To Analyze Electromagnetic Effects of Double Sided Linear Induction Motor using 3D Finite Element Method

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ABSTRACT
A novel 3D design is proposed here of the long primary double sided linear induction motor for the electromagnetic analysis. The calculations based are on the method of finite element method. The cardinal design of the double sided long secondary linear induction motor is obtained and verified with the experimental motor. The design so obtained can be used to calculate various electromagnetic parameters of the motor.

General Terms
Finite element method, Boundary condition

Keywords
Short primary double sided linear induction motor, electromagnetic parameters, 3-D self-adaptive Finite element method

1. INTRODUCTION
With the advancement in technologies and high speed moving systems the need for the development of linear induction motors increased. There are basically two designs of the linear induction motor viz. single sided linear induction motor and double sided linear induction motor. As the motors provide gearless systems and immediate thrust force the linear induction motors are very useful in the designing of the electromagnetic aircraft launch systems or electromagnetic railways. Here separate cooling arrangements can be made for primary and secondary of motor. The backlash effect is eliminated as the gearless system is absent in these motors.[1-4] The guiding principle in the designing of these motors is that when stator of these linear motors carries 3phase sinusoidal ac currents balanced in times with a three phase winding balanced in time such that a magnetic field is produced which moves from leading phases axis to lagging phase axis it is attached to the cart or the object which requires motion with a rotor which is stationary in the rails.[5-7] The field so produced helps in levitating the object along with the propulsion thereby alleviating the problems with gear system and the wheel cart system. Due to the symmetric nature of the double sided linear induction motor the additional normal force f_x is absent in case of double sided linear induction motor. [8]
The working of the linear induction motor is similar to that of the normal induction machine that is when a three phase winding balanced in space carries three phase currents balanced in time the rotating magnetic field is produced which revolves from leading phase axis to lagging phase axis with a magnitude of 1.5 times the leading phase axis and aligned in its direction. This principle is used in the designing of the linear induction motors.[9-10] However, the main difference lies in the application of finite element method due to end effects which become prominent when the magnetic field in the primary starts linking partially with the magnetic field in the secondary. These end effects, are related to the slip and goodness factor. These longitudinal end effects are the main cause for the lower power factor of the linear motors thereby causing poor efficiency. The fringing effect so observed is due to the improper flux linkage of the rotor and the stator fields. The product of efficiency and the power factor of the linear induction motor usually does not exceed $\frac{1}{2}$ whereas the conventional induction motors are found to have this product around 0.8. [11] The design of the double sided linear induction motor under consideration is as shown in figure 1. When the stator of the conventional induction motor is cut open and unrolled it forms the basis for the basic design of the double sided linear induction motor so it has two primaries and one secondary supported with back iron to keep it fixed.

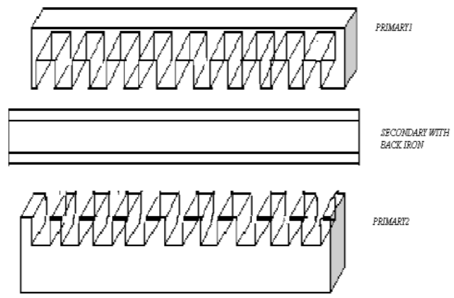

Fig:1 Double Sided Linear Induction Motor

For the development of the double sided linear induction motor the model under consideration has been discussed in the above diagram (fig.1). Once the autocad 3-D design of the motor has been made the finite element based model technique is implemented using finite element based (FEM) software the technique for the finite element is that first of all the meshes are created depending on the design of the model under consideration for example for a 1-D a line segment may be taken into consideration and for a subsequent 3-D design triangular or quadrilateral elements may be taken into consideration though tetrahedron is the most effective of them all as it covers all the irregularities and nonlinear spaces.[12-14] After, this suitable boundary conditions are applied as depending upon the domain of the model under consideration be it electromagnetic electrostatic or transient. Here the zero tangential boundary conditions are applied. Thus when the proper region is selected the fields are calculated on the required parts of the motor thus if the error is more than the required value then the number of meshing elements are increased so as to decrease the relative percentage error caused due to irregularities in the material. The flowchart for the method used is depicted below.

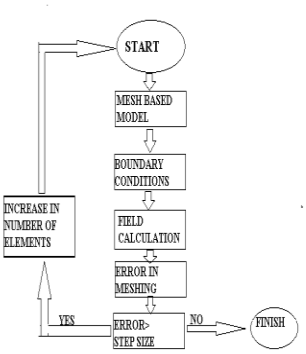

Fig 2: Flowchart Of Finite Element Method

2. LONG PRIMARY DOUBLE SIDED LINEAR INDUCTION MOTOR

The experimental design of the motor specifications under consideration on which analysis has been performed is tabulated as under in table 1.

TABLE 1 Motor Design Paramters[15]

Parameters	Value
Phases	3
Poles,2p	10
Length of primary	3800mm
Width of primary	254mm
Width of secondary	530mm
Number of slots	160
Width of slot	189.369mm
Slot pitch	249.335mm
Number of turns per coil	1
Air gap	38.0mm
Current per phase	1000A

In this paper the main work has been done in the designing of the 3-D Finite element based double sided linear induction motor model using the meshing techniques and the magnetic field linkage has been obtained of the primary with the secondary. The currents supplied to the stator in the linear motor are given by the equation[16-18]

$$I_{ABC}=I\sqrt{2}\cos(wt-(i-1).\frac{2\pi}{3}) \quad (1)$$

The translational magneto motive force so produced by the currents given to the stator are given by

$$F_{(x,t)}=1.5F_m(\left(\cos\left(wt-\frac{\pi}{\tau}x\right)\right)+j\sin(wt-\frac{\pi}{\tau}x)) \quad (2)$$

Where $F_m=\frac{4}{\pi}(\frac{k_w N_{ph}}{2p})I_m$

And the speed of the field so produced is given by

$$V_x=2\frac{\tau}{t} \quad (3)$$

The paramters of the secondary are dependent on the slip(s) and the goodness factor (g)

$$G=w.\tau$$

$$w=2\pi f\,,\tau=\frac{L_m}{R_r'}$$

Where w is the primary frequency

$L_m$is the magnetization inductance

$R_r'$is the resistance of secondary referred to primary

For low speed of linear induction motors the condition with slip and goodness factor is

$$S_n.G=1 \quad [19]$$

3. DESIGN OF FINITE ELEMENT BASED MODEL

The design of the long secondary reaction plate doubles sided linear induction motor shown here. The model is formed using the help of solidworks as shown in fig. 2.

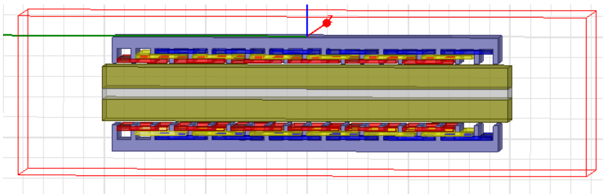

Fig 3: Front View Of Double Sided Linear Induction Motor

The design of the motor when suitable three phase winding connections are applied to the stator of the motor carrying three phase currents is shown in fig. 3. The corresponding sectional view of the motor is shown below.

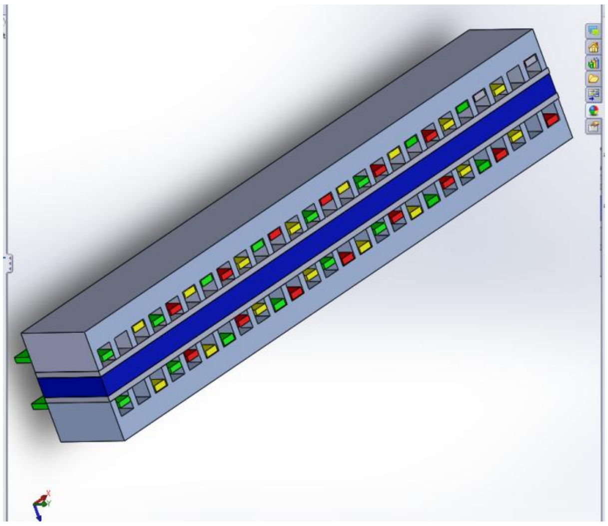

Fig 4: Sectional View Of Double Sided Linear Induction Motor With Three Phase Windings Placed In Slots

The quadrilateral elements are taken for the self adaptive finite element method. For a 1D design the elements taken maybe a line segment and the for 2D analysis the elementsmay be rectangular or triangular in nature for a 3D based model only tetrahedron based elements can be taken into account as they would cover the non linear and non planer surfaces completely.The meshing of the double sided linear induction motor has been done creating 11038 elements as shown in fig.4 [20-22]

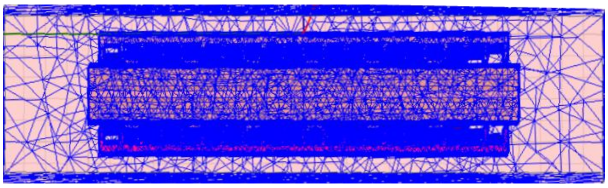

Fig 5: Meshing Of Double Sided Linear Induction Motor

4. RESULTS AND DISCUSSIONS

Once the designing part of the motor has been done the motor elements are further analyzed according to the flowchart mentioned above and the motor is checked for the corresponding errors along with the number of elements taken into consideration and their respective efficiencies along with the time taken for the simulations. As shown in the table below

TABLE 2: Analysis Of Meshing Elements.
Total number of mesh element: 110328

	Num Tetrahedrons	Min edge length	Max edge length	RMS edge length	Min tetvol	Max tetvol	Mean tetvol
Secondary 1	2265	76.4757	342.217	186.877	10771.7	2.21598e+006	269563
Secondary 2	2195	73.8018	360	188.007	28020.8	2.35183e+006	278159
Primary1	6071	42.931	118.898	292.554	985578	65426.4	63095.4
Primary2	6357	48.9683	235.072	117.301	1315.34	498251	62482.9

The graphical view is shown here that is the relative percentage error decrease with the increase in number of meshes the number of finite meshing elements varies inversely with the percentage error and varies directly with the amount of time taken and correspondingly slow convergence which is shown in figure 5 down below.

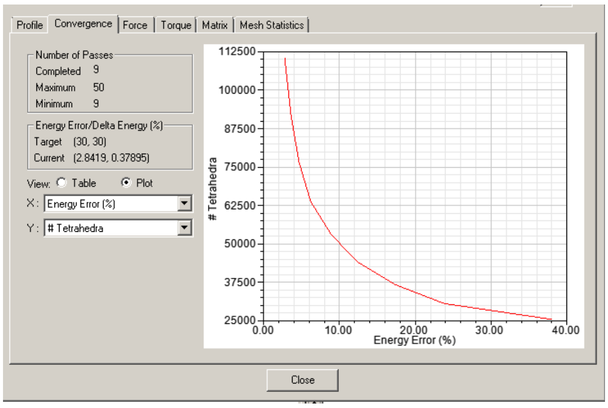

Fig 6: Percentage Error Vs Number Of Elements

When, the number of elements are fixed and the relative percentage error in the refinement of the meshing model is fixed the corresponding linkage of the magnetic flux has been observed linking with the secondary. The end effects are seen here as the magnetic flux is leaking in the exit and the entry ends of the reaction plate. As shown in the figure 6. Only the active view that is the magnetic flux linkage with the secondary is shown .

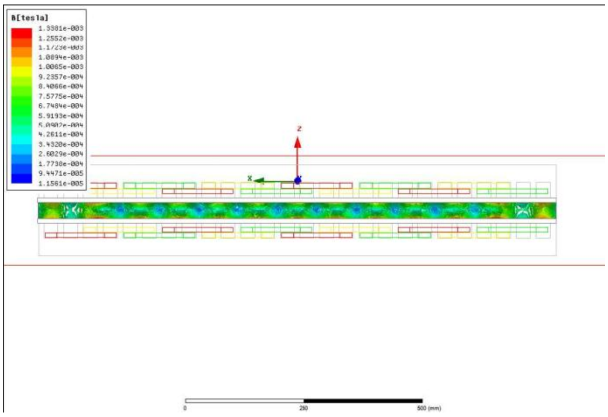

Fig 7: Magnetic Flux Linkage Of The Secondary Windings

With the fig. 7 the end effects are clear that is the main leakage occurs when the magnetic field lines try to enter the secondary. This leakage can be controlled by varying the air gap between the primary and the secondary though other factors like speed of the rail has to be kept under consideration as well.

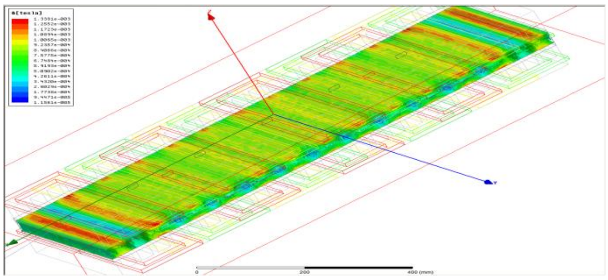

Fig 8: Magnetic Flux Leakage I.E. End Effects

The graph between the variation of the magnetic field as we move along the length of the secondary is shown in fig. 8 as below.

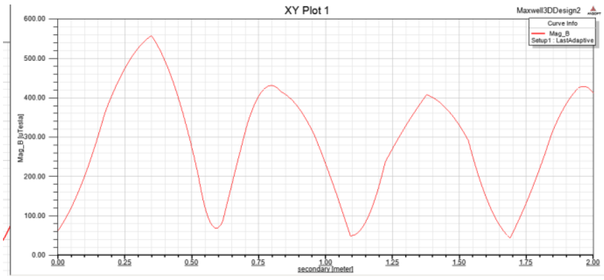

Fig 9: Graph Showing The Magnetic Flux Leakage Maximum Near The End And It's Variation As We Move Away From The End

Hence, in modeling of 3-D finite element method we can clearly see that as the number of tetrahedral formed are increased the percentage error goes on decreasing from 1-D to 2-D to 3-D design of the motor.

Though, the tetrahedral elements are tabooed with convergence being slow and taking more time and huge memory space requirements. It is also seen that the magnetic flux leakage is basically at the entry and exit ends of the secondary leading to poor efficiency and improper flux linkage.

5. CONCLUSION

The long secondary double sided linear induction motor has been designed in this paper to which 3-D finite element method has been applied. The refinement with the use of 3-D elements has been done as they are much more precise and accurate as they are beneficial in calculating the complete geometry of the motor. Further, the design of the motor can be improved there upon by the proper selection of materials and with the variation in air gap. The designing of the proper air gap will help the inventor to design the motor with proper specifications. Air gap remains an important constraint as if it is kept too large there is huge amount of flux leakage and leading to huge amount of losses and end effects. Contrarily if the air gap is kept too small it does not allow the high speed of the trains thereby leading to more wear and tear.

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