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Research Article

Thrust Analysis and Improvement of Single Sided Linear Induction Motor using Finite Element Technique

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Abstract

The end effect of a linear induction motor (LIM) is one of the most important parameters that degrades the performance of a LIM .These effects become prominent in high speed operations of a LIM. The exit part of the LIM created minor end effect as compared with those of the entry part. However, the asymmetric air gap magnetic flux density at the exit zone produces unbalanced normal forces resulting in dolphin effect. In this paper, proposal is made to chamfer the primary outlet teeth to minimize the longitudinal end effect at the exit zone. We report on our proposal of reducing the end effects by analysing LIM by using finite element method. Results proved that chamfering can improve thrust performance effectively.

Keywords: *Linear Induction Motor, End effects, Dolphin effect, Finite element method, Mosebach Model, Thrust.*

1. Introduction

Linear induction motor(LIM) is widely used in places that requires linear motion since it produces thrust directly and has simple structure, easy maintenance and low cost. Because of these features ,the Linear induction motors have many applications such as transportation, material handling, actuators, pumping of liquid metal, sliding door closers, robot base movers, drop towers, elevators etc (C. Gupta et al , 2009). In a LIM, the primary consists of a rectangular slotted structure of steel laminations. Within the slots of the primary stack are laid the polyphase windings to produce the linearly traveling magnetic field, just like the rotating magnetic field in a rotary induction motor (RIM), produced by the polyphase stator windings. The secondary of the LIM is an aluminium sheet (or copper), with or without a solid back iron plate, that completes the magnetic circuit and creates the magnetic flux linkage across the air gap. This in turn induces a voltage on the conductive wall, which generates an eddy current in the conducting outer layer of the secondary. The interaction between this eddy current and the changing electromagnetic field generates electromagnetic thrust on the plate in the longitudinal direction of the motor Laithwaite, E.R et al , 1995).

The main difference between the RIM and LIM is on the occurrence of the end effects. Because of the rotary structure end effects doesn't occur in RIM, as it has no end parts. On the other hand, the LIM has a beginning and an end in the travelling direction. This feature produces end effects in an LIM that adversely influences its performance. In recent decades, a number of papers on the performance analysis of LIM have been available. Yamamura (Yamamura S, 1979) and Poloujadoff (Poloujadoff, M et al , 1980) developed the theoretical aspects of LIM in detail, especially the influence of longitudinal end effects on its performance. The work is concerned with theoretical analysis of single and double-sided linear induction motors. Nasar and Boldea [4,5] discussed in their book the research on the single-sided linear induction motor. Gieras Gieras J.F et al , 1994), in his book covers all aspects of LIM, including constructional features, applications, electromagnetic effects and design. Single sided, double sided linear induction motors and tabular configurations are analysed in terms of equivalent circuits and their components. R.M.Pai and I.Boldea Pai R.M et al , 1988) derived the steady state performance characteristics of LIM using one, two and three dimensional analyses including all the effects in the secondary. E.R. Laithwaite H.-W. Lee et al , 2010) carried out the study of applying linear induction motors to the acceleration of large masses to high velocities. In this paper, chamfering of the primary of the LIM is done to reduce the end effects at high speed operations. For the purpose, LIM is analysed by using the finite element analysis.

2. End Effects of Linear Induction Motor

Due to the finite length of the stator, the generation and

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disappearance of magnetic field causes eddy currents in the secondary plate. These currents affect the air gap flux profile in the longitudinal direction. These flux profile attenuation become severer as the speed increases. Such a phenomena is called 'end effect' of LIM. These effects become increasingly relevant with the increase in the relative velocity between the primary and the secondary. Thus, end effects are considered as the function of the velocity Manna. M. S et al , 2006). The Linear Induction motor has ability to non-adhesive actuation with thrust (drag force) due to air-gap and end-effects which provide with the leakage reactance of the LIM's Primary. The end effects and very precisely the Dolphin Effect which happens to be due the uneven air-gap magnetic flux density at both ends of primary (entry & Exit points).

In LIMs, end effects are of two types, transversal end effects and longitudinal end effects. Transversal end effects are the differences in the magnetic field distribution due to the finite geometry in the transversal direction. These effects are considered to be speed independent. Longitudinal end effects of the LIM are calculated analytically as attenuating magnetic waves travelling in the direction of the movement.

The total air gap flux density can be divided as following H.-W. Lee et al , 2010):

$$B_y(x,t) = B_1(x,t) + B_{entry}(x,t) + B_{exit}(x,t) \quad (1)$$

$$B_1(x,t) = |B_s|\cos\omega t - kx + \delta_s \quad (2)$$

$$B_{entry}(x,t) = B_1 e^{\frac{x}{\alpha_1}} \cos \omega t \quad (3)$$

$$B_{exit}(x,t) = B_2 e^{\frac{x}{\alpha_2}} \cos\omega t \quad (4)$$

Here, $B_s = \frac{w}{K}$, $K = \frac{\pi}{\tau}$

From (1), thrust force is calculated as

$$F_x = \frac{1}{2} Re\left[\int J_e B_y{}^{*} ds\right] \quad (5)$$

Here J_s - Induced current density,

B_y - Y- component of air gap magnetic flux density.

ds- Differential surface element.

F_x – Drag Force (Thrust) in Linear direction.

In practice, the additional hardware at the entry part cannot be installed, thus the end effect at the exit part may be minimized by compromising with geometrical variations of the Primary. The Mosebach Model for the Primary core is introduces here with chamfering the entry and exit corners of Primary core with different angles ranging from 5^0 to 47^0. Hyung-Woo Lee et al , 2011)

3. FE Model of LIM

The two dimensional Finite Element Analysis model of LIM has been designed with the specifications shown in Table 1. The geometry overview of LIM is shown in Fig 1Manna. M. S et al , 2010).

4. FE Model of Mosebach (Chemfered) LIM

The concept of the virtual primary core that we have introduced in our model basically generates drag force and uneven normal force at the exit zone Boldea, I. et al , 1985). Chamfering of the outlet primary teeth is done at the exit and entry part. This will minimize the exit end effect and hence improves the output thrust Pai R.M et al , 1988). The chamfered angle α taken in this paper is 45° and will be changed depending on the air gap length. The geometric view of the chamfered model is shown in Fig. 2.

Table. I. LIM Dimensions and Specifications

LIM Parameters	Dimensions of LIM
Primary Length	170mm
Primary Width	40mm
Length of secondary Sheet	240mm
Thickness of secondary sheet	4mm
Thickness of back iron	10mm
Air gap length	Varied from 1mm to 5 mm
Number of Slots	12

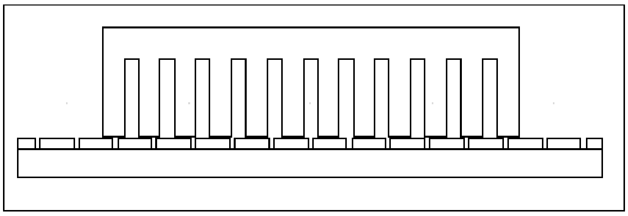

Fig. 1 Geometric overview of LIM

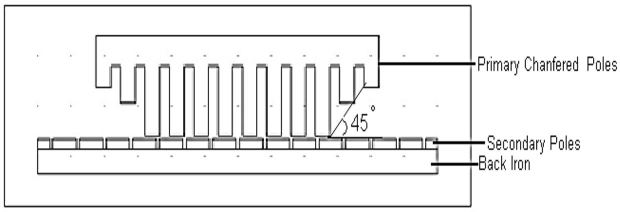

Fig. 2 Geometrical overview of Chamfered Model of LIM

5. Simulation Results

a) Magnetic Flux Density Analysis

The Finite Element Model of Simple Linear Induction Motor as well as Mosebach Model of the Linear Induction motor by keeping all other parameters and Dimensions identical. The surface plots of Mosebach model and simple model are shown in Fig. 3 and Fig. 4 respectively. Hence the Dolphin Effect reduces to certain level which further boasts to the efficiency of the Motor. The magnetic flux density in the different subdomains like in Primary, Secondary and air-gap have been shown for the both the cases in Fig. 5 and Fig. 6 respectively. The Comparative analysis shows that the magnetic flux density at entry and exit part of chamfered model (Mosebach) is decreased by

20% and 37% respectively. With the decreased Dolphin effect, the thrust force remain same to satisfy the performance of the machine, thereby decreasing the thrust ripple by about 5% and hence improve the performance of the machine.

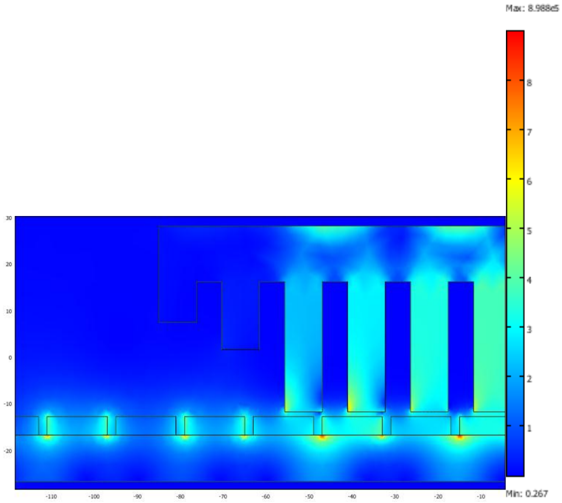

Fig. 3 Surface Plot of Magnetic Flux Density of Chamfered Model

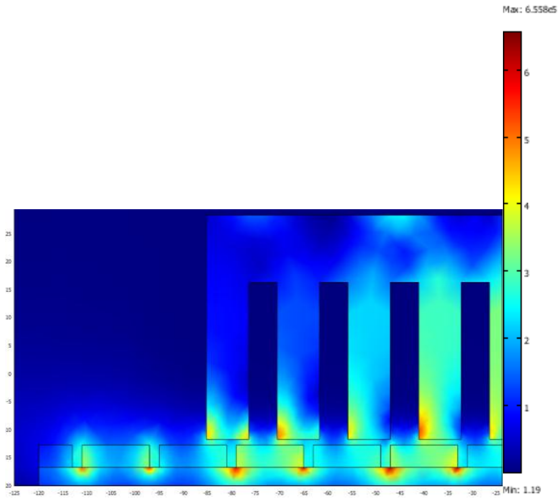

Fig. 4 Surface Plot of Magnetic Flux Density of Simple LIM

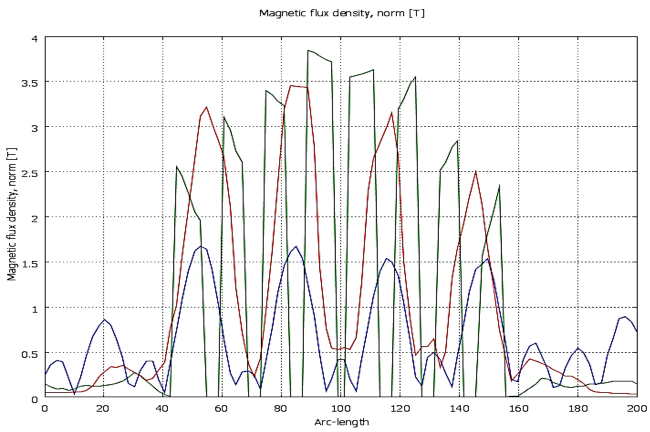

Fig. 5 Magnetic Flux Density for Primary, Secondary and Air-gap domain of Chamfered Model of LIM.

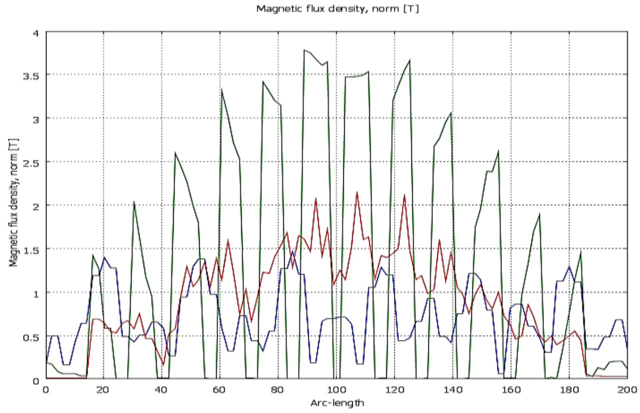

Fig. 6 Magnetic Flux Density for Primary, Secondary and Air-gap domain of Simple Model of LIM.

b. Magnetic Potential Analysis

The further extended analysis has been achieved with help

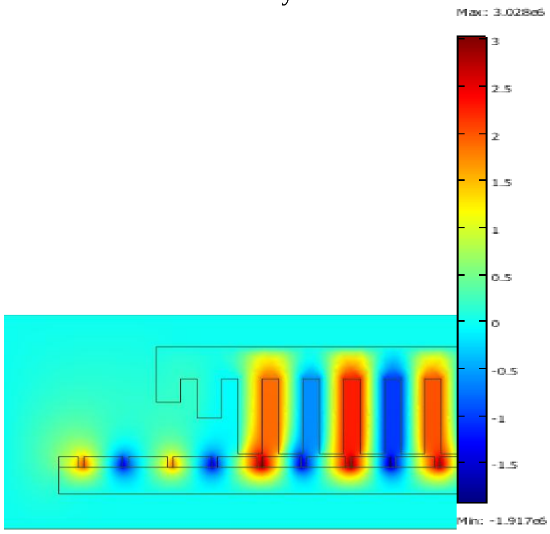

Fig. 7 Surface Plot of Magnetic Potential of Chamfered Model of LIM

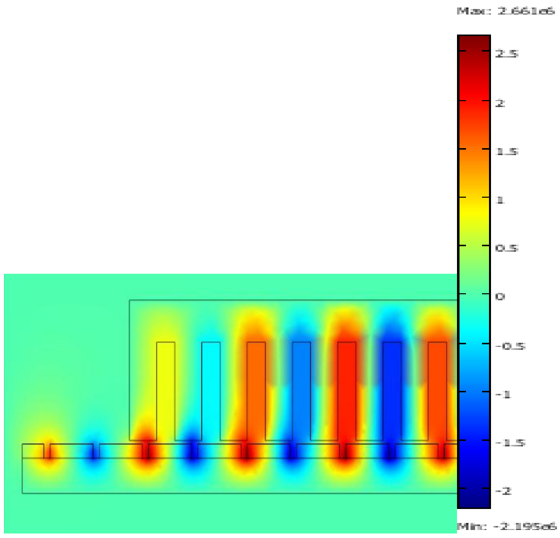

Fig. 8 Surface plot of Magnetic Potential of Simple Model of LIM

of computation of Magnetic Potential, which also depicts the same reduction in the Dolphin effect. The Magnetic Potential Surface Plots for Mosbach Model and Simple Model are shown in Fig. 7 and Fig. 8 respectively. The sub-domain analysis in both models is shown in Fig. 9 and Fig. 10. It can be noticed from here that the drop in the Magnetic potential at the entry as well exit point provides very low flux saturation on the teeth, therefore the fringing flux which creates drag for primary reduces sufficiently.

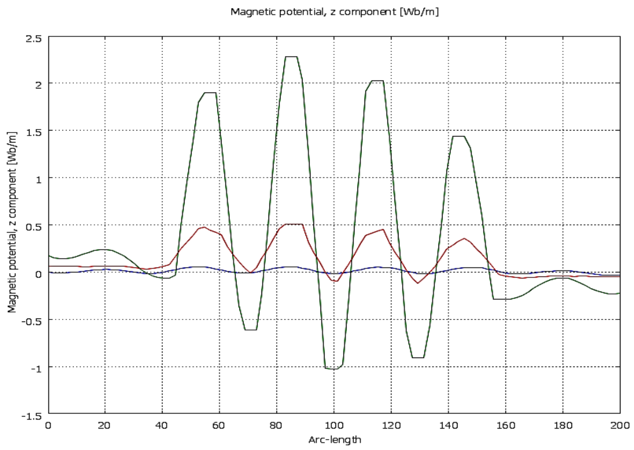

Fig. 9 Magnetic Potential graphs for Primary, Secondary and Air-gap domain of Chamfered Model of LIM.

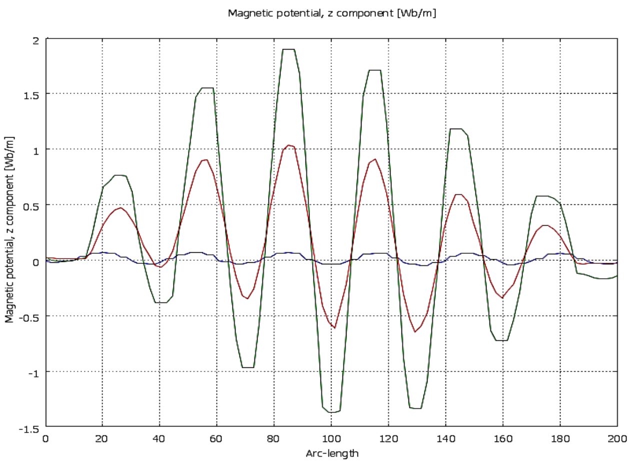

Fig. 10 Magnetic Potential graphs for Primary, Secondary and Air-gap domain of Simple Model of LIM.

Conclusions

End Effects that weakens the performance of linear induction motor has been considered in this paper. Although the effects created by the exit end part is minor as compared with those of entry part, but it is one of the keys to weaken the dolphin effects that occurs in high speed operations of LIM. Chamfering of the both entry and the exit teeth has been done to minimize the longitudinal end effects. The model is than simulated by using the FEM. Results proved that chamfering is effective in reducing the thrust ripples, which improves the performance of the machine. The work can be extended further with different angles of chamfering at the entry and exit point to achieve the best performance with reduced magnetic fringes or dolphin effects.

References

Yamamura S.(1979), Theory of Linear Induction Motors, 2nd Edition, *John Wiley & Sons, Inc*., New York.

C. Gupta, Manna , M.S. and Marwaha, S. (2009), Finite Element Method as an Aid to Machine Design: A Computational Tool, *Proc. of International Conference on Comsol organized by Comsol Multiphysics Ltd*., USA held at Bangalore.

Poloujadoff, M., The Theory of Linear Induction Machinery, Oxford University Press, Inc., New York, 1980.

Nasar, S.A. and Boldea, I (1987)., Linear Electric Motors, *Prentice Hall Inc*., Englewood Cliffs New jersey, 1987.

Manna ,M.S.; Marwaha,S.; Marwaha,A (2009).; and Vasudeva, C., Two dimensional Quasi- Static Magnetic Field Analysis of SLIM using Adaptive Finite Element Method, in *Proc. of International Journal of Recent Trends in Engineering,* Vol.2, No. 6, pp.50-52.

Boldea, I. and Nasar, S.A. (1985), Linear Motion Electromagnetic System, *John Wiley & Sons, Inc*., New York.

Gieras ,J.F. (1994), Linear Induction Drives, *Oxford University Press, Inc*., New York.

Pai,R.M.; Boldea, I.; Nasar, S.A (1988), A Complete Equivalent Circuit of a Linear Induction Motor with Sheet Secondary, *IEEE Transactions on*, Volume : 24, Issue : 1, Pp :639-654.

Manna ,M.S.; Marwaha,S.; Marwaha,A (2009).; and Vasudeva, C., Analysis of Permanent Magnet Linear Induction Motor (PMLIM) using Finite Element Method. IEEE Xplore- *Proc. of Int. Conf. on Advances in Recent Technologies in Communication and Computing, ARTCOM*-2009 , 540-542.

Laithwaite, E.R(1995), Adapting a Linear Induction Motor for the Acceleration of Large Masses to High Velocities, *IEEE Trans. on Electric Power Applications* , Volume :142 , Issue: 4, Pp :262-268.

H.-W. Lee, C.B. Park, B.S. Lee, and H.-J. Park (2010), Exit End Effect Reduction Of a Linear Induction Motor for the Deep-Underground GTX, Proc. of XIX *International Conference on Electrical Machines –ICEM*, Rome.

Hyung-Woo Lee, Chan-Bae Park and Byung-Song Lee (2011), Thrust Performance Improvement of a Linear Induction Motor, in the *Journal of Electrical Engineering & Technology* Vol.6, No.1, pp.81-85.

Manna. M. S.; and Marwaha. S (2006); Performance Evaluation of Single Linear Induction Motor Consider End-effects by using Finite Element Method, Proc. of *IEEE International Conf. on Power and Electronics, Drives and Energy Systems for Industrial growth PEDES*-06, New Delhi, pp. 1-4.

Manna. M.S.; Marwaha .S; and Garg N. (2010); Modelling and Simulation of Linear Induction Motor by using 2D Finite Element Method., Proc. of International *Journal of Engineering Technologies and Applications in Engineering Technology and Sciences*, pp. 286-289.