ANALYSIS OF FLUX DENSITY AND FORCE ON DOUBLE SIDED LINEAR INDUCTION MOTOR WITH DIFFERENT POLE SHAPES

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Abstract—To show signs of improvement outline of electromagnetic devices, it is critical to comprehend the exact evaluation of force and magnetic flux density. The possibility of choice of permanent magnet and proper shape of magnet greatly affects the performance of double sided linear induction motor. The paper presents the analysis of double sided linear induction motor for the evaluation of magnetic flux density and force in the longitudinal direction for several pole shapes. Finite element method is used to carry out the analysis, the behaviour of double sided linear induction motor in terms of magnetic vector potential using commercial software package COMSOL Multiphysics.

I. INTRODUCTION

For the year’s the linear induction motors have not been studied. Linear electric machines were invented in the nineteenth century; they gained fame at commercial stage in 1960s. Now days many researchers have shown there large interest in the performance evaluation of Linear Induction motor due to their large importance of application in the notably in the field of transportation system. Linear machines found many applications broadly classified as force, energy and power machines[1]. Linear machines are the electromechanical devices which produce unidirectional or bidirectional motion. In this regard, they internally develop the electrical forces which results in mechanical forces. In the conventional revolving motors the degree of mechanical freedom is a rotation and rotor rotates with respect to the stator whereas in linear motors the degree of freedom of mechanical freedom is translational i.e. moving member moves linearly with respect to stationary members. Linear drives have less mechanical components, masses of inertia low power losses, less wearing effect[2].

The operating principle of the linear induction motor is identical to that of customary rotating ‘squirrel-cage’ induction motor and can be easily understood. By the easy topological put into effect of splitting and unrolling as presented in Fig. 1[3]. The stator is provided with windings so that circulating a set of balanced polyphase currents induces a sinusoidally distributed magnetic field in the air gap, rotating at uniform speed $2\pi f/P$ where $2\pi f$ represents network pulsation and $P$ represents the number of poles pair. When the rotor rotates at the speed different from $2\pi f/P$, electromotive forces and currents are induced in
the cage and the forces arising due to interaction currents and the magnetic field drag the rotor in the direction of the field. Now the principle would not be modified and produce the drag in a same manner if the cage is replaced by a continuous sheet of conducting material. Stator is designated as primary and rotor is designated as secondary. As a substitute of revolving magneto motive force, the primary now creates a gliding flux. The secondary will then be moved by the primary field which creates an electromotive force and currents. Normally, when the secondary conductor is expelled from the air gap, it has to be supplanted consequently the secondary is drawn longer than the primary.

Fig. 1 Imaginary process of splitting and unrolling

In this paper the two dimensional static behavior of magnetic flux density and force evaluation by the principle of virtual displacement is analyzed for double sided linear induction motor. The finite element analysis tool is used to carry out the analysis for choosing the optimum pole shape as an aid to better design.

II. Model Creation

Fig. 2 shows the model of double sided linear induction motor with an air gap of 0.01mm between primary and secondary. The air gap must be very small, much smaller than the allowable air gap otherwise the current required for the coil becomes unreasonable. The two primaries are considered to be stationary and a secondary is moving. The primary is made up of an array of permanent magnets having remanent flux of 1.23T backed by an iron plate called back iron. Back iron usually a ferromagnetic material plays an important role it helps in maximizing the induced field. The iron plate serves to amplify the magnetic field produced in the coil. Whereas secondary is made up of three phase coil on an aluminium armature.

The permanent magnets gives the magnetization of 0.98e6A/m. The current density is assumed to be 3.66A/mm². The conductivity of the iron and copper is considered to be 5.99e7S/m and 1.03e7S/m respectively. Relative permeability for iron is considered to 2e3.

Fig. 2  Two dimensional model for DLIM for rectangular pole shape

The linear induction motors belongs to the class of motors which the magnetic flux is in the direction of motion. Due to which they are also known as longitudinal flux motors. There are several effects which affect the performance of the machine such as end effects, edge effects, skin effects, winding peculiarities, saturation effect, dolphin effect etc[4].

The model was simulated for the static condition. The movement of electric charge causes effects in the point of the surrounding space, so that it is possible to define the magnetic flux density field B. The flux density’s changes under ending and middle tooth[5]. Varying parameters such as air-gap, thickness of aluminium sheet and number of poles effect was analyzed on double sided linear induction motor[6]. A charge δq
moving within the magnetic flux density field \( B \) at a velocity \( v \) experiences a force given by

\[
\delta F = \delta q v \times B
\]

The force is called Lorentz force

Electromagnetic forces are computed with Maxwell’s stress tensor. In the case the surface enclosing the object is selected then the force is computed an integral over this surface of quantities obtained directly form the potential that describes the field.

The Maxwell’s stress tensor is given by

\[
dF = -\frac{\mu_0}{2} H^2 n dS + \mu_0 (H \cdot n) dH
\]

Where \( H \) is the vector field over the \( S \) surface containing the volume \( \tau \) having the material permeability \( \mu_0 \) and \( n \) is the unity vector normal to surface \( dS \).

The two component of force if both directions are

\[
dF_t = (\mu_0 H_t H_n) dSt
\]

\[
dF_n = \frac{\mu_0}{2} (H_t^2 - H_n^2) dSn
\]

The amplitude of the force is given as

\[
dF = \sqrt{\left(\mu_0 H_t H_n\right)^2 dS + \left[\frac{\mu_0}{2} (H_t^2 - H_n^2) dS\right]^2}
\]

To evaluate the magnetic forces acting the 2D problem the surface is reduced to a line called \( l \). The tangential and normal components are computed by means of line integral along line \( l \).

\[
F_t = L \mu_0 \oint H_t H_n dl
\]

\[
F_n = L \frac{\mu_0}{2} \oint (H_n^2 - H_t^2) dl
\]

The same could also be evaluated by the principle of virtual work displacement. In the is method the variation of magnetic coenergy at different positions is calculated, it requires the solution of at least two field problems with an increase of computation time and with the not negligible problem of the choice of the width of the position variation. That is the method is based on the comparison of energy balanced equation corresponding to virtual displacement.

### III. Finite Element Analysis

FEM is a more powerful and versatile numerical technique for handling problems involving complex geometries. The finite element method not only overcomes the shortcomings of the traditional analytical and numerical methods, but it is also endowed with the features of an effective computational technique. In numerical analysis, the finite element method (FEM) is used for solving partial differential equations approximately. There are three stages in the process of FEM.

Pre-processor: This stage, generally, prepares the issue to be detailed as far as the known factors, limited nodes and their coordinating nodal conditions. Toward the finish of this stage, the issue is formulated to be handled.

Processor Stage: This stage includes the calculation of field factors at the respective nodes by utilizing different accessible processing systems. The methods at the transfer are by and by the distinctive programming packages.
Post-handling Stage: The outcomes registered in the processing stage are currently contrasted and expository outcomes, got therefore of empirical equations. After this, the error investigation is done at this juncture. The error investigation proposes to some degree, the conformity of the got results with the desired ones.

The continuum is divided into discrete components called as finite element by an imaginary axis. These elements constitute a mesh and the interconnection to various elements being made at the nodes as it were. In this manner, with the FE discretization the solution region is partitioned into the elements and the obscure field variables are communicated as far as accepted estimation work inside every element. A scope of element shapes might be utilized.

Finite element model in xy-plane is created for the analysis. The forces were evaluated at different air gap using adaptive finite element meshing as per the mesh statics shown in the Table No. 1 using different pole shapes as shown in Fig.3.

<table>
<thead>
<tr>
<th>Pole Shape</th>
<th>DOF</th>
<th>Triangular Elements</th>
<th>Boundary Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>5300</td>
<td>21200</td>
<td>1272</td>
</tr>
<tr>
<td>Type 2</td>
<td>5729</td>
<td>11320</td>
<td>964</td>
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<tr>
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<tr>
<td>Type 4</td>
<td>5800</td>
<td>11436</td>
<td>1060</td>
</tr>
</tbody>
</table>

IV. RESULTS AND DISCUSSION

Several models was analysed and force component in longitudinal direction was evaluated. The magnetic potential contour plot is shown in Fig. 4.introducing different pole shapes.

Fig. 4 Magnetic potential plot for different pole shapes

The force using the Maxwell stress tensor were evaluated and considering the simulation for the pole shape 1 the force component in the longitudinal direction is 173.28N, while in the case of pole shape 2 the force component if 150.15N, in the case of pole shape 3 the force component is 69.98N and in the last considered shape the value of the force is 142.47N. Similarly the normal component of magnetic flux density is plotted with respect to arc length. The end effects can be easily observed in all the cases with distortions as presented in Fig. 5.
V. CONCLUSIONS
The paper addresses the need of accurate modelling and evaluation of force for the optimum design of the double sided linear induction motor. The finite element analysis of double sided linear induction motor has been carried out for the field response in terms of magnetic vector potential and magnetic flux density. The magnetic flux lines for the rectangular pole shape compared to the others are more concentrated to directly affect the force component. It is also observed that the force component has the higher value in the rectangular shape. Further it is also observed that the magnetic flux density have the highest value for the rectangular shape.

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REFERENCES