Characteristic Analysis and Efficiency Improvement of Linear Induction Motor considering Design Specification

Seok-Myeong Jang[1], Jeong-Man Kim[1], Yu-Seop Park[1], Kyoung-Jin Ko[1], Jang-Young Choi[1], Han-Wook Cho[2]

[1] Dept. of Electrical Engineering, Chungnam Nat'l Univ., 220, Gung-dong, Yuseong-gu, Daejeon, Korea

[2] Dept. of Electric, Electronic & Communication Engineering Education, Chungnam Nat'l Univ., Daejeon, Korea

Jmkim27@cnu.ac.kr

Abstract —Since linear induction motor (LIM) has transverse edge effect causing the variation of equivalent circuit parameters, 3D analysis should be employed for accurate characteristic analysis results. However, it takes very long time if the 3D finite element method (FEM) is only applied. This paper applied analytical method to calculate efficiency characteristic considering secondary structure. With various possible design specifications, the original model is optimized and the efficiency is increased.

I. Introduction

LIM(Linear Induction Motor) has found the widest prospect for applications in transportation systems. Besides, LIM can also play and important part in industrial investigations and test, such as high acceleration of aircraft in aerodynamic tunnels, high acceleration of vessels in laboratory pools and so on [1]. Due to its various advantages and high demands, plenty of researches on LIM have been actively performed [2]-[5]. This paper applied electromagnetic field theory and derived equivalent circuit parameters to analyze the characteristic of LIM and deals with the efficiency improvement procedure by design optimization. At first, the analysis model is simplified to apply electromagnetic field theory, and the flux density of each region is derived based on Maxwell equations and boundary conditions. On the other hand, to calculate equivalent circuit parameters and the current value of primary and secondary, equivalent circuit method is employed. Since, among the losses of LIM, the copper loss is the highest and core loss is vice versa, this paper calculates the efficiency with primary resistance and current, secondary resistance and current, electromagnetic propulsion force, velocity as shown in Fig.1. Considering various design specifications, such as overhang length, air gap length, aluminum thickness and slot structure, the original analysis model is optimized, and the efficiency is increased from 54% to 74[%].

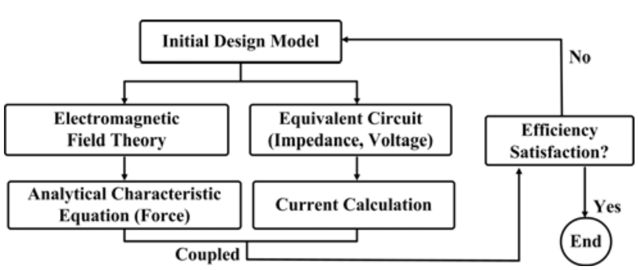

Fig. 1. Optimization procedure of LIM.

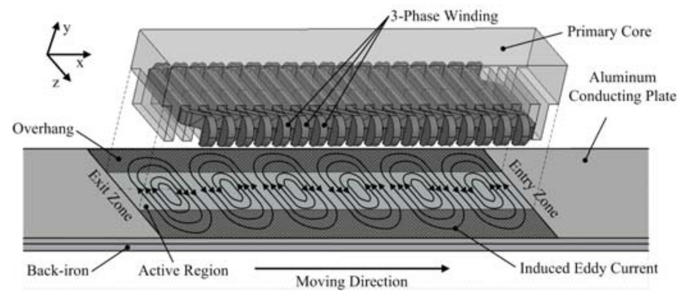

Fig. 2. Analysis Model.

TABLE I
DESIGN SPECICATION OF ANALYSIS MODEL

Parameter	Value	Parameter	Value
Winding Factor	0.93	Turns per phase	450
Pole Number	6	Slot Width	12[mm]
Slot Depth	45[mm]	Phase Number	3
Input Frequency	60[Hz]	Primary Width	91[mm]
Pole Pitch	65[mm]	Air-gap	3.5[mm]
Back-iron Thickness	10[mm]	Aluminum Thickness	5[mm]

II. Characteristic Analysis and Efficiency Improvement by Design Optimization.

A. Analysis Model

Fig. 2 shows the analysis model with design specifications presented in Table I, and the analysis model can be simplified as shown in Fig.3. Based on the analysis model, governing equations and flux density of each region is obtained, and the electromagnetic propulsion force can be calculated. On the other hand, LIM can be expressed by equivalent circuit, and the primary current and secondary current can be calculated by the equivalent circuit parameters, such as primary resistant, primary leakage reactance, magnetizing reactance, secondary resistance and secondary leakage reactance. Here, this paper employed *Russel-Norsworthy* coefficient o consider transverse edge effect caused by secondary structure.

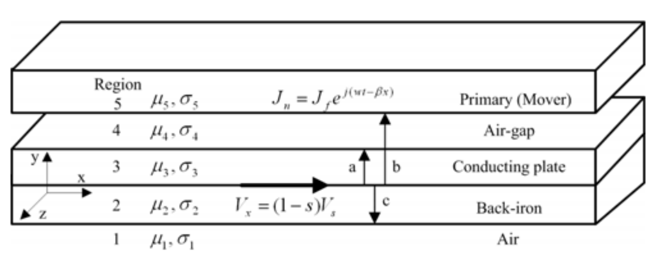

Fig.3. Simplified analysis model.

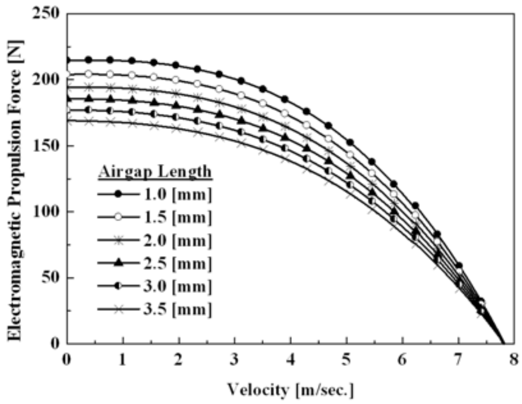

Fig.4. Electromagnetic Propulsion Force according to air--gap length.

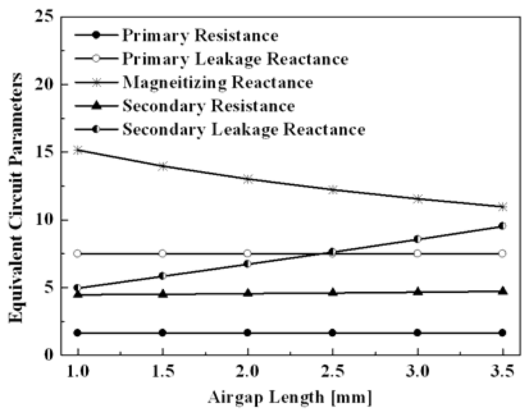

Fig.5. Equivalent Circuit Parameters according to air-gap length.

B. Air-gap length

Fig.4 presents the electromagnetic propulsion force according to air-gap from electromagnetic field analysis. In addition, from Fig.5, it is noticed that the variation of air-gap does not have high effect on both resistances and primary leakage reactions. As the air-gap length increases, the mutual inductance is decreased from secondary to primary, so secondary leakage inductance is increased resulting decreased secondary current. Due to the decreased secondary current, it makes magnetizing current increase. The decreased secondary current also effects on the decrease of electromagnetic propulsion force, and the efficiency is increased due to decreased secondary copper loss. Similar to the characteristic analysis, the other design specifications are considered as follows.

C. Aluminum Thickness

The variation of aluminum thickness does not highly effect on primary parameters, and magnetizing reactance, secondary resistance and leakage reactance are decreased as the aluminum thickness is increased. This is due to increased area of conductor where secondary current flows, and it decreases its resistance. The increased current increases electromagnetic propulsion force, but it causes decreased efficiency.

D. Secondary Overhang Length

The overhang length does not effect on primary resistance and leakage reactance, and the secondary

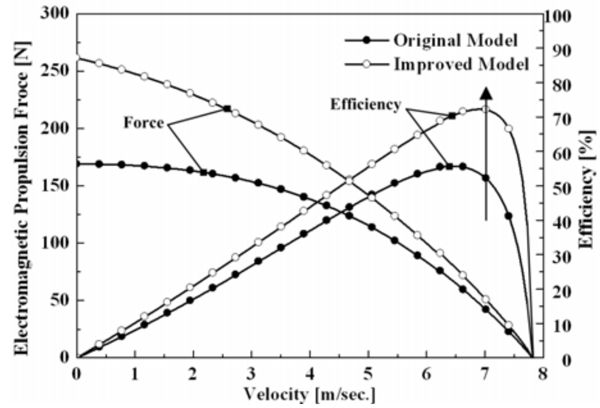

Fig.6. Efficiency Comparison of original model and improved model.

resistance is decreased similarly to the case of aluminum thickness resulting increased secondary current. The increased electromagnetic propulsion force is presented as the secondary current increases, and the decreased efficiency is presented due to the copper loss by increased secondary current.

E. Primary Slot Structure

Differently from other cases, effects of slot structure are minor, but due to the increased slot area allows to use thicker conductor in identical winding turns per phase, so their resistance can be decreased.

III. CONCLUSION

From the efficiency analysis according to design specifications, the original model is redesigned as indicated in the figures. In particular, when the overhang length is zero, which means that the length of primary and secondary is identical, the efficiency is much lower. As a result, the overhang length should be increased, but the exact length has to be determined. From those results, this paper selected the highest point of efficiency at 7[m/sec], and Fig.3(f) compares the original and improved model. It is noticed the efficiency is much more increase from 55[%] to 74[%].

IV. REFERENCES

[1] N. Fujii and T. Harada, “A New Viewpoint of End Effect of Linear Induction Motor from Secondary Side in Ladder Type Model”, *IEEE Trans. on Magn.* Vol.35, No.5, pp.4040-4042, 1999.

[2] Toshiaki Tokoi and Daiki Ebihara, “An Optimal Design Technique for High Speed Single-Sided Linear Induction Motors using Mathematical Programming Method”, *IEEE Trans. on Magn.* Vol.25, No.5, pp.3596-3598, 1989.

[3] Shinya HASEBE and Yoshio KANO, “Effect of the Velocity of Secondary Conductor on Eddy Current and Body Force in Annular Type LIM”, *IEEE Trans. on Magn.* Vol. MAG-23, No.5, pp.2835-2837, 1987.

[4] Satoru Osawa, Masaharu Wada, Mitsuji karita, Daiki Ebihara and Toshiki Yokoi, “Light-weight type Linear Induction Motor and Its Characteristics”, *IEEE Trans. on Magn.* Vol. 28, No.5, pp.3003-3005, 1992.

[5] Dal-Ho Im and Chang-Eob Kim, “Finite Element Force Calculation of a Linear Induction Motor Taking Account of the Movement”, *IEEE Trans. on Magn.* Vol. 30, No.5, pp.3495-3498, 1994.