HEV Motor Comparison of IPMSM with Sintered Rare-Earth Magnet and PMASynRM with Bonded Dy Free Magnet in the Same Size

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This paper studied on the comparison of traction motor for same size with sintered rare-earth magnet and bonded Dy free magnet We designed PMASynRM with bonded Dy free magnet by changing only rotor and experimented to verify performance at the same size IPMSM with sintered rare-earth magnet

***Index Terms*— Traction motor, EV, HEV, Assisted Synchronous Reluctance Motor (PMASynRM), Dy free motor, Rare-earth free**

I. Introduction

The current generation of home electric appliances and electric vehicles/hybrid electric vehicles (EVs/HEVs) uses interior permanent magnet synchronous motors (IPMSMs)that contain rare-earth permanent magnets [1-3].

The IPMSM has high efficiency, a high power factor, and a high power density. However, rare-earth permanent magnets containing dysprosium(Dy) is expensive and there is concern regarding the stable supply of rare earth materials. On the other hand, a synchronous reluctance motor (SynRM) is driven by reluctance torque [4]. The SynRM does not use permanent magnets, and so sacrifices torque density, power factor, and efficiency compared to the PMSM. However, by adding a proper quantity of PM to the SynRM, the torque density and power factor of the SynRM can be improved. Such motors are referred to as permanent-magnet-assisted synchronous reluctance motors (PMASynRMs) [5-9]

In this paper, We designed PMASynRM with bonded Dy free magnet by changing only rotor and experimented to verify performance at the same size IPMSM with sintered rare-earth magnet.

In this study, Aichi Steel Co. Mag-Fine(MF) Dy free bonded magnets are used as the permanent magnets of the PMASynRM. This study investigates the influence of the rotor structure on the characteristics of the PMASynRM with bonded Dy free magnets using a 2D finite element method (FEM)

II. Influences of the PMASynRM Rotor Structure with Bonded Dy Free Magnet

A. IPMSM Model and Specifications

In-this paper, we used same stator structure and target specifications of the IPMSM, because we need one on one comparison with IPMSM and PMASynRM. These motors have same stator but different rotor structure and magnet.

Table.1 shows specifications of the IPMSM and the PMASynRM target specifications are same as IPMSM. Fig.1 is IPMSM model with sintered rare-earth magnet.

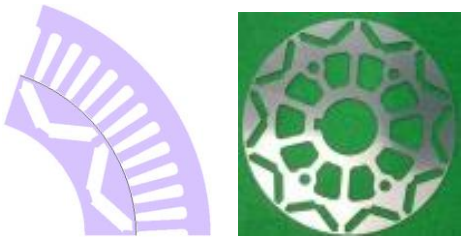


Fig.1. IPMSM model with sintered rear-earth magnet

TABLE I
Specifications of the IPMSM and Target of the PMASynRM

Division	IPMSM
Number of poles	10
Number of slots	60
Max power[kW]	30
Max torque[Nm]	194
Stator internal diameter[mm]	113
Stator external diameter[mm]	160
Stack length[mm]	120
Air gap[mm]	0.6
Max input current[Apk]	340
Torque ripple @Max torque[%]	5↓
Torque ripple @Max rpm[%]	10↓

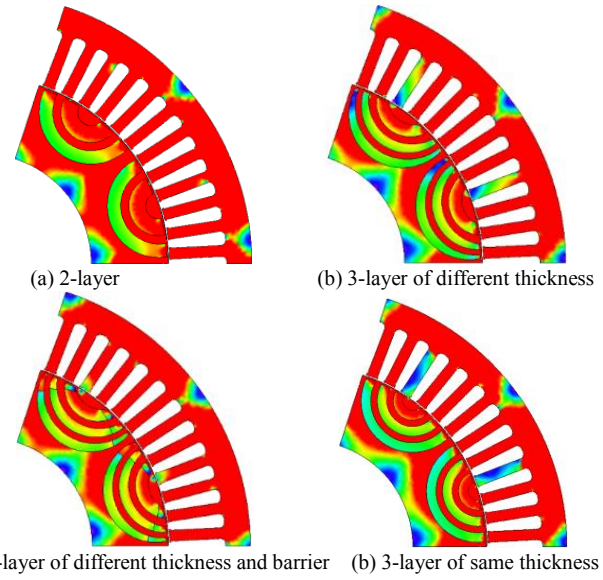
B. PMASynRM Concept Design

There are models of concept design for PMASynRM with Dy free bonded magnet in the fig.2. Table.2 is rare-earth sintered and Dy free bonded magnet characteristics.

TABLE II
Comparison of the Magnet

Division	Rare-earth Sintered	Dy free Bonded
Magnet Br[T]	1.31	0.67
Magnet Hcb[kA/m]	987	478

The target of the amount of the PMASynRM magnet was twice that of IPMSM.



(a) 2-layer (b) 3-layer of different thickness

(c) 3-layer of different thickness and barrier (b) 3-layer of same thickness

Fig.2. Concept rotor models for PMASynRM design.

III. Comparison of the IPMSM with Rear-Earth Sintered Magnet and PMASynRM with Dy Free Bonded Magnet

A. PMASynRM design

We conducted the detailed design with 9 variables to satisfy target specifications in the same motor size. Fig.3 shows design variables and final PMASynRM model.

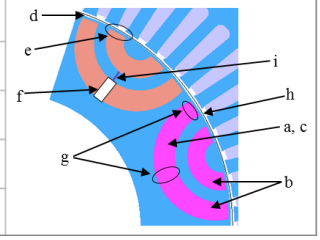
Variables		Final PMASynRM Model
a. Magnet shape	f. Magnet barrier	
b. Magnet layers	g. First layer magnet thickness offset	
c. Magnet amount	h. Rotor external diameter offset	
d. Air gap	i. Thickness between layers	
e. Rib thickness		

Fig.3.Design variables and final PMASynRM model

B. Analysis Results

Table IV shows comparison of the target spec. and PMASynRM analysis results in the same motor size. The amount of magnet of the PMASynRM is twice the amount of the existing IPMSM magnet considering the material cost.

TABLE IV
Comparison of the Target and PMASynRM Analysis Result in the Same Motor Size

Division	Target	PMASynRM
Number of poles	10	←
Stator external diameter[mm]	160	←
Stack length[mm]	120	←
Max. torque[Nm]	195@1480rpm	194@1480rpm
Max. input current[Apk]	340	←
Torque ripple @Max torque[%]	5↓	2.5
Torque ripple @Max rpm[%]	10↓	9.6
Magnet amount[mm^3]	328,800↓	330,360

Fig.4 is magnetic torque and reluctance torque of IPMSM and PMASynRM in the same motor size.

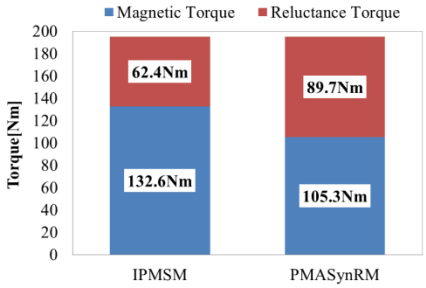


Fig.4. magnetic torque and reluctance torque of IPMSM an PMASynRM in the same motor size

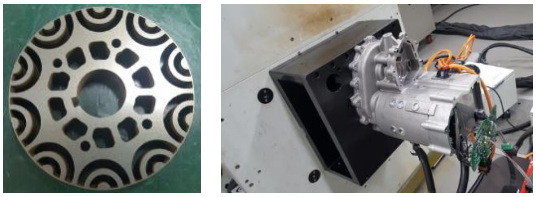


Fig.5.PMASynRM with Dy free bonded magnet..

C. Conclusion

In this paper, we conducted design PMASynRM with bonded Dy free magnet. The PMASynRM used the same size and the same stator structure as the IPMSM, and only the rotor is designed to be changed. We have confirmed the change of characteristics of PMASynRM according to the changes of design parameters and compared with IPMSM through experiment of manufactured motor.

References

[1] Piergiorgio Alotto, Massimo Barcaro, Nicola Bianchi, and Massimo Guarnieri ,"Optimization of Interior PM Motors With Machaon Rotor Flux Barriers" , *IEEE Transactions on magnets*, Vol.47, No. 5, (2011)

[2] Liang Fang, Jae-woo Jung, Jung-Pyo Hong, and Jung-Ho Lee, "Study on High-Efficiency Performance in Interior Permanent-Magnet Synchronous Motor With Double-Layer PM Design," *IEEE Transactions on magnets*, Vol. 44, No. 11, (2008)

[3] K.-C. Kim, S.-B. Lim, D.-H. Koo, and J. Lee, "The shape design of permanent magnet for permanent magnet synchronous motor," IEEE Transactions on Magnetics, Vol.42, No.10, pp.3485-3487, Oct. (2006)

[4] Ki-Chan Kim, Joon Seon Ahn, Sung Hong Won, Jung-Pyo Hong, and Ju Lee, "A Study on the Optimal Design of SynRM for the High Torque and Power Factor," IEEE Transactions on Magnetics, Vol.43, No.6, (2007)

[5] T. Tokuda, M. Sanada, S. Morimoto, "Influence of Rotor Structure on-Performance of Permanent Magnet Assisted Synchronus Reluctance Motor," ICEMS2009, DS2G1-3, (2009)

[6] S. Morimoto, M. Sanada, Y. Takeda, "Performance of PM-Assiated Synchronous Reluctance Motor for High-Efficiency and Wide Constant-Power Operation," IEEE Transactions on Industry Applications, Vol.37, No.5, (2001)

[7] H. Murakami, Y. Honda, Y. Sadanaga, Y. Ikkai, S. Morimoto, Y. Takeda, "Optimum Design of Highly Efficient Magnet Assisted Reluctance Motor," IEEE Transactions on Industry Applications, Vol.4, pp. 2296 - 2301, (2001)

[8] Won-Ho Kim, Kwang-Soo Kim, Seung-Joo Kim, Dong-Woo Kang, Sung-Chul Go, Yon-Do Chum, and J. Lee, "Optimal PM Design of PMASynRM for Wide Constant-Power Oration and Torque Ripple Reduction," IEEE Transactions on Industry Applications, Vol.45, No.10, pp. 4460 -4463, (2009)

[9] P. Niazi, H. A. Toliyat, D. H. Cheong, J. C. Kim, "A Low-Cost and Efficient Permanent-Magnet-Assisted Synchronous Reluctance Motor Drive," IEEE Tranductions on Industry Applications, Vol.43, No.2, (2007)