Design and Performance Analysis of Single Sided Linear Induction Motor

K.S.Lingamurty, P.Mallikarjuna Rao* , T. Sandhya , K.Sri chandan

ABSTRACT: This paper suggests and describes the methodology for the design of a linear induction motor which will accelerate the rotor (Aluminum sheet) with a specified mass with the required acceleration to the target distance. The study throws new light on the fundamental principles of linear induction. A Single sided linear induction motor (SLIM) of specified parameters is designed using a user-interactive MATLAB program. The SLIM design and performance equations and design procedures are developed and its performance is predicted using equivalent circuit models. End effects and edge effects are neglected in this study. Optimum design parameters are obtained by the iterative procedure of the design algorithm by choosing various design parameters. The performance of the SLIM for different values of thrust, rotor acceleration, rotor thickness and slip values is analyzed. The effect of variation of such parameters on the performance of the machine is discussed.

Keywords- Electrical machine design, Linear motors, single sided linear induction motor (SLIM), Equivalent circuit model.

Dr.K.S.Lingamurty,Professor & HOD, Department of Electrical and Electronics Engineering, GIT, GITAM University, Andhra Pradesh, India (email:professorkandukuri@gmail.com)

***corresponding author:** Dr. P.Mallikarjuna Rao**,** Professor, Dept. of Electrical Engineering, Andhra University, Visakhapatnam, A.P., India-530003, (email:doctormallik@gmail.com)

T.Sandhya. and K.Sri Chandan. Asst. Professors in the Department of Electrical and Electronics Engineering, GIT, GITAM University,Andhra Pradesh, India (email: sandhyathotakura@gmail.com, srichandank@gmail.com)

I. INTRODUCTION

Linear motors have been around for nearly a century, and yet are still in their early stages of development. Because of their large air gaps, low efficiencies and low power factor they have not been considered viable design options for many high-speed linear motion application [1].

Recently linear motors have been getting a primary look by variety of users that require a traction force by means of something other than friction. High speed trains and monorails are just a few of the recent designs using linear motors.

Conceptually all types of motors can have possible linear configurations (dc, induction, synchronous and reluctance). Due to high starting thrust force, simple structure, alleviation of gear between motor and the motion devices, reduction of mechanical losses, high speed operation, low noise, low cost linear induction motors (LIMs) have been broadly used in industrial applications like conveyor systems, material handling and storage, people movers, liquid metal pumping, accelerators and launchers, machine tool operation, airport baggage handling, opening and closing drapes, operation of sliding doors and low and medium speed trains.

II.SINGLE-SIDED LINEAR INDUCTION MOTOR (SLIM)

The structure diagram of a single-sided linear induction motor (SLIM) is shown in Fig. 1. The SLIM primary can be simply regarded as a rotary cut-open stator and then rolled flat [1]. The secondary, similar with the rotary induction motor (RIM) rotor, often consists of a sheet conductor, such as copper or aluminum, with a solid back iron acting as the return path for the magnetic flux. The thrust corresponding to the RIM torque can be produced by the reaction between the air-gap flux density and the eddy current in the secondary sheet.

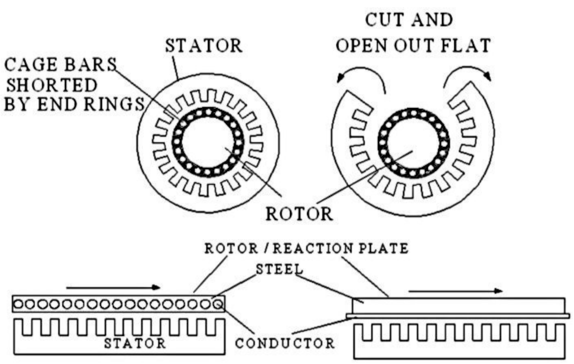

Fig1. Single-sided LIM

The stator produces a sinusoidally distributed magnetic field in the air-gap rotating at the uniform speed 2ω/p, with ω representing the network pulsation (related to the frequency f by ω= 2πf) and p the number of poles [2]. 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. Slip is the relative motion needed in the induction motor to induce a voltage in the rotor, if the velocity of the rotor is V_r, then the slip of LIM/ SLIM can be denoted as,

$$S = \frac{V_S - V_r}{V_S} \quad \text{… (1)}$$

Where V_s is the synchronous velocity , is the same as that of the rotary induction motor, given by

$$V_s = \frac{2\omega R}{p} = 2f\tau \quad \text{…(2)}$$

Where R is the stator radius of the rotary induction motor.

It is important to note that the linear speed does not depend upon the number of poles but only on the pole pitch. The parameter τ is the distance between two neighboring poles on the circumference of the stator, called pole pitch. The stator circumference of the rotary induction motor, $2\pi R$, in Eqn.(3) is equal to the length of the SLIM stator core, L_s. Therefore the pole pitch of a LIM is defined as

$$\tau = \frac{2\Pi R}{p} = \frac{L_s}{p} \quad \text{…. (3)}$$

The analysis and design of a low-speed flat SLIM can be done by the use of an approximate equivalent circuit that is developed. To determine the parameters of the circuit, the design formulas of the rotary induction motor for the given application will be attributed to the SLIM. As it is well known that often the secondary of a SLIM is made of a conducting sheet. The concept of surface resistivity is very useful in finding the resistance of such a secondary.

III . EQUIVALENT CIRCUIT MODEL

The approximate equivalent circuit [5] of a LIM is presented as shown in Fig. 2.
This circuit is on a per phase basis.

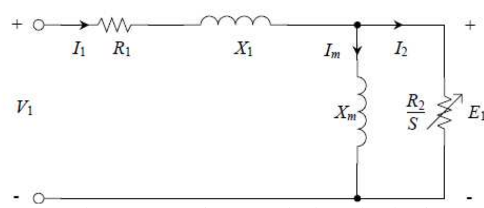

Fig. 2. Approximate equivalent circuit of LIM

A. Per-phase stator resistance (R_1) :
This is the resistance of each phase of the LIM stator windings. R_1 is calculated from

$$R_1 = \rho_w \frac{l_w}{A_{wt}} \quad \text{…(4)}$$

where, ρ_w is the volume resistivity of the copper wire used in the stator winding, l_w is the length of the copper wire per phase, and A_{wt} is the cross-sectional area of the wire.

The length of the copper wires l_w is calculated from

$$l_w = N_1 l_{wl} \qquad \ldots (5)$$

Where l_{wl} = mean length of one turn of the stator winding per phase

B. Per-phase stator-slot leakage reactance(X_l) :
The flux that is produced in the stator windings is not completely linked with the rotor conductors. There will be some leakage flux in the stator slots and hence stator-slot leakage reactance X_l. This leakage flux is generated from an individual coil inside a stator slot and caused by the slot openings of the stator iron core. In a LIM stator having open rectangular slots with a double-layer winding, X_l can be determined from

$$X_1 = \frac{2\mu_o \pi f \left[\left(\lambda_s\left(1+\frac{3}{p}\right)+\lambda_d\right)\frac{W_s}{q_1}+\lambda_e l_{ce}\right] N_1^2}{p} \qquad \ldots(6)$$

Where W_s=stator width, l_{ce} =length of end conductor wire , N_1= Turns per phase , q_1 =slots per pole per phase .

C. Per-phase magnetizing reactance (X_m):

The per-phase magnetizing reactance, X_m [4] , is shown in Fig.8

$$X_m = \frac{24\mu_o \pi f W_{se} k_w N_1^2 r}{\pi^2 p g_e} \qquad \ldots (7)$$

where k_w is the winding factor , g_e is the equivalent air gap given by and W_{se} is the equivalent stator width

D. *Per-phase rotor resistance (R_2) :*

The per-phase rotor resistance R_2 is a function of slip, as shown in Fig. 2. R_2 can be calculated from the goodness factor *G* and the per-phase magnetizing reactance X_m as

$$R_2 = \frac{X_m}{G} \qquad \ldots(8)$$

where the goodness factor is defined as

$$G = \frac{2\mu_o f \tau^2}{\pi\left(\frac{\rho_r}{d}\right) g_e} \qquad \ldots (9)$$

Where ρ_r is the volume resistivity of the rotor conductor outer layer, which is aluminum here.

IV. PERFORMANCE CALCULATION

The procedure of performance analysis based on the equivalent circuit shown in Fig. 2, where the magnitude of the rotor phase current I_2 [6] can be calculated from

$$I_2 = \frac{I_1}{\sqrt{\frac{1}{(SG)^2}+1}} \qquad \ldots (10)$$

The LIM electromagnetic thrust [F_s] becomes

$$F_s = \frac{m I_1^2 R_2}{\left[\frac{1}{(SG)^2}+1\right] V_s S} \qquad \ldots (11)$$

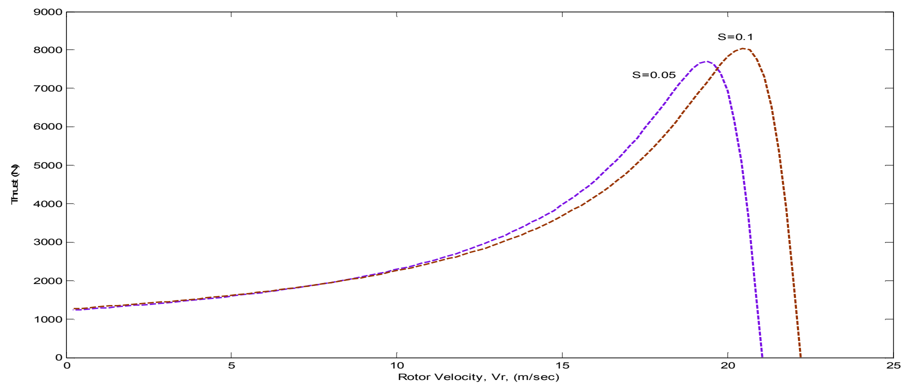

Fig 3. Thrust versus Rotor Velocity of SLIM with change in slip

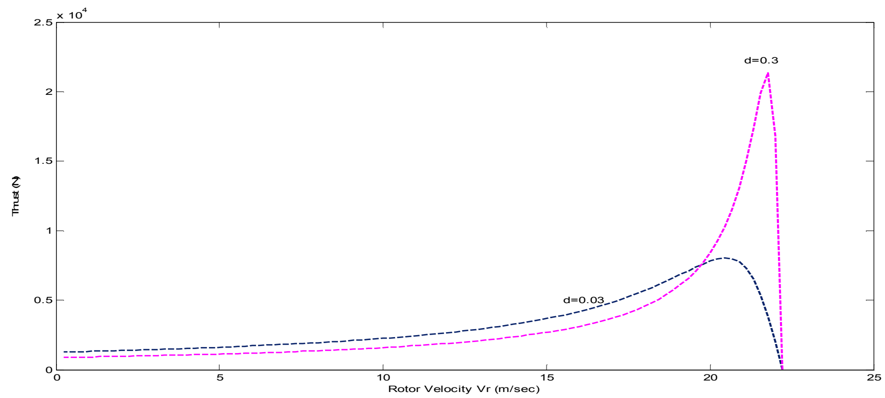

Fig 4. Thrust versus Rotor Velocity of SLIM for Aluminum thickness

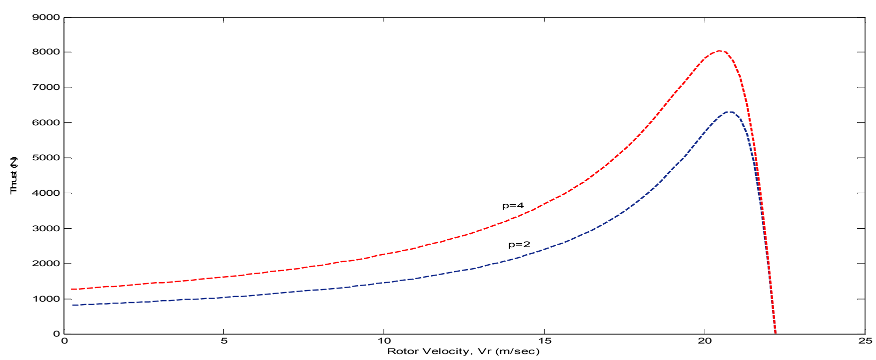

Fig 5. Thrust versus Rotor Velocity of SLIM for No. of poles

The LIM input active power is the summation of the output power and the copper losses from the stator and rotor,

$$P_i = P_o + mI_1^{\,2}R_1 + mI_2^2R_2 \qquad \ldots (12)$$

Where, P_o =output power given by

$$P_o = mI_2^2\frac{R_2}{S} - mI_2^2R_2 = mI_2^2R_2\left(\frac{1-S}{S}\right) \quad .. (13)$$

$mI_1^{\,2}R_1, mI_2^2R_2$ = stator & rotor copper loss.

The efficiency of the LIM is found by

$$\eta = \frac{P_o}{P_i} \qquad \ldots (14)$$

V. RESULTS

The input data used for SLIM design in MATLAB program was given in appendix along with the slot geometry .The output results at rated slips of 5% and 10% are tabulated below .

Description	5 %slip	10% slip
Pole pitch , τ ((m)	0.2105	0.2222
Slot pitch , λ (m)	0.035	0.037
Stator length ,L_s(m)	0.8421	0.8889
"Target" thrust (N)	**4905**	**4905**
Slot width , w_s(m)	0.0205	0.02419
Tooth width ,w_t (m)	0.0145	0.0128
Slot depth , h_s (m)	0.01101	0.0112
Actual thrust at specified *Vr* (N)	**6026.44**	**6028.1**
Stator efficiency , η	94.98	89.98 %
Rated stator Current , I_1(A)	348.02	512.64
Rotor Phase current I_2 (A)	288.23	491.46

The performance characteristics of the SLIM, thrust F_s as a function of rotor velocity V_r, at different slips of 5% and 10% are shown in Fig.3, for different rotor aluminum thickness of 0.03m and 0.3m are shown in Fig.4 and for change in number of poles for p=2 & 4 are shown in Fig.5.

VI . CONCLUSION

In this research article, the equivalent circuit has been derived to analyze the performance of the short-secondary SLIM. It can be concluded that the slip, the thickness of rotor aluminum outer layer, number of poles plays a very important role in the performance of the SLIM. As the slip of the machine increases thrust of the machine decreases. Also when the thickness of the aluminum sheet is increased thrust increases. Hence, care should be taken in choosing the best value for aluminum thickness which yields maximum thrust at a required efficiency. Further , increase in the number of poles, results in increase in the thrust. So, from the parametric analysis it can be concluded that the input parameters like the slip, thickness of aluminum sheet and number of poles play a vital role in the performance parameters, thrust and efficiency. Based on the target values of rotor velocity and thrust, these parameters should be chosen which gives the best possible thrust closest to the target value at a required efficiency. The results show that the proposed equivalent circuit gives more accurate solutions and can be used as an effective tool to determine the performances of such type of motor.

REFERENCES

1. A complete equivalent circuit of a linear induction motor with sheet secondary *Pai, R.M.; Boldea, I.; Nasar, S.A.; Magnetics, IEEE Transactions on* , Volume:24 , Issue: 1 , Jan. 1988 Pages:639 – 654

2. The causes and consequences of phase unbalance in single-sided linear induction motors *Adamiak, K.; Ananthasivam, K.; Dawson, G.E.; Eastham, A.R.; Gieras,J.F.; Magnetics, IEEE Transactions on* , Volume: 24 , Issue: 6 , Nov 1988 Pages:3223 – 3233.

3. Obtaining the operating characteristics of linear induction motors: a new approach *Mirsalim, M.; Doroudi, A.; Moghani, J.S.; Magnetics, IEEE Transactions on, Volume: 38, Issue: 2, March 2002 Pages: 1365 – 1370.*

4. Optimum Design of Single-Sided Linear Induction Motors for Improved Motor Performance Bazghaleh, A.Z. ; Naghashan, M.R. ; Meshkatoddini, M.R. ; Power & Water Univ. of Technol., Tehran, Iran Magnetics, IEEE Transactions on Issue Date : Nov. 2010 Volume : 46 , Issue:11 On page**(s):** 3939 ISSN **:** 0018-9464.

5. An Improved Equivalent Circuit Model of a Single-Sided Linear Induction Motor. Wei Xu Jian Guo Zhu Yongchang Zhang Yaohua

Li Yi Wang Youguang Guo Univ. of Technol. Sydney, Sydney, NSW, Australia. IEEE Transactions on Issue Date : Jun 2010 Volume : 59 , Issue:5 On page(s): 2277 ISSN : 0018-9545

6. Equivalent circuits for single-sided linear induction motors . Wei Xu Jianguo Zhu Youguang Guo Yi Wang Yongchang Zhang Longcheng Tan Sch. of Electr., Mech. & Mechatron. Syst., Univ. of Technol. Sydney, Sydney, NSW, Australia , Energy Conversion Congress and Exposition, 2009. ECCE 2009. IEEE Issue Date : 20-24 Sept. 2009 On page(s): 1288 Print ISBN: 978-1-4244-2893-9

APPENDIX

Specifications of SLIM

Aluminum thickness, d (in meters) = 0.03
Number of phases, m = 3
Primary line to line voltage(V) = 440
Supply frequency, f (Hz) = 50
Number of poles , p= 4
Number of slots per pole per phase, N1 = 2
Rated slip, S = 0.1
Width of the stator,Ws(m) = 0.02
Acceleration due to gravity, g (m/sec^2) =50
Weight of the rotor ,m (kg) =10
Rated rotor velocity, Vr (m/sec) = 20

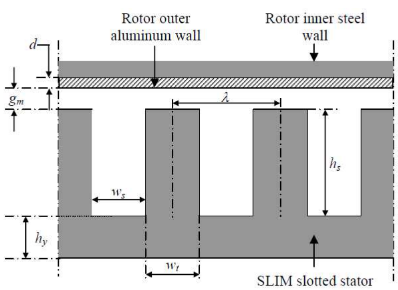

Fig. 6 .SLIM geometry