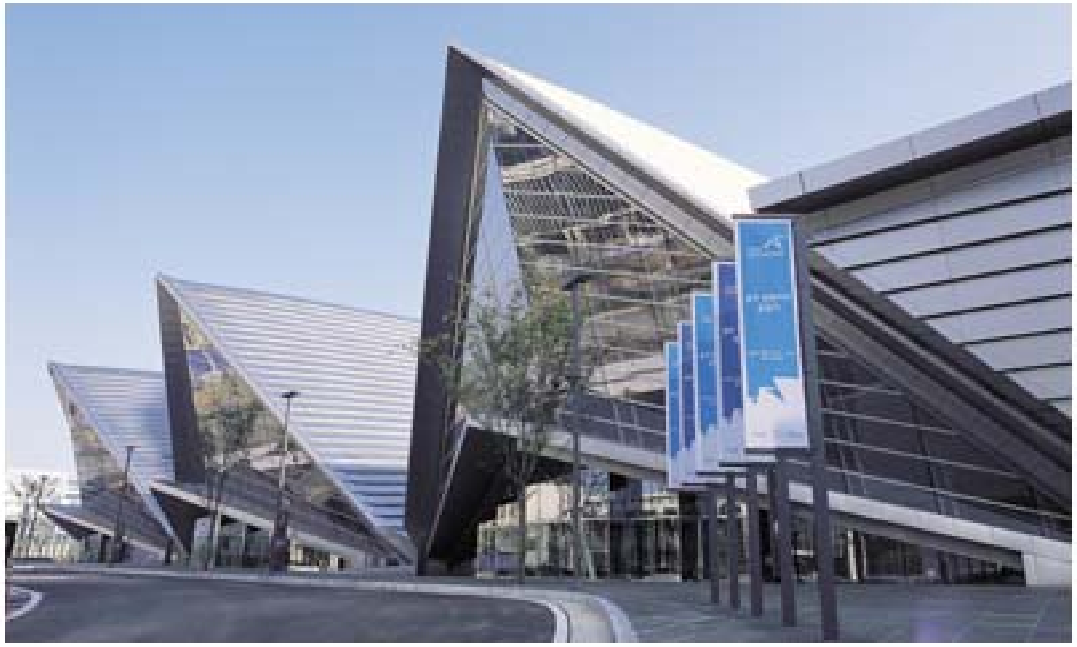
2010 International Conference on Electrical Machines and Systems

October 10-13, 2010, Songdo Convensia, Incheon, Korea



01. Home
02. Session List
03. Author's Index
04. Search

IEEE Catalog Number: CFP10801-CDR
ISBN: 978-89-86510-12-6
Vendor: Prof. Jin Hur
Tel: +82-52-259-1282 / Fax: +82-52-259-1686
E-mail: jinhur@ulsan.ac.kr

Organized by

KIEE (The Korean Institute of Electrical Engineers)

Co-organized by

CES (China Electrotechnical Society)
IEEJ (The Institute of Electrical Engineers of Japan)

Technical Co-sponsor

IEEE Industry Application Society

Jung-Pyo Hong

- The Effect of Silicon Steel Sheet on Core Loss in Induction Motor

Jung-Pyo Hong

- Effect of Vibration and Noise on IPMSM Type Integrated Starter and Generator According to Number of Slots

Jung-Pyo Hong

- Reduction Design of Eddy Current Loss in IPMSM using Response Surface Methodology

Jung-Pyo Hong

- A Study on the Relation Between Rotor Rib and Maximum Power of IPMSM in Flux Weakening Region

Jung-Pyo Hong

- Design of an Interior Permanent Magnet Synchronous In-Wheel for Electric Vehicles

Jung-Pyo Hong

- Vibration Analysis according to Stator Shape Design in a PMSM

Jung-Pyo Hong

- Characteristic Analysis of the Water Pump Motor considering Polar Anisotropic Ferrite Bonded Magnet

Jung-Pyo Hong

- A Study on the Reduction of Noise and Vibration of SPM According to Reduction of Permanent Magnet

Jung-Pyo Hong

- Evaluation and Improved Design about Acoustic Noise and Vibration in IPMSM

Jung-Pyo Hong

- Reduction Eddy Current Loss Design and Analysis of In-Wheel Type Vehicle Traction Motor

2010 International Conference on Electrical Machines and Systems, Oct. 10-13, 2010, Incheon, Korea

The Effect of Silicon Steel Sheet on Core loss in Induction motor

Jeong-Jong Lee[1], Soon-O Kwon[2], Jung-Pyo Hong[2]
[1]Korea Electronics Technology Institute, Yatop-Dong, Bundang-Gu, Seongnam-Si, Korea
[2]Department of Automotive Engineering, Hanyang University, Korea
E-mail: leejj@keti.re.kr, hongjp@hanyang.ac.kr

Abstract — In this paper, the core loss effect of silicon sheet is studied in three phase induction motor. In induction motor, the core loss is affect core loss resistance in equivalent circuit which is connected parallel to excitation inductance. The loss resistance is changed by the loss of material. The effect of three varieties of steel materials on core loss resistance and rated current has been investigated.

I. INTRODUCTION

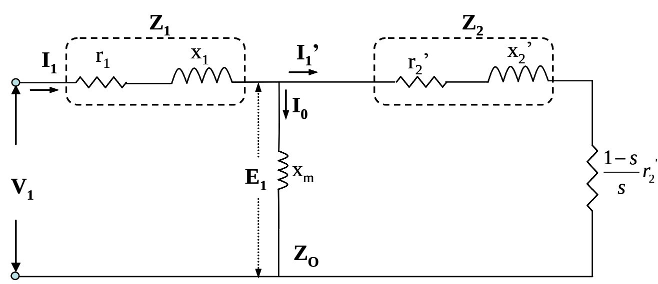
The induction motors widely used in industry applications because of convenient direct starting, high reliability, easy of maintenance. But, induction motor demands both convenient and high efficiency recently. Various reports have been published on this study over a long period of time about high efficiency[1-5]. There are many methods for reducing the losses in induction motor as replace the aluminum to copper, change core width to reducing the core losses. In many study, decreasing model of core loss was reduced the current. But, sometimes the reduced flux density of material is increasing the operating current. This current increases copper loss.

In this paper, the core loss effect of silicon sheet is studied about three phase induction motor. The material of three kinds of POSCO Corporation was applied in this study. The characteristic of induction motor is defined as torque, and power, current, power factor, etc. In order to analysis the characteristic, the induction motor equivalent circuit is used. The main circuit parameter is calculated by FEA except the primary resistance. The core loss resistance(r_c) is calculated by core loss analysis method[2]. In order to calculate the core loss resistance, the core loss is calculated at a point. After this works, the core loss resistance is estimated in all operation range. The core loss and b-h curve is different according to quality of the material. In the some case, the model which core loss reduced is can not show fine efficiency. Because magnetic permeability is low in area that flux is high, electric current is increase. Increased current is effect to decreasing the efficiency. In this paper, more easily implemented modeling approach for computing the steady state performance of a cage induction motor is presented. This approach is based on the determination of the per-phase equivalent circuit parameters from 2D nonlinear eddy-current finite element solution. This model allows accurate prediction of motor performance at any load condition with involving the rotor movement. Core saturation and the rotor bar skin effect are directly considered in the filed calculation. And 3D effect such as end winding can be easily including into the model using classical formulas.

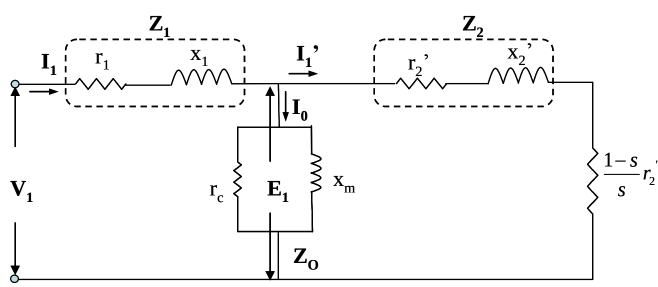
II. ANALYSIS METHODS

A. Three-phase Induction Circuit model

The basic equivalent circuit for induction motor per phase shows in Fig. 1. Where, $\mathbf{Z}_1$ is consisted the primary resistance and reactance and complex impedance. x_m is excited reactance. Because the process for calculate x_1, x_2, r_2, x_m is complex, I used for the FEM methods [2]. Fig. 1(a) is shown the equivalent circuit per phase without core-loss resistance. When the core-loss resistance is added into this circuit, the resistance is parallel connecting to excitation reactance.



(a) Equivalent circuit without core loss resistance



(b) Equivalent circuit with core loss resistance (r_C)

Fig. 1. Equivalent circuit model of induction motor

B. Analysis Model

Fig. 2 and Table I show the half cross-section and brief specifications of the analysis model. The model consisted of 4 pole, 24 slot and squirrel cage with 34 bars. This model is designed 100Vrms line to line voltages at 50Hz. The mechanical airgap length is 0.3mm. And rated power is 134W at slip 0.1.

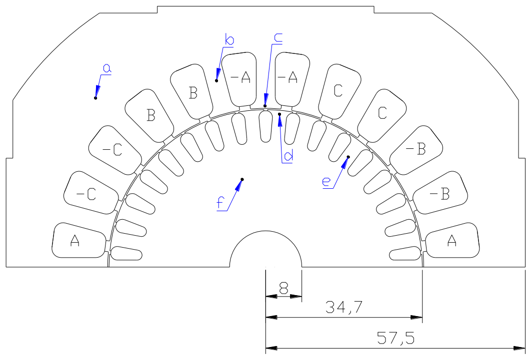


Fig. 2. Analysis model

TABLE I
BRIEF SPECIFICATIONS OF 3-PHASE INDUCTION MOTOR

Item	Unit	Value
Phase number		3
Line voltage	Vrms	100
Input frequency	Hz	50
Rated speed		1350
Output power	W	134
Rated current	Arms	1.6
Rated slip		0.1
Number of pole		4
Number of stator slot		24
Number of rotor conductor		34
Stack length	mm	42
Stator outer diameter	mm	134
Rotor outer diameter	mm	69.4
Connection		Y
Core material		Si-steel
Airgap	mm	0.3

C. Coreloss Analysis Using FEM

Fig. 3 shows the flow chart for the core-loss calculation. The temporal and the spatial variations of the magnetic flux density waveforms are calculated by performing time-stepping FEM. Spectrum analysis is used for the frequency analysis of the magnetic flux density at each element of the finite element (FE) analysis model. The iron losses $P_{ce}{}^{i}$ at each element are calculated from the summation of the losses $P_{ce\nu}{}^{i}(B_\nu,\ \nu f)$ according to frequencies using harmonic analysis and iron loss curves. Finally, the total iron loss P_c is obtained by the summation of the iron losses in all the elements. In order to calculate the core-loss, the material is tested by Epstein method.

Fig. 4 show the core-loss density of 50PN1300 of POSCO cooperation. In order to estimation the coreloss in steady state, the FEA model is analyzed for several periodic from initial starting. Fig. 5 show the current waveform by transient FEA analysis result. The phase current is convergence after 2 or 3 periodic of 50Hz. Therefore, the core-loss is calculated after 0.07s form starting.

D. Equivalent Circuit Analysis

The synchronous speed of induction motor is shows as in(1).

$$N_S = \frac{120 f}{P}\ ,\ \ \omega_S = \frac{2\pi N_S}{60} \tag{1}$$

where, Ns is rotation speed, f is input frequency, P is number of pole, ω_S is synchronous radius speed.

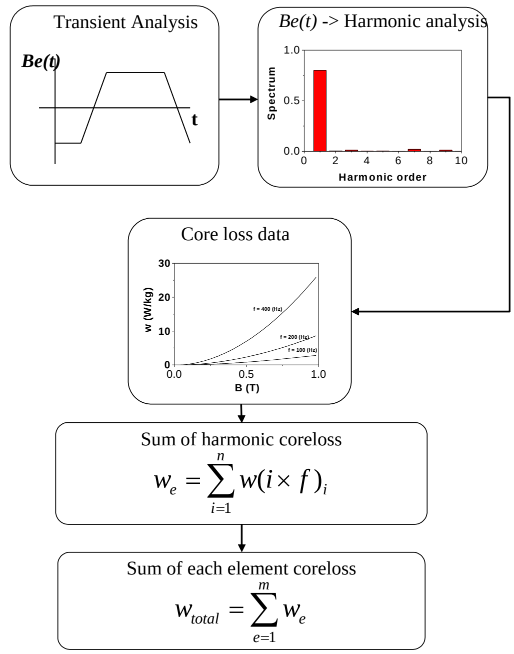


Fig. 3. Process for calculate the core-loss.

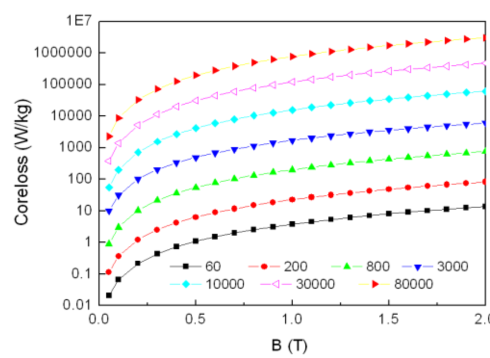


Fig. 4. Core-loss density measured by Epstein tester

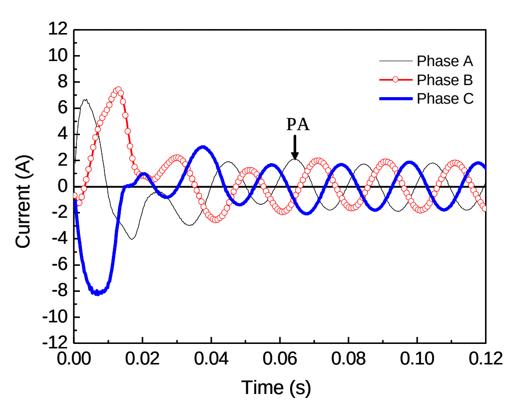


Fig. 5. Current waveforms by FEM analysis

The secondary impedance referred to the stator is as in (3)

$$\mathbf{Z_2} = \frac{r_2'}{s} + jx_2' \tag{3}$$

where, r_2', x_2' is secondary resistance and leakage reactance referred to the stator respectively.
The total impedance combined secondary and excited impedance is calculate as in (4) .

$$\frac{1}{\mathbf{Z_g}} = \frac{1}{r_c} + \frac{1}{jx_m} + \frac{1}{\mathbf{Z_2}} \tag{4}$$

Therefore, total impedance form source is as in (5).

$$\mathbf{Z_T} = r_1 + jx_1 + \mathbf{Z_g} \tag{5}$$

The input current is determined as in (6)

$$\mathbf{I_1} = \frac{\mathbf{V_1}}{\mathbf{Z_2}} \quad \text{(Arms)} \tag{6}$$

The input power is determined as in (7)

$$P_{in} = m_1 V_1 I_1 \cos\theta \tag{7}$$

The output power and torque is determined as in (8) ,(9)

$$P_2 = m\, I_1'^2 \frac{(1-s) r_2'}{s} \quad \text{(W)} \tag{8}$$

$$T = \frac{60}{2\pi} P_2 \frac{1}{(1-s)N_s} \quad (N \cdot m) \tag{9}$$

where, *m* is number of phase.

E. Core-loss Interpolation

The function for interpolate the core-loss is defined as in (10). In traditional ac machine theory the iron loss is viewed as being caused mainly by the fundamental frequency. Normally, under alternating flux conditions, the iron loss P_c in W/kg is separated into a hysteresis loss component P_h, and an eddy current component P_e, both in W/kg, as shown in (6). And, the anomalous loss is added in (6).

$$P_{core} = k_h f B^2 + k_e f^2 B^2 + k_a f^{1.5} B^{1.5} \quad \text{(W/kg)} \tag{6}$$

where f and B are the frequency and the peak value of the magnetic flux density, respectively. k_e, k_h and k_a are constants provided by the manufacturer.

F. B-H Curve of Materials

Fig. 6. shows the B-H curve of tested material. The thickness of 50PN1300 is 0.5mm. The first number of PN means the thickness. 50PN1300 material is high flux density in high field intensity. But, the lower area of H, the flux density is lower than 35PN230. The characteristic of 50PN1300 is high flux density and high core-loss density.

III. Result & Discussions

A. Core-loss Test Result according to Material

Fig. 7 shows the core-loss test result of the suggested model. The simulation is executed by transient FE analysis. And core-loss is obtained by Fig. 3 methods. The experiment result is obtained by rating load of induction motor. From input and output performance, the resistance loss and mechanical loss is considered. The lasted value is defined as core-loss. 50PN1300 has large core-loss compared 35PN230. This result is predicted because the original core-loss is higher than other one. The method using FEA and FFT is very complex than traditional method. But this method can be suggested the high simulation quality compared with simplistic methods. Fig. 8 shows test setup configuration.

B. Characteristic Analysis

In order to analysis the equivalent circuit, the equivalent parameter is required. The main parameter of motor is shown in Table II. This value is verified the FEA and Test.

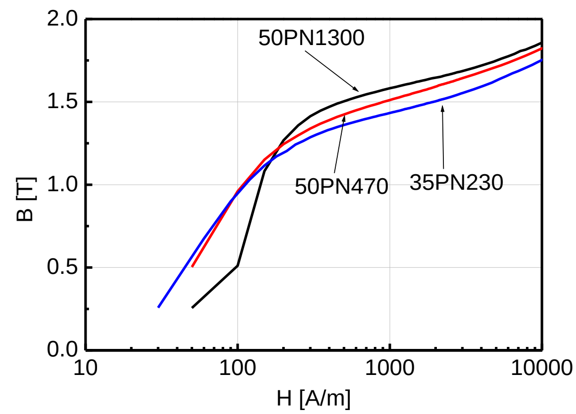


Fig. 6. B-H curve of the measurement model

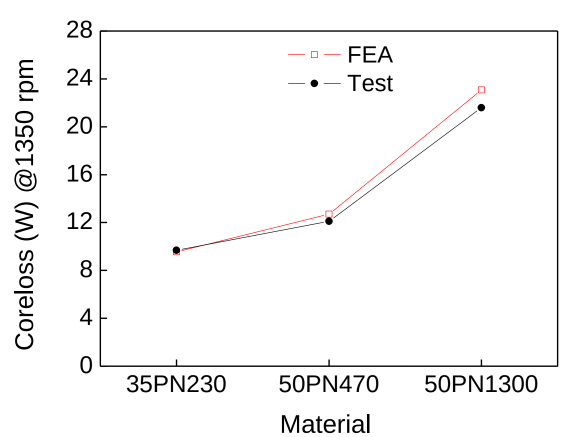


Fig. 7. Comparison core loss between simulation and tested

Fig. 9 show the results of the equivalent circuit analysis of induction motor with 35PN230. The analysis result shows the current, power factor, torque and efficiency. When the motor is starting, the current is very high. Fig. 10 show the efficiency according to materials. The efficiency of 35PN230 is higher than other material motor.

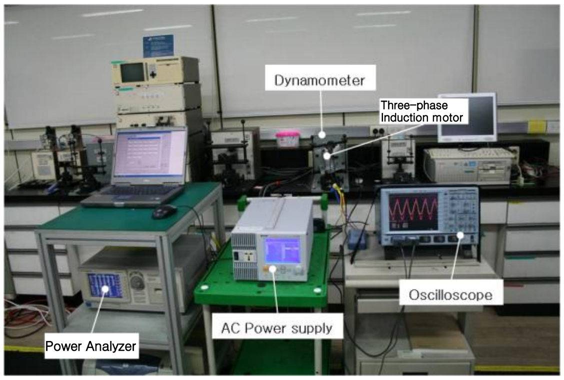


Fig. 8. load test setup for induction motor

TABLE II
EQUIVALENT PARAMETER OF 3-PHASE INDUCTION MOTOR

Parameter	Unit	Value
Primary phase resistance	Ω	3.6
Primary leakage inductance	mH	11.5
Exciting inductance	mH	124
Secondary resistance refer to primary	Ω	5.2
Secondary inductance refer to primary	mH	18

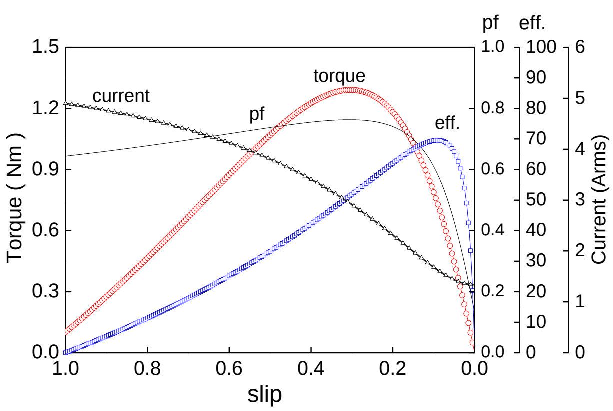


Fig. 9. Equivalent circuit analysis of 35PN230

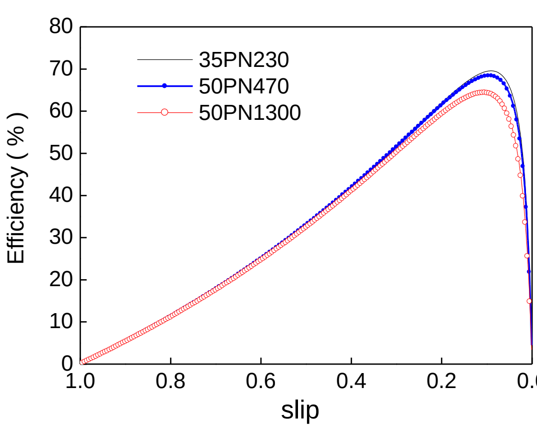


Fig. 10. Efficiency simulation result according to materials

As slip decreases, electric current is looked tendency that decrease for increasing. And, efficiency is decreased after slip 0.07.

C. *Core-loss Resistance*

Fig. 11 shows relation of core-loss and R_c resistance. As increasing R_c, core-loss is decreasing as inverse proportion relation. The R_c position of each materials is display in figure.

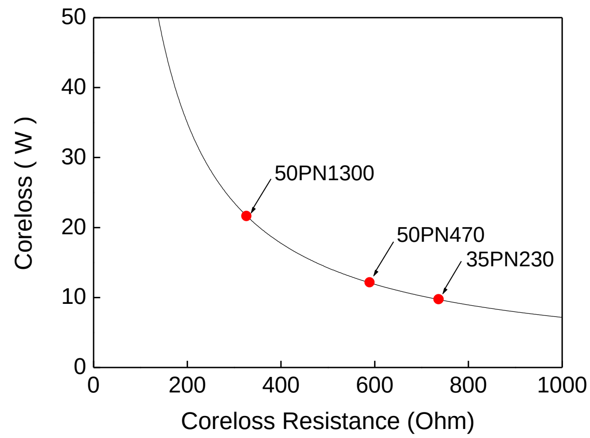


Fig. 11. Core-loss according to core-loss resistance (R_c)

IV. CONCLUSIONS

This paper presents equivalent circuit analysis considering core-loss resistance. In order to decide the core –loss resistance, FEA and harmonic analysis of flux density is used. The core loss is evaluated by the frequency analysis of the magnetic flux density distribution by the time-stepping FEM and the iron loss curves, which are provide by manufacturer. The harmonic analysis is used to analyze the magnetic flux density waveform in each element model. The method using FEA and FFT is very complex than traditional method. But this method can be suggested the high simulation quality compared with simplistic methods. After the core-loss resistance is estimated, the equivalent circuit is analyzed to get the induction motor characteristic for wide range.

REFERENCES

[1] H. Nam, K. H. Ha, J. J. Lee, J. P. Hong, and G. H. Kang, "A studcy on 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, pp. 1472-1475, May 2003.

[2] Ping Zhou, John Gilmore, Zsolt Badics, Zoltan J. Cendes, "Finite Element Analysis of Induction Motors Based on Computing Detailed Equivalent Circuit Parameters", *IEEE Trans. Magn.*, vol. 34, no. 5, pp. 3499-3502, Sep. 1998.

[3] Tine Marˇciˇc□, Bojan ˇStumberger, Gorazd ˇStumberger, "Line-Starting Three- and Single-Phase Interior Permanent Magnet Synchronous Motors—Direct Comparison to Induction Motors." , *IEEE Trans. Magn.*, vol. 44, no. 11, pp. 4413-4416, Nov. 2008.

[4] S. O. Kwon, J. J. Lee, B. H. Lee, J. H. Kim, K.H.Ha, and J. P. Hong, "Loss Distribution of Three-Phase Induction Motor and BLDC Motor According to Core Materials and Operating" , *IEEE Trans. Magn.*, vol. 45, no. 10, pp. 4740-4743, Oct. 2009.

[5] Jeong-Jong Lee, Young-Kyoun Kim, Hyuk Nam, Kyung-Ho Ha, Jung-Pyo Hong, Don-Ha Hwang, "Loss distribution of three phase induction motor fed by pulsewidth modulated inverter", " , *IEEE Trans. Magn.*, vol. 40, no. 2, pp. 762~765, Mar. 2004.