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Investigation on Core Loss according to Stator Shape in Interior Permanent Magnet Synchronous Motor

Investigation on Core Loss according to Stator Shape in Interior Permanent Magnet Synchronous Motor

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***Abstract*- This paper deals with the core loss reduction according to the change of stator shape in an interior permanent magnet synchronous motor (IPMSM). The number of slots per pole per phase of the IPMSM is 0.5, and the tooth width and yoke thickness are chosen as design factors. According to the ratio of tooth width and yoke thickness, the core loss is analyzed under considering the rotating and alternating magnetic field at the main operation. Base on the functional core loss data obtained by the Steinmetz equation, the core loss is calculated by using finite element method (FEM). In this study, the determination of ratio of tooth width and yoke thickness to minimize the core loss in the IPMSM is presented. In additional, the torque characteristics according to the ratio are also investigated.**

I. INTRODUCTION

Recently, as the interest about the energy savings in the various industrial fields is increasingly raised, the high efficient motors have been demanded. In order to design the motors, the consideration of power losses in the design stage is necessary, and the reduction of core and copper loss is important because they occupy the most of the losses generated in the motor. Moreover, the improvement of efficiency in traction motor, IPMSM, brings about large energy saving. The copper losses are proportional to the resistance of the phase winding and to the square of the current flowing through the phase, and the core losses are proportional to the frequency and flux density. Especially, the core losses are affected by the motor shape. Furthermore, the core loss reduction design in the traction motor for a hybrid electric vehicle (HEV) is necessary, because magnetic saturation is relatively high due to the size limitation. Consequently, this paper investigates the core loss according to the shape of the motor [1].

When the rotor rotates with synchronous speed, the core loss in the rotor is smaller than that in the stator because of a little the flux density variation in the rotor. Hence, the most of the core losses in the motor are generated in the stator. The various design factors of the stator have considerably an effect on the core loss. There are many papers about the reduction of core loss according to the shape of tooth tip and slot [2]. However, there are very few technical papers about the ratio of the tooth width and yoke thickness.

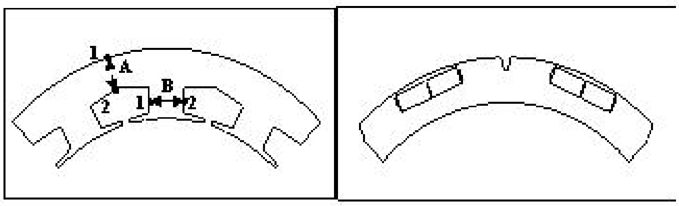
Finally, this paper presents the ratio between the tooth width and yoke thickness to minimize the core losses according to the combination of slot and pole number in the IPMSM. Moreover, torque characteristics are shown according to the combination.

II. ANALYSIS MODEL

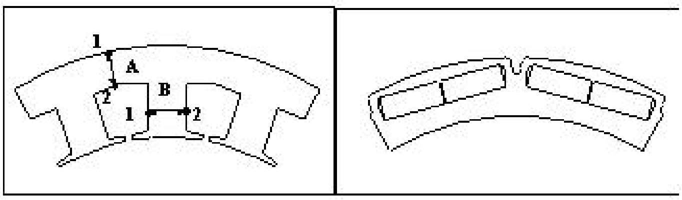
In order to find the changes of aspect of the core loss by the number of slots and poles combination, the number of slots per pole per phase of the analysis models is 0.5. Hence the determined model is as follows among the models: 8 poles 12 slots, 12 poles 18 slots and 16 poles 24 slots.

Fig.1 displays yoke thickness (design variable A) and tooth width (the design variable B). The slot area and volumes of the permanent magnet in each model classified by the pole number are all the same. Because core loss is considerably affected by the tooth tip in the stator, the shape is also the same shape in all of the models.

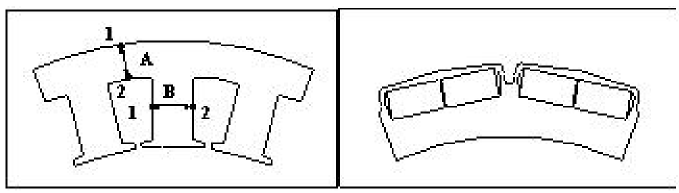
Core material of the entire model is 35PN230 and stack length is 56[mm]. Dimensions and slot areas in each model are shown in Table I.



(a) 8 poles 12 slots



(b) 12 poles 18 slots



(c) 16 poles 24 slots

Fig.1. Configuration of the models.

TABLE I
DIMENSIONS AND SLOT AREAS IN EACH MODEL

Ratio between the tooth width and yoke thickness		Dimension [mm] Yoke thickness (A)	Dimension [mm] Tooth width (B)	Slot area [mm^2]
0.5	8P 12S	15.30	30.60	299.80
	12P 18S	10.80	21.60	235.01
	16P 24S	9.20	18.00	167.71
0.6	8P 12S	15.90	26.66	293.4
	12P 18S	12.00	19.80	225.99
	16P 24S	10.50	17.20	167.63
0.7	8P 12S	17.20	24.50	292.2
	12P 18S	13.30	19.00	234.39
	16P 24S	11.70	16.30	168.83
0.8	8P 12S	17.85	22.30	293.90
	12P 18S	14.50	18.00	229.59
	16P 24S	12.70	15.50	169.75
0.9	8P 12S	18.60	20.60	290.8
	12P 18S	15.30	17.00	228.95
	16P 24S	13.50	14.90	169.58

TABLE II
CALCULATION OF THE NO-LOAD CORE LOSS

Ratio of the tooth width and yoke thickness		Base speed (1500rpm)	Max speed (6000rpm)
0.5	8P 12S	36.00	305.85
	12P 18S	61.40	520.26
	16P 24S	98.62	849.57
0.6	8P 12S	35.33	300.84
	12P 18S	60.03	510.28
	16P 24S	97.21	837.90
0.7	8P 12S	36.69	314.47
	12P 18S	61.73	525.40
	16P 24S	97.14	838.17
0.8	8P 12S	35.76	306.78
	12P 18S	61.77	527.81
	16P 24S	98.14	848.12
0.9	8P 12S	34.92	299.51
	12P 18S	62.52	535.85
	16P 24S	98.49	852.01

III. FINITE-ELEMENT ANALYSIS

A. *No-load core loss*

The core loss is directly proportional to the flux density and frequency, and core loss is calculated from the functional core loss data obtained by the Steinmetz equations which are comprised of hysteresis loss, eddy current loss and anomalous loss. The total core loss is expressed in following form for sinusoidal varying magnetic flux density B with frequency f.

$$P_c = P_h + P_e + P_a \\ = k_h f B^2 + k_e f^2 B^2 + k_a f^{1.5} B^{1.5} \quad (1)$$

where k_h, k_e, k_a are the hysteresis loss, eddy current loss and anomalous loss coefficient, respectively.

These constants can be obtained by curve fitting from based on raw core loss data. Fig.2 is the functional core loss data used for calculation of core loss. This paper analyzes the flux distribution in the steels at the main operating condition. The core loss considering the rotating magnetic field and alternating is calculated from the each tooth and yoke [3] - [5].

The finite element method (FEM) is used in order to calculate the core loss. Fig.3 shows the procedure of core loss calculation using core loss data of magnetic materials. Fig.4. and Table II are presented the no load core loss at base speed (1500 [rpm]) and max speed (6000[rpm]) in each model.

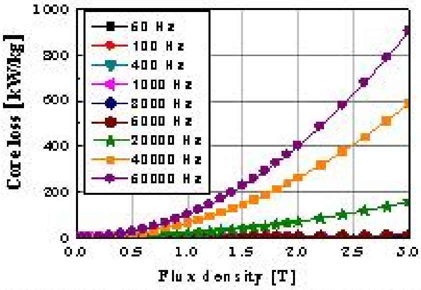


Fig.2. Functional core loss data obtained by the Steinmetz equations.

B. *Load core loss*

Load core loss is also obtained by the way calculating the no-load core loss. In order to calculate the load core loss, the input current and current angle is needed. They are obtained from the result of characteristic analysis [6]. Input current and current angle in each model is presented in the table III. Table IV and Fig.5 shown the result of the load core loss.

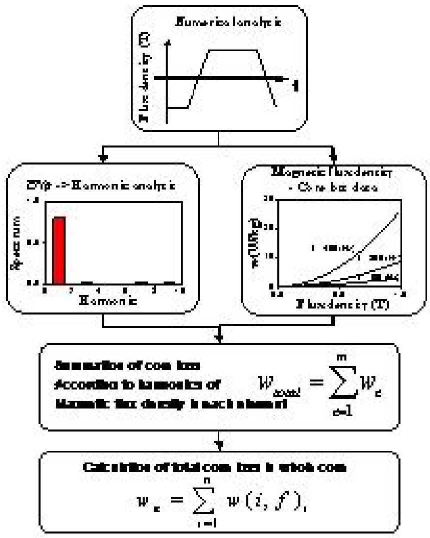
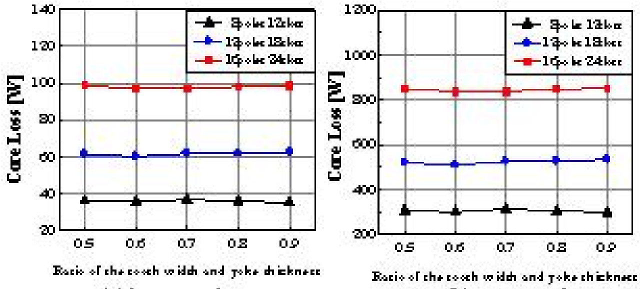


Fig.3. The core loss calculation process.



(a) base speed (b) max speed

Fig.4. Result of the no-load core loss at base and max speed.

TABLE III
LOAD CURRENT AND CURRENT ANGLE

Ratio of the tooth width and yoke thickness		Input current [A_{peak}]	Current angle [°]
0.5	8P 12S	171.66	74.6
	12P 18S	281.84	46.9
	16P 24S	271.45	19.20
0.6	8P 12S	175.99	73.2
	12P 18S	280.79	45.4
	16P 24S	270.98	17.80
0.7	8P 12S	169.99	73.5
	12P 18S	280.56	44.4
	16P 24S	272.44	17.50
0.8	8P 12S	179.12	71.9
	12P 18S	282.27	43.7
	16P 24S	273.00	17.80
0.9	8P 12S	182.01	71.6
	12P 18S	284.62	42.8
	16P 24S	280.93	18.10

TABLE IV
CALCULATION OF THE LOAD CORE LOSS

Ratio of the tooth width and yoke thickness		Base speed (1500rpm)	Max speed (6000rpm)
0.5	8P 12S	103.84	963.87
	12P 18S	134.14	1208.68
	16P 24S	212.45	1903.92
0.6	8P 12S	92.12	850.41
	12P 18S	126.21	1142.38
	16P 24S	198.64	1777.80
0.7	8P 12S	83.01	769.19
	12P 18S	127.27	1152.56
	16P 24S	187.01	1672.74
0.8	8P 12S	80.15	738.09
	12P 18S	122.46	1111.47
	16P 24S	178.36	1596.92
0.9	8P 12S	77.46	712.06
	12P 18S	119.68	1088.45
	16P 24S	170.44	1526.81

The core loss estimated in the entire models is a same aspect. Because the 16 poles 24 slots have higher flux density than the others, the load core loss is the highest among the models.

C. *The flux density Variation in the tooth and yoke*

We have defined the magnetic vector potential in the relationship

$$\nabla \times \boldsymbol{A} = \boldsymbol{B} \quad (2)$$

An equivalent mathematical expression for **A** is as follows, and Stokes's theorem is applied.

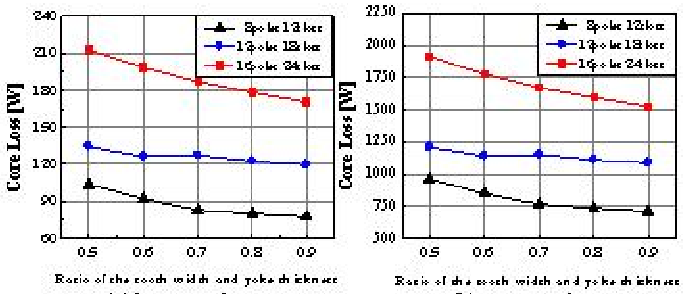
$$\oint_L \boldsymbol{A} \cdot d\boldsymbol{l} = \int_S \boldsymbol{B} \cdot d\boldsymbol{S} = \Phi \quad (3)$$

Therefore, the line integral of the vector potential around a closed path is equal to the magnetic flux linking that path [7]. This gives the total flux per unit depth linking the circuit as

$$\Phi = \boldsymbol{A}_1 - \boldsymbol{A}_2 \quad (4)$$

The change of the flux density in the tooth and yoke is calculated the vector potential difference between point $\boldsymbol{A}_1$ and $\boldsymbol{A}_2$. That is expressed as following form (5).

$$B = \frac{\boldsymbol{A}_1 - \boldsymbol{A}_2}{l} \quad (5)$$



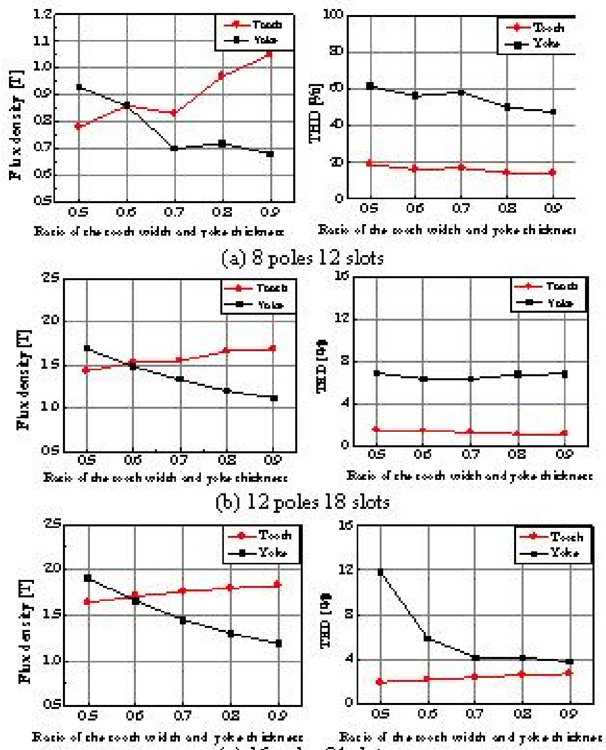
(a) base speed (b) max speed

Fig.5. Result of the load core loss

where $\boldsymbol{A}_1$, $\boldsymbol{A}_2$ are the magnetic vector potential in each point, and l is the distance between $\boldsymbol{A}_1$ and $\boldsymbol{A}_2$.

Fig.6 presents that the magnitude of fundamental component and Total Harmonic Distortion (THD) of the flux density variation according to the tooth width and yoke thickness at the load condition.

From the Fig.6, it is able to know that the magnitudes of fundamental component and THD of changes of the flux density in the yoke have an effect on the load core loss. The result of the magnitude of fundamental component and THD of variation of the flux density in tooth and yoke in the entire models also is a same aspect.



(a) 8 poles 12 slots

(b) 12 poles 18 slots

(c) 16 poles 24 slots

Fig.6. The magnitude of fundamental component and THD of the flux density variation in yoke and tooth at the load.

D. Torque characteristics

The torque characteristics in each model are calculated by the FEM. From the result, Fig.7 shows the result of the torque characteristics according to its ratio, respectively. Consequently, the ratio between tooth width and yoke thickness is more and more being increased in the 12 poles 18slots and 16 poles 24 slots, the torque is reduced by the saturation in the tooth.

IV. Comparison of characteristics from the Fea

In the all models, there is nothing change of the core loss according to the tooth width and yoke thickness at the no-load. However, the load core loss is higher than that. From Fig.5, the flux density variation and its THD in the tooth are smaller than that in the yoke. So, the yoke thickness affects the load core loss.

Therefore, in order to minimize the core loss while maintaining the demanded slot area, the yoke thickness has to increase and the tooth width has to reduce. However, at this time, since the torque is reduced, the appropriate trade-off is needed.

V. Conclusion

By choosing the appropriate ratio of the tooth width and yoke thickness, the efficiency performance can be improved because of the reduction of the core loss.

In case of the motors which have the low flux density, there is little variation of the core loss and torque by the ratio. On the contrary, the change of the ratio in the motors which have high magnetic saturation causes severe difference of the core loss.

Thus, when the designer determines the initial shape of IPMSM which have a high flux density such as the traction motor, the study results investigated in this paper are useful.

Moreover, if this paper adds the investigation about the stator shape such as the tooth tip and slot opening, it will be a good indicator for the core loss reduction design.

References

[1] C. C. Mi, G. R. Slemon, R. Bonert, "Minimization of iron losses of permanent magnet synchronous machines," *IEEE Trans. Energy Conv.*, vol.20, March 2005.

[2] S. B. Park, H. B. Lee, and S. Y. Hahn, "Stator Slot Shape Design of Induction Motors for Iron Loss Reduction," *IEEE Trans. Magn*, vol. 31, no. 3, pp. 2004-2007, May 1995.

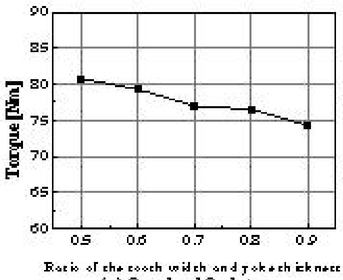
[3] Y. Chen, and P. Pillay "An Improved formula for lamination core loss calculations in machines operating with high frequency and high flux density excitation," *in Conf. Rec. IEEE-IAS Annu. Meeting*, vol2, pp.759-766, Oct. 2002.

[4] N. Stanges and R.D.Findlay, "Importance of Rotational Iron Loss Data for Accurate Proceeding of Rotating Machine Core Losses," *in Conf. Rec. IEEE-IAS Annu. Meeting*, vol.1, pp.123-127, 1994.

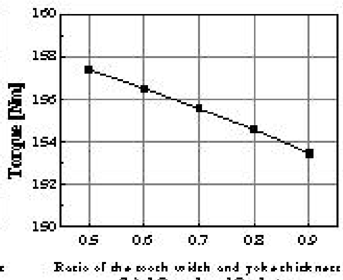
[5] J. J. Lee, Y. K. Kim, H. Nam, K. H. Ha, J. P. Hong, and D. H. Hwang, "Loss distribution of three phase induction motor fed by pulsewidth modulated inverter," *IEEE Trans. Magn.*, vol. 40, no. 2, pp.762-765, March 2004

[6] J. Y. Lee, S. H. Lee, G. H. Lee, J. P. Hong, J. Hur, "Determination of parameters considering Magnetic Nonlinearity in an Interior Permanent Magnet Synchronous Motor" *IEEE Trans. Magn.*, vol. 42, no 4, pp.1303-1306, April 2006

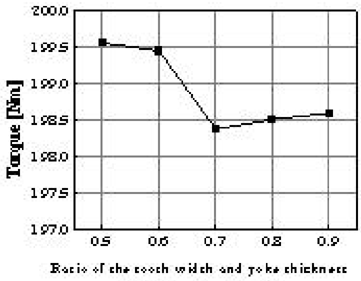
[7] J. Salon, *Finite element analysis of electrical machines*, 1995.



(a) 8 poles 12 slots



(b) 12 poles 18 slots



(c) 16 poles 24 slots

Fig.7. Predicted the torque.