HEV/EV 전기강판 및 구동모터 특성해석

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Electrical steel and traction motor performance analysis for HEV/EV

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Abstract – This paper presents the characteristic of newly developed electrical steel and motor performance analysis for HEV/EV. This material is developed and optimized for high frequency operation to reduce the core losses in traction motors to increase fuel efficiency. Four types of electrical steel are introduced, which are optimized for high flux density (PNHF), high frequency low core loss (PNF), high punchability (PNS) and high strength (PNT) to meet different specifications from different types of traction motors. To identify the motor performance with this material, finite element analysis was used to calculate core loss as well as Ld and Lq for efficiency map. Also structure analysis was performed to calculate stress on bridge rotor.

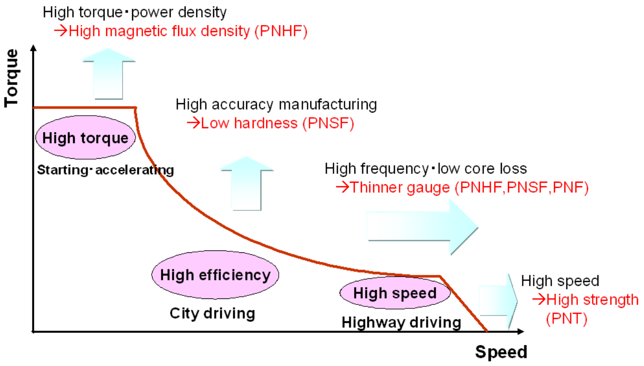
1. Introduction

Due to restriction of CO2 emission and increase of fuel price, Eco-friendly vehicle or HEV/EV development and sales start booming nowadays. According to report, by 2020 more than 5.2 million HEV/EV or 7.3% of total sales per year will be expected[1].

Traction motor specifications are different from motor makers as well as automotive makers because they have used their own specification to meet the mileage with their unique development strategy. Therefore like the international combustion engines, it is unlikely to see that international standard for traction motors will be made in the near future. Furthermore, due to difficulty in souring problems and cost of rare earth magnet, magnet free motors such as induction motors or switched reluctance motors are considered for the replacement of IPMSM..

Fig. 1. shows the requirement of traction motors for HEV/EV. For the traction motors, high speed or high frequency efficiency is directly related to mileage for vehicles, therefore low core loss at high frequency characteristic is required for electrical steel. At standstill or accelerating, high flux density is required to produce high torque. To reduce core loss, increasing resistivity by adding Si , Al and so on is one of approach via chemical composition, also thinner electrical steel will be effective to decrease the eddy current loss which is proportional to the square of frequency.

To increase motor power, in addition, high strength on electrical steel is required to increase motor speed. Otherwise the bride on rotor that has the strongest stress may tear apart due to the centrifugal force at high speed.



<Fig 1> Traction motor requirement

2. Electrical steel for HEV/EV

In response to different requirement on electrical steel, 4 series of electrical steel for HEV/EV were developed with different thickness as shown in Fig. 2.

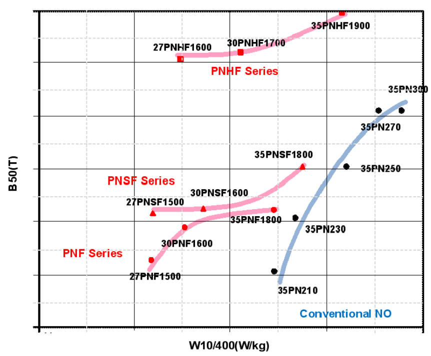
Conventional electrical steel core loss notation is W15/50 or core loss measured at 1.5T at 50Hz, however like high frequency application ie. traction motors 1T at 400Hz coreloss or W10/400 notation is used nowadays.

PNF series has low core loss at high frequency with fair flux density.

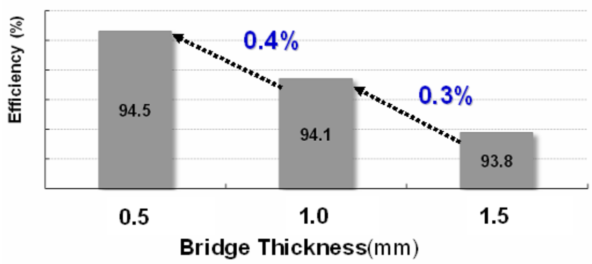
PNS series has low core loss equivalent with PNF, however It has lower hardness compared with PNF series so that one can expect better punchability up to 30% increase of the number of shots for motor cores. Generally PNF and PNS material is effective IPMSM.

PNHF series have fair core loss at high frequency with excellent permeability for high flux density. Therefore this series is ideal for induction machines or magnetic free motors. All PNF, PNS and PNHF series has 0.35, 0.3 and 0.27mm in thickness.

PNT series has relatively higher core loss, however, they have excellent mechanical strength more than 500MPa. Therefore this type of material is effective to use rotor where higher mechanical stress is expected due to high speed or thinner width of bridge on rotor. According to 15kW motor FEA result as shown Fig. 3, by changing the bridge, motor efficiency can be varied due to leakage flux of magnet through the bridge, therefore designers want to decrease its width as long as the mechanical strength permits the material strength.



<Fig 2> Newly developed electrical steel for HEV/EV



<Fig 3> Newly developed electrical steel for HEV/EV

3. Motor performance analysis

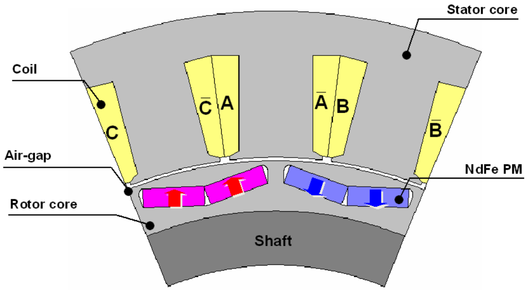
To identify each material's performance used for traction motors, 15kW IPMSM is introduced as shown in Fig. 4. This motor is intended for understanding of electrical steel's performance called "model motor".

These days finite element analysis is commonly used to predict motor performance accurately considering non liner characteristic of magnetization. For this study, equivalent circuit model is introduced to calculate motor performance efficiently [2]. For core loss calculations, FFT on each element is performed for harmonic considerations [3]

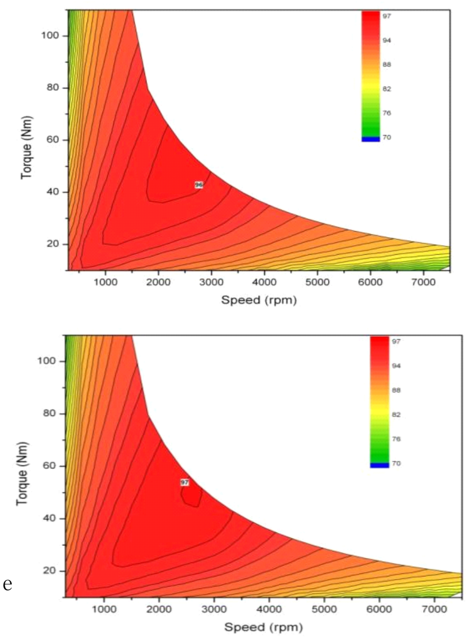
Fig. 5. presents efficiency map comparison for 35PN250, 30PNSF1600 and 27PNSF1500. 0.3% of maximum efficiency is increased by using 27PNSF1500 replacing 35PN250, in addition, this result shows maximum operation region is enhanced as well as increased lowest efficiency up to 3% or more at high speed region as shown in Fig. 6.

This study shows thinner material with low core loss at high frequency is the most effective way to increase motor efficiency.

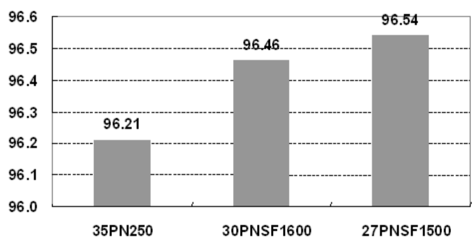
Also thinner material is the best way to decrease core loss expecially at high speed region, which is eddy current loss is dominant as shown in Fig. 7.

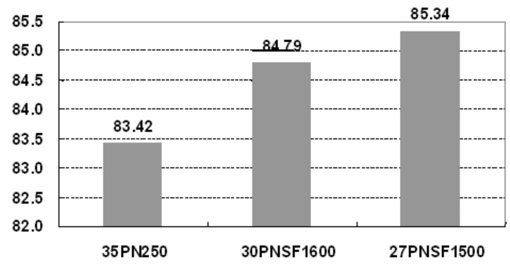


<Fig 4> 15kW model motor configuration

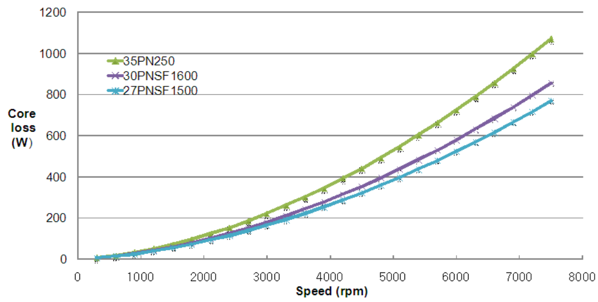


<Fig 5> efficiency map
(Top: 35PN250, Bottom: 27PNSF1500)





<Fig 6> motor efficiency
(Top: maximum efficiency, bottom: efficiency at highest speed)



<Fig 7> core loss calculation result

rpm	Max. Stress (Mpa)		
	0.5mmt	1.1mmt	1.5mmt
6000	178	154	152
9000	402	354	342
10000	490	430	424
12000	714	618	608

35PN230 설계 가능 영역

35PNT650Y 설계 가능 영역

<Fig 8> Stress calculation result

Mechanical stress on bridge is due to centrifugal force during rotation. Fig. 8. shows calculated stress on different bridge width and speed. This stress is calculated with von mises stress showing that use of high strength steel extend rotor speed and decrease bridge width as well.

However the use of high strength steel should be considered relatively poor magnetic properties due to its nature and high cost since this material can only adopted in rotor.

4. CONCLUSION

PNF, PNSF, PNHF and PNT material is developed for HEV/EV traction motors. Each material is optimized for high frequency and high speed application with various thickness of 0.35, 0.3 and 0.27mm. This will enable motor designers to have many choices that will applicable for various motor specifications. This analysis study shows use of high frequency low core loss with thinner material will be the most effective way to increase motor efficiency for high mileage.

[References]

[1] JP Power, "Drive Green 2020", Special report, Nov, 2010.

[2] T.M Jahns et.al ,"IPMSM for Adjustable Speed Drives", IEEE Trans. Industry Applications, vol. IA-22,no. 4 July/August 1986.

[3] H. Nam, et. al "A study of iron loss analysis method considering the harmonics of the flux density waveform using iron loss curves tested on epstein samples,"IEEE Trans. Magn., vol. 39, no. 3, pt. 1, pp. 1472-1475, May 2003