Air Gap Field Analysis of Single Sided Linear Induction Motor with Time Harmonic Finite Element Method

Manpreet Singh Manna[2], S. Marwaha[2] and Navpreet Kaur[1]
[1] Deptt. of ECE, Universal Group on Institutes, Lalaru, Punjab, India
[2] Deptt. of EIE, Sant Longowal Inst. of Engg. & Tech.,
(Deemed University), Longowal, India
Email: nav1984.94@gmail.com, mannasliet@gmail.com

Abstract- In recent years, the single-sided linear induction motor (SLIM) has been the most suitable choice for electric vehicles of the wheel and touchless type. The reason is simplicity in manufacturing, capability in applying direct force, moving and braking and low pollution. To study the influence of air gap between the stator and mover of linear induction motor the prototype model of SLIM used as benchmark, which could incorporate the natural asymmetry for the SLIM. There are two common approaches for simulating electrical machines are the transient approach and time-harmonic approach. In this paper, the time-harmonic FE approach is generalized to situations with arbitrary set of relevant air gap field harmonics. In this technique, a new idea is introduced to account for the longitudinal end-effect factor. Meanwhile, other electromagnetic effects, such as transverse edge effects and skin effect are taken into account. The simulation results have been achieved by using Comsol multiphysics software with AC/DC machine tool box for 2D/3D analysis of flux distribution analysis.

***Keywords*—Single Sided Linear Induction Motor, End Effect, Transverse Effect, Finite Element Method, Magnetic Distribution**

1. INTRODUCTION

Linear Induction motor is rotary, squirrel cage induction motor, split radially along its axis of rotation and flatten out is a linear induction motor that produces direct linear force instead of torque.LIM is non-contacting and very high speed motor, Linear motor that operates on the same principle as a rotary, squirrel induction motor. The capable speeds of LIM is up to 1800 in/sec [45 m/s].The application of LIM is used in where accurate positioning is not required. The basic principle of LIM operation is similar to that of a conventional rotating squirrel-cage induction motor. Stator and rotor are the two main parts of the conventional three phase rotary induction motor. The stator consists of a balanced polyphase winding which is uniformly placed in the stator slots along its periphery. The stator produces a sinusoidally distributed magnetic field in the air-gap rotating at the uniform speed $2\omega/p$, with ω representing the network pulsation (related to the frequency f by $\omega = 2\pi f$) and p the number of poles. The relative motion between the rotor conductors and the magnetic field induces a voltage in the rotor. This induced voltage will cause a current to flow in the rotor and will generate a magnetic field. The interaction of these two magnetic fields will produce a torque that drags the rotor in the direction of the field. This principle would not be modified if the squirrel cage were replaced by a continuous sheet of conducting material. Thus, LIMs may be classified as either short- primary (also called short-stator in) or short- secondary (called short-rotor) LIMs. LIMs may also be classified based on its construction as Single Sided LIM (SLIM) in which there is one primary and one secondary placed one on top of the other, Double Sided LIM (DLIM) in which there are two primaries on the two sides of a secondary, Tubular LIM (TLIM) in which the primary and secondary are placed co-axially etc. They are also classified as high-speed and low-speed LIMs.

The basic difference in the analysis of the rotary induction motor and the SLIM lies in the open air gap of the LIM. The longitudinal end effect degrades the performance and bring to question the very feasibility of the use of SLIMs.[5] Also, the air gaps in LIMs are usually of higher magnitude than those in normal induction motors. Electromagnetic vibration and noise are mainly generated by electromagnetic forces resulting from the combination of harmonic fluxes in the air gap. [7]

2. SLIM Model Formulation

The two dimensional finite element analysis model of SLIM has been designed with following specifications [6]

Length of primary stack:130 mm
Width of magnet:10 mm
Length of mover: 90 mm
Height of mover: 35 mm,
Height of permanent magnet teeth:2 mm
Thickness of back-iron: 10 mm
Air gap length: varied from 0.5 mm to 1.5 mm

The governing equation which describes the magnetic vector potential in a single sided linear induction motor is given by

$$\mathrm{rot}\frac{1}{\mu}\mathrm{rot}\ \vec{A}=\overrightarrow{J_o}-\rho\left(\frac{\partial\vec{A}}{\partial t}-\vec{v}Y\vec{C}\right) \quad (1)$$

Where ρ is an equivalent conductivity of mover's material taking account of transverse edge effect [2] and v is the velocity of mover. The current density of the sheet at the primary surfaces is denoted by $\overrightarrow{J_o}$. the current sheet distribution is given by

$$\overrightarrow{J_o}=\mathrm{J_o}\exp\left(j(\omega t-kx)\right) \quad (2)$$

$\mathrm{J_o}$ is related to primary current which is given by

$$\mathrm{J_o}=\frac{3\sqrt{2}\,\omega_1 k_{\omega_1} I_1}{P\tau} \quad (3)$$

Where ω_1 is the number of turns, k_{ω_1} is the primary winding factor, τ is the pole pitch and P is the number of poles. The circuit equation coupled with the field equation can be written as

$$[V]=[I][R]+[L_o]\frac{d}{dt}[I]+[E] \quad (4)$$

Where [V] is supply voltage vector, [R] & [L_o] are primary circuit parameters and [E] is an emf vector of winding. To solve the above equation the Garlerkin Finite element method is used. After solving and coupling of equation (1) and (4) the resultant equation achieved as

$$\left\{\begin{bmatrix}\frac{1}{\mu}S & -N\\ 0 & R\end{bmatrix}+\frac{1}{\Delta t}\begin{bmatrix}T & 0\\ L_{effN^T} & L\end{bmatrix}\right\}\begin{bmatrix}A\\ I\end{bmatrix}_t$$

$$=\frac{1}{\Delta t}\begin{bmatrix}T & 0\\ L_{effN^T} & L\end{bmatrix}\begin{bmatrix}A\\ I\end{bmatrix}_{t-\Delta t}+\begin{bmatrix}0\\ V\end{bmatrix}_t \quad (5)$$

From the equation-5 further computation of force acting on machine could be derived [1]

$$F_x=\int_l\frac{\omega}{2\mu_o}\{(C_x^2-C_y^2)m_x+2mC_xC_y\}dl \quad (6)$$

$$F_n=\int_l\frac{\omega}{2\mu_o}\{(C_y^2-C_x^2)m+2m_xC_xC_y\}dl \quad (7)$$

where m_x and m_y are the unit normal direction vectors, ω is the primary stack width. In order to improve accuracy, the SLIM has been computed at different air gaps and it was observed that entry-end-effect could be reduced to high extent with change in the air-gap by keeping the speed of SLIM at constant value of 30 m/s.

3. ADAPTIVE MESH GENERATION

After defining the distinguish boundary conditions, meshing is performed with following statics for the different air gaps varies from 0.5 mm to 2.0 mm. Mesh refinement has been done by Adaptive Mesh technique (as shown in figure.1). After applying the Adaptive Mesh refinement technique the degree of freedom could be increased to times and number of boundary element increased to 1.45 times of the slandered meshing statics as shown in Table 1.

Table 1 Adaptive Meshing Refinement Statics

Items	Standard Meshing	Adaptive Mesh
Number of degree of freedom	267	75071
Number of mesh points	267	4005
Number of elements	490	7840
Triangular	490	7840
Number of boundary elements	154	616
Number of vertex elements	52	52
Minimum element quality	0.701	0.701
Element area ratio	0.141	0.141

The two dimensional mesh geometry of SLIM has further been solved for analysis of magnetic potential vector and current density vector by post processing tool of Comsol Multiphysics ver 3.5a.[10]

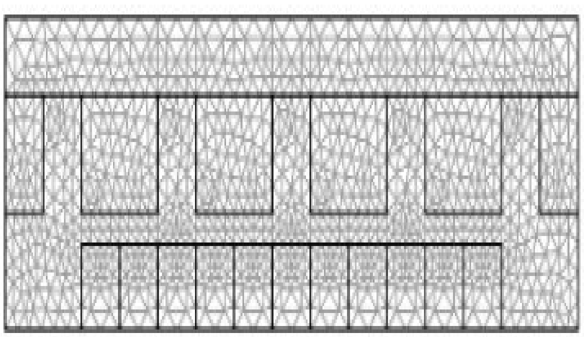

Figure 1. Meshing of SLIM Model

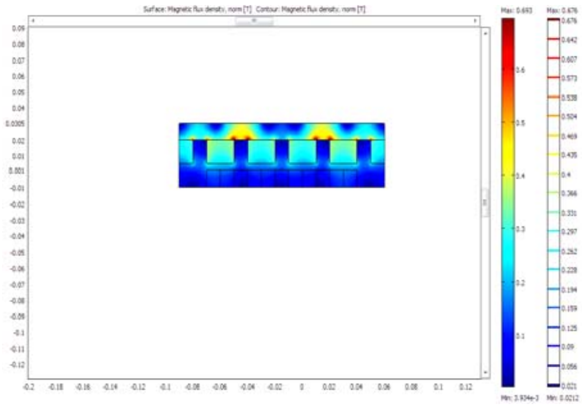

Figure 2. Simulation of SLIM for Magnetic Flux Distribution

4. Results and Discussion

The magnetic field distribution of SLIM after geting it simulated with Comsol Multiphysics is shown in figure.2. The magnetic potential at the different parts of SLIM including air gap has been shown in figure.3. It is evident; the magnetic field in the air gap can be divided into three parts. After collective and comparative analysis It has been found that the best performance can be achieve for SLIM Model design for work is between 0.5 to 1mm and more precisely 0.85 mm with this value most of the effects like End effects, Transversal edge effects can be controlled or minimized to improve the Thrust(Force) between the mover and stator. The efficiency improvement which depends upon Power factor, Goodness factor, Correction factor those are further depends upon air gap, slot pitch, tooth width and secondary sheet thickness. The Magnetic field distribution in the LIM is effected by air gap between the stator and mover. The air gap (and also the surface resistivity) affects length of penetration differently at low speed and high speeds. So by varying the air gap the optimum performance can be achieved without compromising to the speed of the motor. The surface current density was also computed at the different air gaps and there was little achievement in this area as the speed is the main factor for the current density to become uniform.

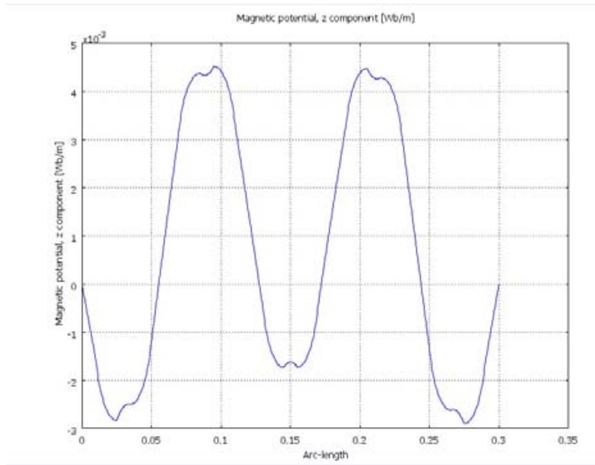

Figure 3. Magnetic Potential of SLIM at air gap of 1mm

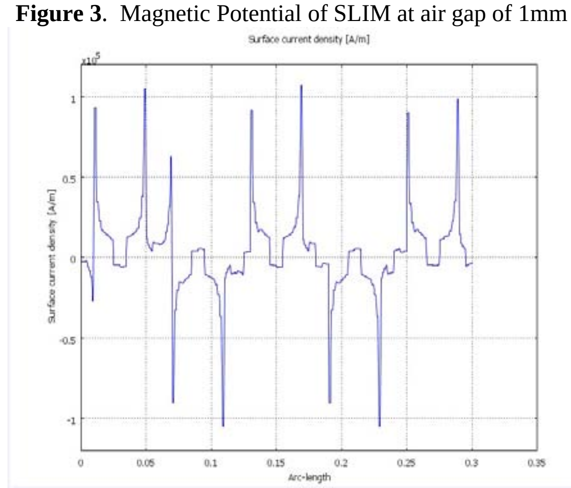

Figure 4. Surface current density of SLIM air gap 1 mm

5. CONCLUSIONS

The SLIM has several potential applications. Chief among which is in transportation.[3,4] For this purpose, the efficiency of SLIM can be improve to certain level by varying the air gap between the mover and stator upto some permissible value. The most significant effect that is End effects of motor which reduces the thrust can be minimize by selecting appropriate material also mover (secondary sheet) which is normal practice is made up of aluminum with backing of iron. The Computational and Simulation work has been carried out by using one of the latest Finite Element Tool i.e. Comsol Multiphysics Software Inc.USA.

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