International Journal of Science and Engineering Applications
Volume 7–Issue 10,386-390, 2018, ISSN:-2319–7560

Design of Single-Sided Linear Induction Motor Used in Elevator

Aye Mya Mhway
Department of Electrical Power Engineering
Technological University (Thanlyin),
Myanmar

Nan Win Aung
Department of Electrical Power Engineering
Technological University (Thanlyin),
Myanmar

May Nwe Yee Tun
Department of Electrical Power Engineering
Technological University (Thanlyin),
Myanmar

Abstract: Linear induction motor (LIM), is basically an advanced types of motor that is use to obtain rectilinear motion instead of rotational motion as in ordinary conventional three phase induction motors. The LIM has been used in many different applications starting from moving sliding door to high speed trains around the world, due to easy maintenance, high acceleration/deceleration and no need of transformation system from rotary to translational motion. There are different types of linear induction motors (LIMs), among them, single-sided linear induction motors (SLIMs) are widely used in transportation system. In this paper, the methodology for the design of a single-sided linear induction motor which will accelerate the secondary (Aluminum sheet) with a specified mass with the required acceleration to the target distance are suggested and described. The SLIM design and performance equations and design procedure are developed and its predicted by using equivalent circuit model. Longitudinal end effect and other effects account (transverse edge, saturation ,etc.) are ignored in this study.

Keywords: Single-Sided Linear Induction Motor (SLIM),Equivalent Circuit Model, Linear Machine Design

1. INTRODUCTION

Linear induction motors (LIMs), are counterparts of rotary induction motors. LIM operates on the same principle as the conventional rotary induction motor.They may be obtained by "cutting" and "unrolling" the rotary induction machines to yield flat, single-sided topologies, where the cage secondary may be used as such or replaced by an Aluminium sheet placed between two primaries to make the double-sided LIM. Linear motor potentially have unlimited applications. Linear induction motors (LIMs) alone have found application in the following general areas: conveyor systems, material handling and storage, people mover (Elevators), liquid metal pumping, machine tool operation, operation of sliding doors and low and high speed trains. The single-sided linear induction motor (SLIM) is by far the most widely used in linear induction motor. In this paper, single-sided linear induction motor (SLIM) with short primary has been studied for the vertical conveying application because its main characteristic is the linear motion, which takes place without transformation mechanisms, increasing efficiency and the reliability of the system and also eliminating the need for large machine room on the roof. The SLIM has the following advantages comparing with the rotary induction motor (RIM): simple construction, direct electromagnetic thrust propulsion, safety and reliability, precise linear positioning, separate cooling, all electro-mechanical controlled systems used for an induction motors can be adopted for a SLIM without any bigger changes, economical and cheap maintenance.

2. STRUCTURE OF THE SINGLE-SIDED LINEAR INDUCTION MOTOR

The structure diagram of a single-sided linear induction motor (SLIM) is shown in figure 1.The primary or stator of a SLIM consists of a rectangular slotted structure formed by a stack 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, produced by the polyphase stator windings. The secondary, similar with the rotary induction motor (RIM) rotor, often consists of a sheet conductor, such as copper or aluminum, with or without a solid back iron plates, 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 the eddy current and the changing electromagnetic thrust on the plate in the longitudinal direction of the motor.

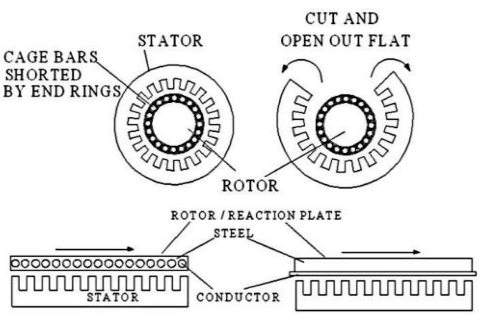

Figure 1.Structure of the single-sided linear induction motor(SLIM)

3. DESIGN PROCEDURE OF SINGLE-SIDED LINEAR INDUCTION MOTOR

The specifications of SLIM
Targe thrust, F'_s: 16000 N
Rated velocity, v_r : 10 m/s
Rated Slip, s : 10%
Rated line voltage,V_1: 400 V
Number of phase, m : 3phase
Number of poles, p : 4poles
Frequency, f: 50 Hz
Types of winding: Single Layer Winding

And, this machine is supposed to be applied in the elevator, achieving vertical transportation with ascending/rising speed v_r and acceleration a up to 10m/s and 2m/s^2 upwards, respectively. Therefore, the size of the cabin, total weight of cabin and necessary mechanical connection to it, and maximum allowable passenger and the average weight of each passenger are needed to know. All the necessary information are mentioned below

Size of cabin,(height ×length ×width)$_{cabin}$ =2.5 ×2 ×1m^3
Total weight of cabin and bearing, m_{cabin}: 500kg
Number of passenger in one cabin, n_p: 5
Average weight of each passenger, $m_{passenger}$: 75kg

3.1 Design of Primary (Stator)

Stator unit is designed according to the following procedure. First, assign the constant values

Permeability of free space, $\mu_0=4\pi\times10^{-7}$H/m
Volume resistivity of Copper, $\rho_w=19.27\times10^{-9}\Omega$m
Volume resistivity of Aluminum $\rho_r=28.85\times10^{-9}\Omega$m
Stator current density, $J_1=6$A/mm^2
Maximum tooth flux density, $B_{tmax}=1.6$Tesla
Maximum yoke flux density, $B_{ymax}=1.3$Tesla
Coil span in electrical radians, $\theta_p=\pi$
Number of slot per pole per phase, $q_1=1$
Aluminum thickness, d=3mm
Width of stator, $W_{st}=1000$mm
Mechanical air gap, $g_m=5$mm

Continuously, to obtain the target thrust in a Single-Sided Linear Induction Motor, the following equations are used.

Synchronous velocity, $v_s=\dfrac{v_r}{1-s}$ (1)

Pole pitch, $\tau=\dfrac{v_s}{2f}$ (2)

Slot pitch, $\lambda=\dfrac{\tau}{mq_1}$ (3)

Length of primary (Stator), $L_s=\tau p$ (4)

$\tau=3W_s+3W_t$ (5)

In this design, the number of slot is 12 and single-layer winding

$W_t=1.5W_s$ (6)

And then, get the value tooth width and slot width shown in figure 2.

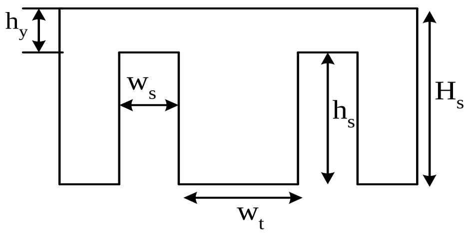

Figure. 2 Dimension of Stator Slot

Number of turn per phase, $N_1=N_c p q_1$ (7)

Where N_1 is the number of turn per phase and set the number of turn per slot N_c to one and increment it by one until the target thrust is obtained.

Now, let assume the product of $\eta\cos\phi$ between 0 and 1 arbitrary.

And find, the value of stator current,

$$I_1^{'}=\frac{F_s^{'}v_r}{3V_{ph}\eta\cos\phi} \quad (8)$$

Area of copper wire, $A_w^{'}=\dfrac{I_1^{'}}{J_1}$ (9)

Total cross-sectional area of copper wire,

$A_{wt}=N_c A_w^{'}$ (10)

Cross-sectional area of slot, $A_s=\dfrac{10}{7}N_c A_w^{'}$ (11)

Stator slot height, $h_s=\dfrac{A_s}{W_s}$ (12)

Length of end connection, $L_{ce}=\dfrac{\theta_p}{180}\tau$ (13)

Effective stator width, $W_{est}=W_{st}+L_{ce}$ (14)

Mean length of one turn of the stator winding per phase,

$L_{w1}=2W_{est}$ (15)

Length of copper wire per phase, $L_w=N_1 L_{w1}$ (16)

Total length of copper wire, $T_{Lw}=mL_w$ (17)

After assuming the value of Aluminum thickness of conducting layer, d, the magnetic air gap, g_0 is calculated

$g_0=g_m+d$ (18)

And also find the equivalent stator width,

$W_{seq}=W_{st}+g_0$ (19)

Gamma for calculating carter's coefficient,

$$\gamma=\frac{4}{\pi}\left[\frac{W_s}{2g_0}\arctan\left(\frac{W_s}{2g_0}\right)-\ln\sqrt{1+\left(\frac{W_s}{2g_0}\right)^2}\right] \quad (20)$$

Carter's coefficient, $k_c=\dfrac{\lambda}{\lambda-\gamma g_0}$ (21)

Effective air gap, $g_e=k_c g_0$ (22)

The goodness factor, $G=\dfrac{2\mu_0 f\tau^2}{\pi \dfrac{\rho_r}{d} g_e}$ (23)

Pitch factor, $k_p=\sin\dfrac{\theta_p}{2}$ (24)

Slot angle, $\alpha=\dfrac{\pi}{mq_1}$ (25)

Distribution factor, $k_d=\dfrac{\sin q_1 \dfrac{\alpha}{2}}{q_1 \sin\dfrac{\alpha}{2}}$ (26)

Winding factor, $k_w=k_p\times k_d$ (27)

3.2 Equivalent Circuit Model

The equivalent parameters of SLIM can be determined using the per-phase equivalent circuit as shown in figure 3.

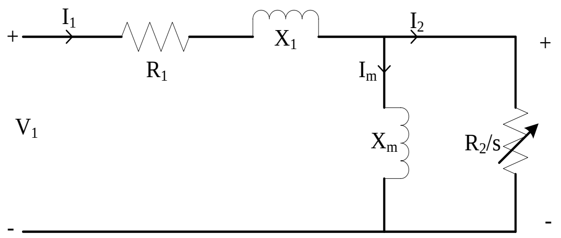

Figure. 3 Equivalent Circuit of Linear Induction Motor

Per-phase stator resistance, $R_1=\dfrac{\rho_w L_w}{A_{wt}}$ (28)

Per-phase slot leakage reactance,

$$X_1=\frac{2\mu_0\pi f\left\{\left[\lambda_s\left(1+\frac{3}{p}\right)+\lambda_d\right]\frac{W_{st}}{q_1}+\lambda_e L_{ce}\right\}N_1^2}{p} \quad (29)$$

Slot, differential and end connection permeance are

$$\lambda_s=\frac{h_s\left(1+3k_p\right)}{12W_s}$$

$$\lambda_d=\frac{5\left(\frac{g_e}{W_s}\right)}{5+4\left(\frac{g_e}{W_s}\right)} \quad (30)$$

$$\lambda_e=0.3(3k_p-1)$$

Magnetizing reactance per phase,

$$X_m=\frac{24\mu_0\pi f W_{seq} k_w N_1^2\tau}{\pi^2 p g_e} \quad (31)$$

Per-phase rotor resistance, $R_2=\dfrac{X_m}{G}$ (32)

Using the equivalent circuit parameters from the above equations (28), (29), (31) and (32),and the circuit diagram shown in figure 3, the rated value of impedance can be calculated by

$$Z=R_1+jX_1+\frac{j\left(\frac{R_2}{s}X_m\right)}{\frac{R_2}{s}+jX_m} \quad (33)$$

Power factor the design motor, $\cos\phi=\dfrac{\mathrm{Re}(Z)}{|Z|}$ (34)

The rated primary RMS phase current, $I_1=\dfrac{V_1}{|Z|}$ (35)

Then magnitude of magnetizing current,

$$I_m=\frac{\frac{R_2}{s}}{\sqrt{\left(\frac{R_2}{s}\right)^2+X_m^2}}\times I_1 \quad (36)$$

Also the magnitude of secondary phase current I_2 can be calculated from

$$I_2=\frac{X_m}{\sqrt{\left(\frac{R_2}{s}\right)^2+X_m^2}}\times I_1 \quad (37)$$

The SLIM input active power, $P_i=mV_1I_1\cos\phi$ (38)

The output power, $P_0=P_i-mI_1^2R_1-mI_2^2R_2$ (39)

And then efficiency is calculated by following equation

$$\eta=\frac{P_0}{P_i}\times 100\% \quad (40)$$

The electromagnetic force F_s produced by a machine is given by

$$F_s=\frac{P_0}{v_r} \quad (41)$$

3.3 Required Force Calculation

Resulting magnetomotive force (MMF),

$$\theta_m=\frac{4\sqrt{2}mk_w N_1 I_m}{\pi p} \quad (42)$$

By mean of MMF, the peak value of the normal component of the magnetic flux density is given by

$$B_{gmax}=\frac{\mu_0\theta_m}{2g_0} \quad (43)$$

Theoretically, the flux in the air gap is sinusoidal because of the sinusoidal voltage source. Thus, the average flux density B_{gavg} can be gained, based on the relation with the peak value of that, i.e

$$B_{gavg}=\frac{2}{\pi}B_{gmax} \quad (44)$$

The yoke of the primary core refer to the section at the top of the core showed in figure 2.

$$h_y=\frac{B_{gavg}\tau}{2B_{gmax}} \quad (45)$$

Making use of L_s, W_{st} and h_y ,the volume of the yoke is

$$V_{yoke} = L_s W_{st} h_y \tag{46}$$

In addition, the volume of one tooth of the primary core is

$$V_{tooth} = W_{st} W_t h_s \tag{47}$$

Since the teeth have uniform size, the volume of the total teeth is derived as

$$V_{teeth} = (mpq_1) V_{tooth} \tag{48}$$

Where mpq_1 is the number of slot in a primary core. So, the volume of the iron core of the primary V_{iron} is

$$V_{iron} = V_{yoke} + V_{teeth} \tag{49}$$

The weight of the entire iron core, $W_{iron} = \rho_i V_{iron}$ (50)

The weight of copper wire, $W_c = \rho_c A_w T_{lw}$ (51)

The weight of one primary unit W_{stator}, consisting of iron core and copper wire, is easily obtained as

$$W_{stator} = W_{iron} + W_c \tag{52}$$

Number of primary unit, $n_{stator} = \frac{h_{cabin}}{1.2L_s}$ (53)

And then, the **total output thrust** can be calculated as

$$F_t = n_{stator} F_s \tag{54}$$

Now checking the require force by **Newton's Second Law**, The mass of the whole rising system,

$$m_t = n_p m_{passenger} + n_{stator} W_{stator} + m_{cabin} \tag{55}$$

The moving resistance of the system D, consists of two components in this specific case, which are

Rolling resistance, $D_r = m_t (c_1 + c_2 v_r)$ (56)

Where c_1 and c_2 are coefficient of correlation, normally defined as 0.01-0.02 N/kg and 0.00015-0.0003 N/kg.

and aerodynamic resistance, $D_a = \frac{1}{2}\rho v_r^2 A$ (57)

Where ρ is the air density $1.205 kg/m^3$ and A is the top or bottom area of cabin $2m^2$.

Total moving resistance is given by

$$D = D_r + D_a \tag{58}$$

Now, making use of Newton's Second Law of Motion, the force required to be produced by the propulsion system

$$F_s' = m_t (a+g) + D \tag{59}$$

Where g is acceleration of gravity, $9.8 m/s^2$.

Finally, $F_t \geq F_s'$ becomes a greatly important criterion to decide whether this machine design is satisfied or not.

3.4 Design of Secondary

The single-sided linear induction motor secondary (rotor) design contains conduction layer design and reaction plate design, it is illustrated in figure 4.

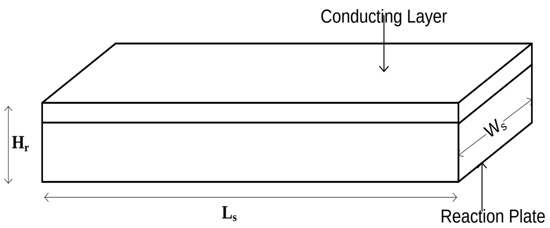

Figure.4 Dimension of Secondary (Rotor)

The secondary reaction plate design which can consist of either solid or laminated design. To improve performance, the reaction plate is coated with conduction sheet of either aluminium or copper. For standard operating, the reaction plate should not be any less than 6mm thick and the attached conducting sheet should not be any less than 3mm thick. The best thrust per size ratio is obtained.

$$W_{se} = W_{st} + \frac{2\tau}{\pi} \tag{60}$$

Where W_{se} is width of secondary and W_{st} is width of primary.

4. RESULT AND DISCUSSION

According to the design procedure in section 3, design calculation result of single-sided linear induction motor are mentioned with the following tables.

Table 1. Design of Primary

	Parameters	Symbol	Values	Unit
Stator winding design	Copper wire size	-	1	SWG
	Diameter of wire	-	7.62	mm
Stator core design	Length of stator	L_s	450	mm
	Width of stator	W_{st}	1000	mm
	Slot width	W_s	14.7	mm
	Tooth width	W_t	22	mm
	Slot height	h_s	32.73	mm
	Yoke height	h_y	12.51	mm

Table 2. Design of Secondary

Parameters	Symbol	Values	Unit
Length of secondary	L_{se}		
Width of secondary	W_{se}	1100	mm
Thick of conducting layer	d	3	mm
Thick of reaction plate		6	mm

The length of the secondary will be as long as the motion length. So, the length of secondary is not illustrated in table 2. The design data sheet of electrical parameters of SLIM is presented in table 3.In the electrical parameters design, neglect the core losses.

Table 3. Design Output of Electrical Parameters

Parameters	Symbol	Values	Unit
Per-phase stator resistance	R_1	0.00356	Ω
Per-phase stator slot leakage reactance	X_1	0.1371	Ω
Per-phase magnetizing reactance	X_m	1.1795	Ω
Per-phase rotor resistance	R_2	0.2055	Ω
Supply current	I_1	201.605	A
Input active power	P_i	62.854	KW
Output power	P_0	56.211	KW
Efficiency	η	0.89	%
Power factor	$\cos\phi$	0.45	-

This motor is designed to move the total mass of 1643.5kg.It is needed 19.54KN output thrust with the rated velocity 10m/s. The outputs for the design motor are tabulated below table 4.

Table 4. Design Output of SLIM

Parameters	Symbol	Values	Unit
Total output thrust	F_t	22.5	KN
Velocity	v_r	10	m/s

5. CONCLUSION

In this paper, the main features of a single-sided linear induction motor with short primary designed for vertical transportation application are described. The design procedure was first done analytically considering the parameters required like velocity, output thrust, efficiency, size of elevator cabin, etc. The motor design was thus carried out systematically and desired characteristics and performance was obtained. In this study, the study of elevator system was not performed because the goal of this study was the designing the model for a single-sided linear induction motor based on the elevator system. The single-sided linear induction motor was chosen only as an application case study to show how the technology can be used and optimized. Finally, it can be concluded a single-sided linear induction motor with short primary is a suitable electric motor to fulfill all the demands of modern elevator system.

6. ACKNOWLEDGMENTS

The author is deeply grateful to Dr. Nan Win Aung, my dissertation supervisor and Daw May Nwe Ye Tun, my co-supervisor. The author also thanks to all teachers at Technological University (Thanlyin) and all who provided her with necessary assistance for this paper. The author wishes to express her guidance to all persons who helped directly or indirectly towards the successful completion of paper. Finally, the author wishes to express her special thanks to her parents for their support and encouragement to attain her destination without any trouble.

7. REFERENCES

[1] Hoang, Viet Nam: “Design of A Single-Sided Linear Induction Motor”, University of Queensland, (2003).

[2] IN. ,.Degree Project Electrical Power Engineering 120 Credits. Second Cycle. ,.Stockholm Sweden 2015. “Linear Induction Motor Investigation and Design for Articulated Funiculator”. YIFEI HU

[3] Sarveswara Prasad Bhamidi: “Design of a Single-Sided Linear Induction Motor (SLIM) Using a User Interactive Computer Program”, M.sc. Thesis, University of Missouri- Columbia, May (2005).

[4] Boldea, I., and Syed N. A: “The Induction Machine Handbook”., Electric Power Engineering Series, (2002)

[5] Yamamura: “Theory of Linear Induction Motors”, 2nd Edition, John Wiley & Sons, Inc. New York, (1979).

[6] http://www.electricalpowerenergy.com/Linear-induction-motor/

[7] https://en.m.wikipedia.org/wiki/Linear-induction-motor

[8] Nahid Ahmadinia. “The linear Induction Motor(LIM) & Single Linear Induction Motor (SLIM)”. American Journal of Electrical Power and Energy Systems.Vol. 3, N0. 4,2014.

[9] “Design & Performance Analysis of Single Sided Linear Induction Motor”,K.S.Lingamurty, P.Mallikarjuna Rao , T.Sandhya , K.Sri chandan/International Journal of Engineering Reserch and Applications(IJERA),www.ijera.com

[10] Nasar, S.A. and Boldea, I.: “Linear Electric Motors”,, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, (1987).

[11] Kaye, R.J and Prof. Eisuke Masada: “Comparison of Linear Synchronous and Induction Motors,” Sandia National Laboratories, Science University of Tokyo, Japan, June (2004).