shown in Fig. 1. When laminating the rotor, only a part of the rib is present and the remaining part of the rotor can effectively reduce the leakage flux by removing the rib.

Based on main parameters of a typical motor for chassis component shown Table I, two concentrated flux type IPMSM models with conventional and alternate iron ribs are established. With identical stator employed, comparisons are carried out between the two models, including the leakage flux distribution and the torque capability.

No-load flux distributions of the two concentrated flux-type IPMSM models are investigated by 3D FE analysis. It can be seen that the model with alternate iron ribs, which is mainly due to the much lower permeance of airspace barriers involved in the leakage path.

III. Finite Element Analysis

In this paper, finite element analysis is used to analyze structural and magnetic circuit characteristics. The result in characteristic of permanent magnet synchronous motor (PMSM) using FEA is small error. Therefore, this is used on basis of PMSM design. Case of the existing radial field PM rotary machine, as the advantage to a reduction of calculation time and the simplicity of modeling, is widely used in 2D FEA. But is necessary the condition that this have a fixed size with geometric and amount of mechanical as vertical direction of cross section in case of 2D FEA. Also, to consider alternate rib rotor core effect, 2D FEA has a problem in adjusting to the characteristics analysis and this is neglected.

Therefore, 3D FEA should be required. However, 3D FEA requires huge calculation time even though high specification computer is used. But, the 3D electromagnetic model of concentrated flux type IPMSM considering alternate rib rotor core effect.

For this, the concept of equivalent 2D-3D FEA model is applied. The magnetic equivalent circuit is modeled to reflect the alternate rib structure of the rotor 2D FEA model. Then, 2D rib dimensions are calculated by using the magnetic equivalent circuit so as to be equal to the reluctance of the 3D structure. The details of the derivation of the equivalent 2D-3D FEA model are covered in the full manuscript.

IV. FEA Applying Equivalent 2D-3D Model

Although the loading has great influences on the motor performance, preliminary prediction can be made based on the open-circuit result. The equivalent 2D-3D model reflecting the alternate rib rotor core effect, the 2D model not reflecting, and the magnetic field distribution of the 3D model were compared. As shown in Fig. 2, the equivalent 2D-3D model results and the 3D model results are similar. Therefore, it support the plausibility of equivalent 2D-3D model.

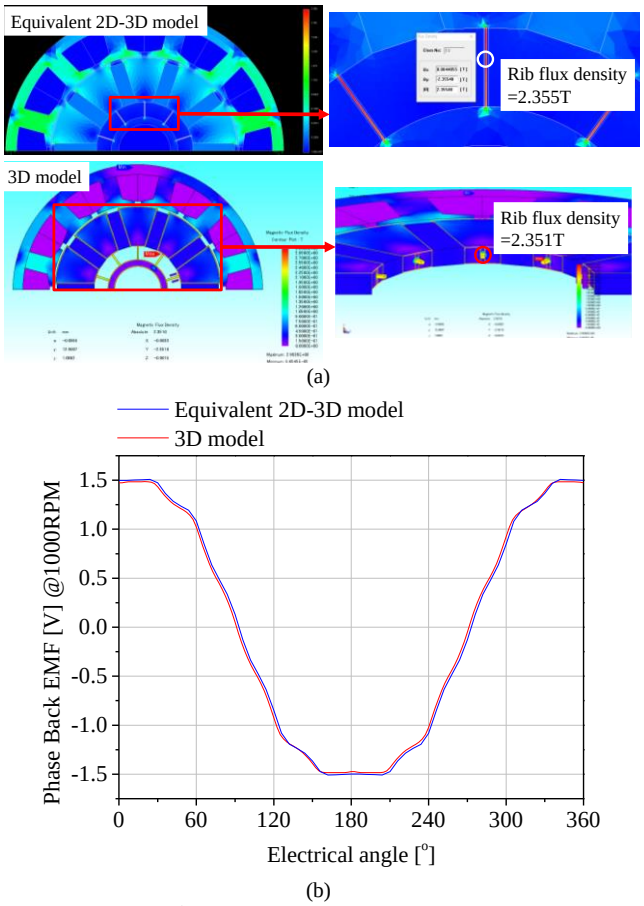

Fig. 2 Comparison of equivalent 2D-3D model and 3D model analysis result. (a) Magnetic field distribution. (b) Phase Back EMF.

V. Conclusion

This paper present reduction leakage flux method using alternate rib and analysis method consider alternate rib rotor core effect. For this 3D electromagnetic model of concentrated flux-type IPMSM using alternate rib rotor core can be approximated as the equivalent 2D-3D electromagnetic model considering alternate rib rotor core effect.

In order to improve on the electromagnetic characteristics of concentrated flux-type IPMSM, it was expected that analysis time will quite effective in progress. Details will be included in the full paper.

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