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# A Study on Design of Single Sided Linear Induction Motor and Controlling with Voltage Source Inverter Fed Convertor

**M. Tech. Scholar S. Venkata Sai Kumar**
Department of Electrical and Electronics Engineering
Eswar College of Engineering and Technology
A.P., India

***Abstract*** - **Now-a-days, Linear Induction Motors are widely used, in many industrial applications like transportation, conveyor systems, actuators, material handling, pumping of liquid metal, and sliding door closers, etc. The advantages of linear motor is that it requires no mechanical rotary-to-linear converters, high efficiency and economical. The linear induction motor is very useful at places requiring linear motion since it produces thrust directly and has a simple structure, easy maintenance, high acceleration/deceleration and low cost. Linear Induction Motor is basically a rotating squirrel cage induction motor opened out flat. Instead of producing rotary torque from a cylindrical machine it produces linear force from a flat one. The stator of the linear induction motor acts as the primary and the rotor of the linear induction motor acts as the secondary of linear induction motor. As a result, the stator is built with steel laminations and rotor is built with conductor sheet and black iron. The single sided linear induction motor construction is easy and low cost. The working principle of single sided linear induction motor is same as the conventional induction motor. In the secondary eddy current is generated due to an induced EMF. The EMF is induced because of relative velocity between travelling magnetic flux and secondary. The thrust force or linear force is produced due to interaction between travelling flux and eddy current. In this paper, a single sided linear induction motor design parameters are analyzed and prototype has been designed and motor will be control with Voltage Source Inverter Fed Convertor.**

***Keywords*** - **Single Sided Linear Induction Motor (SLIM); Voltage Source Inverter (VSI); Linear Induction Motor (LIM).**

## I. INTRODUCTION

A linear induction motor (LIM) is an AC asynchronous linear motor it works on same principles as that of an induction motor but is typically designed to directly produce motion in a straight line. Characteristically, linear induction motors have a finite length primary and long secondary, which generates end-effects, whereas a conventional induction motor is arranged in an endless loop. Despite their name, not all linear induction motors produce linear motion; some linear induction motors are employed for travelling of large ranges where the cost of a primary would be very expensive.

They also, unlike their rotary counterparts, can give a levitation effect. As with rotary motors, linear motors frequently run on a 3 phase power supply and can support very high speeds. However, there are end-effects which reduce the force, and it's often not possible to fit a gearbox to trade off force and speed. Linear induction motors are thus frequently less energy efficient than normal rotary motors for any given required force output. LIMs are often used where contactless force is required, where low maintenance is desirable, or where the duty cycle is low. Their practical uses include magnetic levitation, linear propulsion, and linear actuators. A SLIM, is obtained by the imaginary process of "cutting" and "unrolling" a rotary induction motor. In practice, the primary or stator of a LIM consists of a rectangular slotted structure formed by a stack of steel laminations.

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 changingelectromagnetic field generates electromagnetic thrust on the plate in the longitudinal direction of the motor.

## II. CONSTRUCTION AND OPERATION OF SLIM

SLIM consists of mainly two components. They are named as

- Primary
- Secondary

In this SLIM the three phase winding contained primary is placed only one side and secondary placed on other side. Fig.1. Volcanic area in the south western. region of KSA.

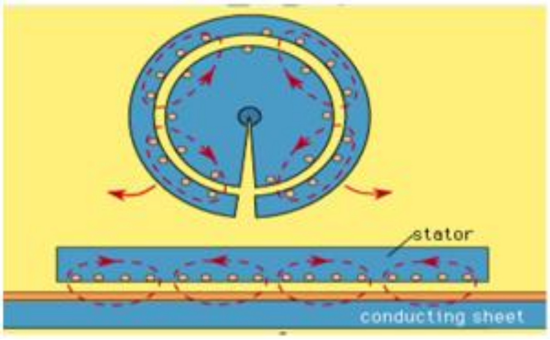


Fig.1.Volcanic pumice powder (4VPP).

The construction of SLIM is cut and flat the three phase induction motor as shown in figure 2.1. Upper part resembles the stator core and bottom part represents the rotor. The circular stator core laid down horizontally to form primary of SLIM and secondary is stationary in SLIM.

**1.Primary**

Primary core is made up of CRNO (Cold Rolled Non-Oriented steel) sheets of thickness 0.3 mm and it is laminated to reduce the eddy current losses. These laminations are insulated from one another with varnish. The entire assembly can be encapsulated with thermally conductive epoxy for insulation and stability. The primary core is provided with semi enclosed slots at one side to house the three phase winding conductors. This three phase windings are connected to three phase supply to get flux in the air gap. This air gap flux is travelling flux in the place of rotating magnetic flux in the conventional induction motor. The primary constructional diagram is shown in Figure 2.2.

Fig.2. Primary of SLIM.

**2. Secondary**

The secondary of SLIM mainly consists of two plates. One is made up of non magnetic and highly conductive material (Aluminum plate or copper plate) and another one is black iron plate. The black iron plate is used to provide return path for magnetic flux and to amplify the magnetic field produced in the coil. Conductive material is used to cut the magnetic flux. If the thickness of aluminum plate is small the conducting plate will get hot, if it is too big the air gap would be large and the efficiency of the machine will be decreased. The plate may be little bit wider than primary iron to allow the current closing its path outside the active area. The reaction plate is used as secondary shown in the figure 2.3.

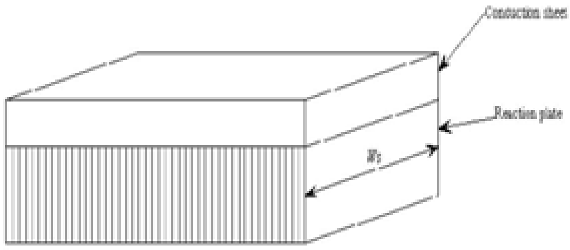

Fig.3. Secondary of SLIM.

**1. Operation**

The LIM operates on the same principal as an induction motor. When the three phase supply is given to the primary it produces the travelling magnetic flux in the air gap. The induced EMF in induced in the conductor plate like the conventional induction motor by the Faraday's law of electromagnetic induction because of relative motion between travelling flux and conductor plate. The current (eddy current) is generated due to this induced EMF. A linear force or thrust force is produced due to the interaction between eddy current and travelling flux. If the secondary is fixed and primary is free to move, because of the thrust force the primary will move.

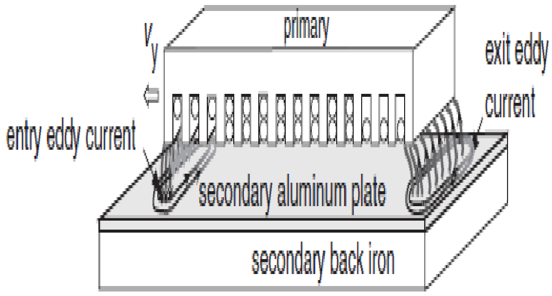


Fig.4. Schematic diagram of SLIM.

## III. DIFFERENT PARAMETERS THAT AFFECT THE PERFORMANCE OF SLIM

**1.Linear Synchronous Speed**

Consider a conventional rotary motor; it is possible to lay a section of the stator out flat without affecting the shape or speed of the magnetic field. Hence, the flat stator would produce a magnetic field that moves at constant speed. The linear synchronous speed is given

Where

Vs= linear synchronous speed [m/s]

p = width of one pole-pitch [m]

f = frequency [Hz]

It is important to note that the linear speed does not depend upon the number of poles but only depend on the pole-pitch width. By this logic, it is possible to for a 2-pole linear machine to have the same linear synchronous speed as that of a 6-pole linear machine, provided that they have the same pole-pitch width. [4]

$$V_s = 2 * p * f(m/\sec) \quad (3.1)$$

**2.Forces**

The main forces involved with the LIM are thrust, normal and lateral. Thrust is what this thesis interested in and its relationship with the other adjustable parameter the normal force is perpendicular to the stator in the z direction. Lateral forces are side forces that are undesirable, due to the orientation of the stator. Under normal operation, the LIM develops a thrust proportional to the square of the applied voltage and this reduces as the slip is reduced similarly to that of an induction motor with a high rotor resistance. The amount of thrust produced by a SLIM is as follows:

F=Pr/Vs (3.2)

Where,

F=Thrust [N],

Pr=power transmitted to the rotor [W],

Vs=linear synchronous speed [m/s]

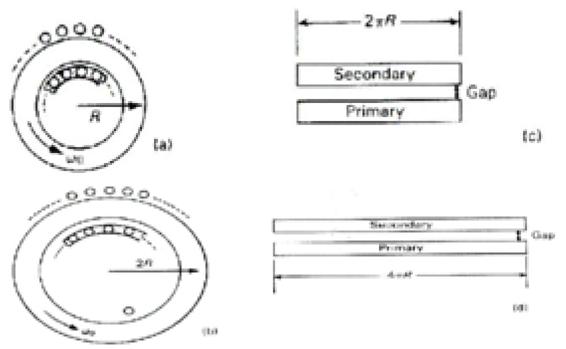


Fig.5. Linear and rotary gap sizes.

For each one cycle of current the field travels two pole pitches. The results clearly indicate that linear synchronous speed does not depend on the number of poles, but depend on the pole pitch as shown in figure 3.1. To increase the linear synchronous speed of the LIM, the designer could either:

- Design a longer pole pitch.
- Increased the supply frequency.

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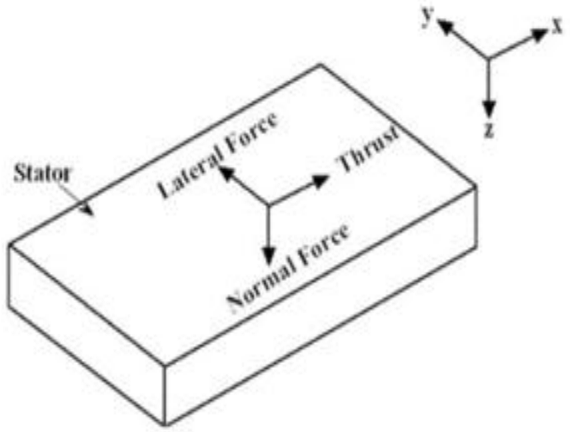


Fig.6. Forces.

**1. Lateral Force**

Lateral force moves in the y-direction as shown in Figure 3.2. These occur due to the asymmetric positioning of the stator in a LIM. Any displacement from the central positioning will result in an unstable system. Generally, small displacements will only result in very small lateral force. At high frequency operation, the lateral force can be become quite chaotic. A set of guided mechanical wheel tracks is sufficient to eliminate small lateral force.

**2. Thrust Force**

Under normal operations, the LIM develops a thrust proportional to the square of the applied voltage and this reduces as the slip is reduced similarly to that of an induction motor with a high rotor resistance. [2]

The amount of thrust produced by a LIM is as follows and shown in figure 3.2

F=Pr/Vs (3.3)

Where,

F=Thrust [N],

Pr=power transmitted to the rotor [W],

Vs=linear synchronous speed [m/s]

Normal Force

In a double-sided linear induction motor (DLIM) configuration, the reaction plate is centrally located between the two primary stators. The normal force between one stator and the reaction plate is equal and opposite to that of the second stator. Therefore, the resultant normal force is zero. A net normal force will only occur if the reaction plate (secondary) is placed asymmetrically between the two stators. This force tends to center the reaction plate. A small displacement of the reaction plate from the center is directly proportional to the displacement.

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### 3.End Effect

One obvious difference between LIM and conventional rotary machines is that the fact that LIM has ends. This means that the travelling magnetic field cannot join up on itself, and introduces end effects. The end effects can result in characteristics that are much different from rotary machines. [6] The end effect is clearly exhibited in the form of a non-uniform flux density distribution along the length of the motor.

For a LIM supplied with a constant current, typical variation of the normal flux density with slip and position along the length is illustrated in Figure 3.3. With constant primary current, it's magnetizing component and consequently the air gap flux decreases as the load component increases with increasing slip. This is true for any induction motor, with or without end effect. For a given slip, the flux density builds up along the LIM length, beginning with a small flux density at the entry end. Depending on the length of penetration of the entry-end- effect-wave, the flux density may not even reach the nominal level that would be found in a motor without end effect.

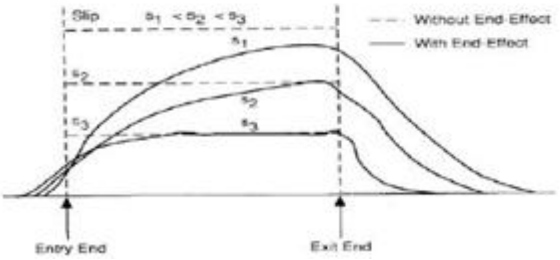

Fig.7. End Effect.

The theoretical evaluation of these effects is much too complicated to explain, but the results can be stated fairly simply. Laithwaite states that, if the total number of pole-pitches on the shorter member (either short stator or short rotor) exceeds four, the additional effect of the transients due to the edges is likely to be so small that it can be neglected, except in large, powerful machines. [3]

### 4.Edge Effect

The edge effect is generally described as the effect of having finite width for a linear motor. This effect is more evident with lower values of width-to-air gap ratio. Figure 3.4 illustrates the variation of the normal flux density in the transverse direction. The figure shows a dip at the centre due to the edge effect, and the dip is more obvious at higher slips. [2].

### 5.Effect of Losses

Mainly SLIM consists of Copper losses rather than mechanical losses. This is due to no friction exists between the moving parts. Then efficiency of the motor will be high. Also the copper losses are also less when compared to the losses in normal Induction motor.

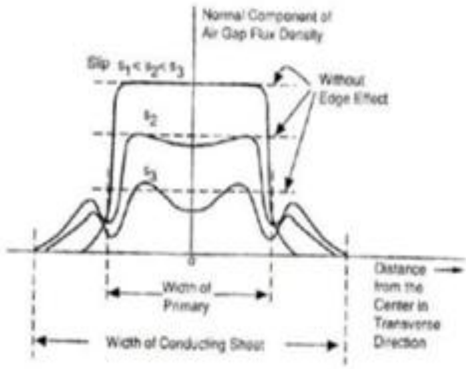

Fig.8. Edge Effect.

## IV. DESIGN OF SLIM

### 1. Design Parameters

### 1. 1 Air Gap

The length of the air gap is very important parameter in machine design. A large air gap requires a large magnetizing current and results in a smaller power factor. In the case of an LIM, exit-end zone losses increase with a larger air gap. Also, output force and efficiency decrease when the design incorporates a large air gap. The goodness factor is inversely proportional to the air gap. Using the goodness factor concept, machine design can be optimized, since for a low-speed LIM, to a certain extent, the larger the goodness factor, the better the machine. Thus, it is clear that the air gap should be as small as is mechanically possible.

### 2. Pole Pitch

For larger goodness factor, the pole pitch should be as large as possible. Note that the pole pitch (τp) is squared in the expression goodness factor. However, too large pole pitch results in increased back iron Thickness, which could tremendously increase the weight of the LIM. Also, if pole pitch increases, efficiency decreases, resulting in less active length of conductor (conductor in the slot) to the total length of the conductor (conductor in the slot plus the end connections). As known, end connections serve no useful purpose and can produce very high leakages and losses. Synchronous speed (vs) is related to frequency and pole pitch as follows:

$$V_s = 2 * \tau * f (m/\sec) \quad (4.1)$$

Thus, for a given frequency, the pole pitch alone determines the synchronous speed of the machine .For a given machine length, a large pole pitch results in a smaller number of poles, which is usually not desired.

### 3. Number of Poles

End effects are reduced with an increase in the number of poles, in the LIM. This is because more poles tend to share the constant end-effect a loss between them, resulting in a better performing machine. Thus, it would be advantageous to have a machine with a large number of poles. [4]

## 4. Primary Core

The variations in stator core design also affect the performance of a LIM. Given a constant cross-sectional area of copper in the slot, a machine with narrower teeth produces more force and has better efficiency and a better power factor than a machine with wider teeth. This is because a machine with narrower teeth has lower primary and secondary leakage reactance that results in a smaller secondary time constant. A smaller time constant produces an end-effect travelling wave of smaller magnitude, and this leads to larger machine output. To determine the narrowest tooth width, the flux density in the tooth must be considered, tooth saturation setting the limit on the narrowest tooth. [3] The SLIM system consists of multiple SLIM stator units which are identical and connected physically in series, but electrically in parallel. These SLIM stator units power the capsules in this system. In this section, a single stator unit is designed using the equations presented. Various SLIM winding configurations are discussed and then the design procedures and the design algorithm of the SLIM are presented and discussed. The iterative procedures given in the algorithm are also discussed.

## 5. Winding Configurations

There are many winding arrangements possible for a LIM. Prominent among them are the single layer, double layer and the triple layer winding configurations. This project is interested in the feasibility of double layer winding configurations in LIM's.

## 6.Double Layer Winding

The armatures of nearly all synchronous generators and motors, and most induction motors above a few kilowatts, are wound with double-layer windings. In a double layer winding, there are two sets of windings of different phases placed in the same slot, except the end slots, as shown in Figure each coil has two sides. The end of each coil or its second coil side is placed below the start of the adjacent coil or its first coil side. This ensures that the windings are placed identically with respect to each other. This winding configuration results in a balanced arrangement with all three phases carrying the same amount of current. The number of turns in each coil and the parallel arrangements depends on the supply current and the size of each slot.

It is possible to construct a winding with a coil pitch less than the pole pitch. When the span from center to center of the coil, which constitutes a phase belt, is less than the pole pitch, the winding as a whole is said to be a fractional-pitch winding. Fractional pitch windings are extensively used, particularly with two layer windings because they reduce harmonics in the voltage wave and produce a more nearly sinusoidal current waveform than with full-pitch windings. They also give a saving in the amount of copper used in the overhang and the greater stiffness of the coils due to shorter end connections. The fractional-pitch, double layer winding having a coil pitch equal to one-third the pole pitch is shown in the Figure 4.1.

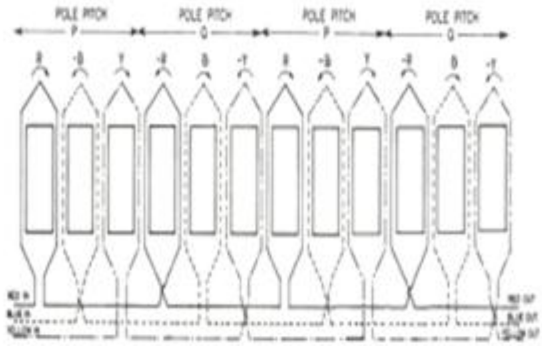


Fig.9. Double Layer Winding in SLIM.

The advantages and disadvantages of these windings are related to the manufacturing costs and the capacity for producing an air-gap field distribution approaching a purely sinusoidal wave. The double layer winding utilizes double the number of coils than a single layer winding but it produces a very good forward traveling wave of fewer harmonics components than its counterpart. Thus, there is a tradeoff between cost and performance in choosing the type of winding for a SLIM. In high-thrust applications, the double layer winding is most suitable. In general, it may be said that modern practice favors the double-layer winding except where the slot openings would be large compared with the length of the air-gap, as in high voltage induction motors. [5]

## 7.Design Specifications

Type of machine: 3Φ linear induction motor
Supply Voltage: 300 V,
Rating: 1HP,
Poles: 4 Pole,
Frequency: 50 Hz.,
Slot: 12, double layer

## 8.Design Implementation

Here the stator design is particularly important, many different design were evaluated and analyze before achieving the final design. There's no particular design procedure given in any book or research paper, so we have tried to develop the design procedure step from our knowledge of conventional This project describes the design and implementation of the stator component of LIM. The design incorporates the theory discussed in the previous chapters along with any additional theory required to produce induction motor. Care has been taken by us to make necessary changes and modification in the design as per requirements.

**9.Design Calculations**

From the induction motor principle explained above, we obtain a linear motor if we imagine cutting and unrolling the motor, as shown in Figure, causing the motor to have a linear motion. Instead of rotating flux, the primary windings now create flux in a linear fashion. The primary field interacts with the secondary conductors and hence exerts a force on the secondary. Generally, the secondary is made longer than the primary to make maximum use of the primary magnetic field. [2]

As stated earlier, there should be relative motion between the conductor and the magnetic lines of flux, in order for a voltage to be induced in the conductor. That's why induction motors, normally operate at a speed Vr that is slightly less than the synchronous velocity Vs. Slip is the difference between the stator magnetic field speed and the rotor speed. Slip is the relative motion needed in the induction motor to induce a voltage in the rotor, and it is given by

S=Vs – Vr / Vs (4.2)

The SLIM synchronous velocity Vs is the same as that of the rotary induction motor, given by

Vs = 2wR/p = 2 f τ (4.3)

Where, R is the stator radius of the rotary induction motor, as shown in Figure. 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, defined as

τ= 2πR/ p (4.4)

The stator circumference of the rotary induction motor, 2πR, in above equation is equal to the length of the SLIM stator core, Ls as shown in above figure. Therefore, the pole pitch of a SLIM is

τ= 2πR/P = Ls/ p (4.5)

If the velocity of the rotor is Vr, then the slip of a SLIM can be defined as

S=Vs – Vr / Vs (4.6)

The air-gap shown in Figure is the clearance between the rotor wall and the SLIM stator in a SLIM system.

**10. Concept of Current Sheet**

As mentioned earlier, the stator of an induction machine consists of several coils, each having many turns of wires – the windings – embedded in slots in laminated iron. The current carried by the windings can be replaced by a fictitious and infinitely thin layer of current distributed over the surface of the stator facing the air gap. This current is called the "current sheet." The current sheet produces the same sinusoidal magneto motive force (mmf) in the air gap as that produced by the conductors. The current sheet strength, i.e., the amount of current per unit stator length (Ls) in a current sheet of a SLIM, can be calculated as in Nasar and Boldea as follows:

$$Jm = \frac{2\sqrt{2}mK_W N_C I_1}{L_s} \quad (4.7)$$

In above formula, Jm is the current sheet strength (amp/meter); m is the number of phases of the motor; kw is the winding factor, defined below; Nc is the number of turns per slot; I1 is the RMS value of the input current; Ls is the length of one section of the stator of the LIM, which is equivalent to the circumference of a rotary motor, namely,

Ls = 2πR= pτ.

The winding factor, kw, is defined as the product of pitch factor kp and the distribution factor kd

$$K_w = K_p * K_d \quad (4.8)$$

Where Kp is the pitch factor of the coil, which is given by

$$K_p = Sin(\frac{\theta_p}{2}) \quad (4.9)$$

Where θp is the coil span in electrical degrees and Kd is the distribution factor which is given as

$$K_d = \frac{Sin(\frac{q_1\alpha}{2})}{q_1 Sin(\frac{\alpha}{2})} \quad (4.10)$$

Where α is the slot angle in electrical degrees and it is given as

$$\alpha = \frac{\Pi}{(mq_1)} \quad (4.11)$$

One pole pitch is equal to 180 electrical degrees. So, in a full pitch coil where the coil span is equal to one pole pitch, the pitch factor becomes one. Therefore, the winding factor for the fundamental harmonic of a full pitch coil can be obtained by substituting kw and α values in kd.

**11. Power Rating**

The electrical power input to the stator windings is converted into useful mechanical power by the principle of electrical induction, as explained before, and the expressions relating to the power balance are derived as follows. The power input to the stator windings is given by P = mV1 I1 cos ϕ. (4.12) Where m is the number of electrical phases, V1 and I1 are the RMS input phase voltage and current, respectively, and φ is the power factor, which is the phase angle between V1 and I1.

Included in this input power is a component for the copper losses in the stator windings, and a component for the iron losses in the stator core and teeth. The remaining

input power is transferred to the rotor through the magnetic field of the air-gap. Neglecting the rotor conductor losses and friction and windage losses, the power transferred to the rotor can be equated to the mechanical power developed by the rotor. [4]
The total mechanical power developed by the rotor of the SLIM is given by
Po = FsVr, (4.13)
Where Fs is the electromagnetic thrust generated on the rotor by the stator, and, as stated before, Vc is the speed of the rotor. The SLIM efficiency η is calculated from

$$\eta = \frac{F_s V_r}{m V_1 I_1 \cos\phi} \quad (4.14)$$

From above equation, we initially assume a suitable operating value for ηcosφ, and then the rated input phase current can be estimated from

$$I_1 = \frac{F_s V_r}{m \eta V_1 \cos\phi} \quad (4.15)$$

## 12. Flux Linkages and Induced Voltages

Consider a coil of N turns carrying a current of I amperes and let Φ be the resulting flux linking the coil. If we assume that the flux density Φ in the air-gap is purely sinusoidal, then it can be expressed as

$$\phi_p = \phi \sin \omega t \quad (4.16)$$

where Φp is the amplitude of the flux linkage per pole. By flux linkage, we mean the product of flux in Weber and the number of turns with which the flux is linked. The induced voltage per turn in the above coil due to a change of flux is given by the first derivative of the above equation, and is represented as

$$e = \frac{d\phi}{dt} = \omega \phi_p \cos(wt) \quad (4.17)$$

The RMS value of e is

$$E_1 = \frac{2\Pi}{\sqrt{2}} f\phi_p = \sqrt{2}\,\Pi\, f\phi_p \quad (4.18)$$

If the coil has N1 turns per phase and a winding factor kw, E1 becomes

$$E_1 = \frac{2\Pi}{\sqrt{2}} f\phi_p K_w N_1 \quad (4.19)$$

Magnetic flux density is found by dividing the flux by the cross sectional area. Hence, the average air-gap magnetic flux density, Bgavg can be determined as

$$B_{gavg} = \frac{\phi_p p}{L_s W_s} \quad (4.20)$$

Where Ws is the width of SLIM stator iron core, and Ls is the length of stator and p is the number of poles. We assume that the flux produced in the air-gap is sinusoidal, having a maximum of Bgmax. Hence, the average value of the rectified magnetic flux density is

$$B_g = \frac{2}{\Pi} B_{g\max} \quad (4.21)$$

## 13.Motor in Motion

In this section there is a detailed study of outer structure of motor and wheels.

### 13.1 Chassis Design

Chassis design refers to outer structure. The outer structure of SLIM is purely based on the application of the motor

### 13.2 Specifications

Length=15 cm
Width = 10 cm
Height= 15.24cm
The chassis of the SLIM along with primary is shown in figure 4.3

### 13.3. Wheel Design

Wheels are used to move the cage on the track.
Specifications
Outer diameter = 7cm
Inner diameter = 10cm
Bearing diameter = 1.27cm
The wheels of SLIM is shown in figure 4.4

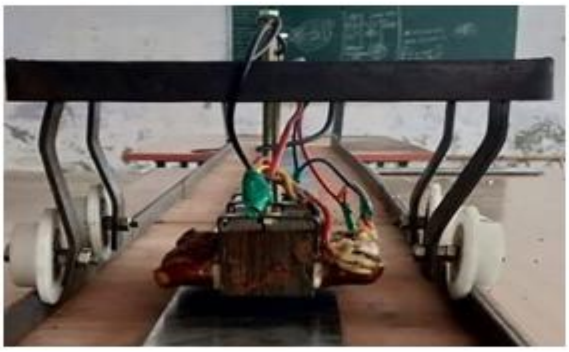

Fig. 10. Outer cage of SLIM.

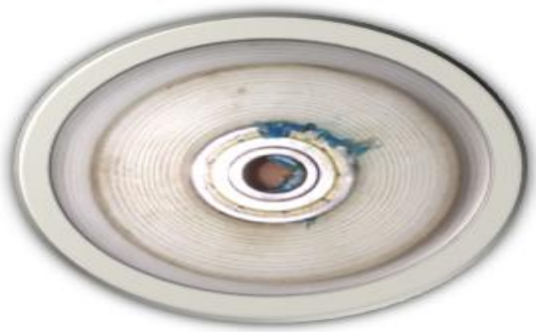

Fig.11. Wheel Design.

### 13.4. Aluminum and Iron Sheets

Aluminum and iron sheets are used as secondary for the motor and the dimensions of the sheets are as follows
Specifications
Iron

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Thickness = 0.5cm
Width = 10cm
Aluminum
Thickness = 0.2cm
Width = 10cm
The track of SLIM is shown in figure 4.5

Fig.12. Track for SLIM.

**13.5 Whole View of SLIM**

The whole view of SLIM along with primary, secondary, chassis, wheels and track is shown in figure4.6

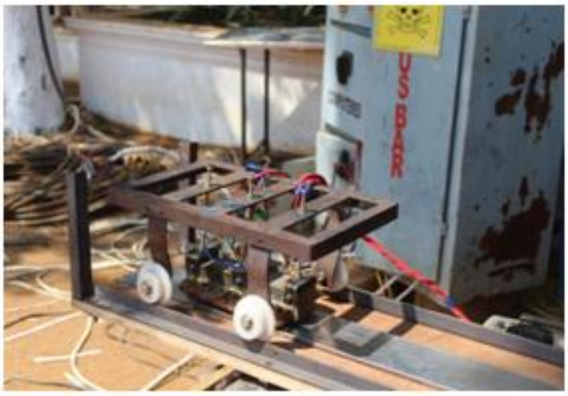

Fig.13. Whole View of SLIM.

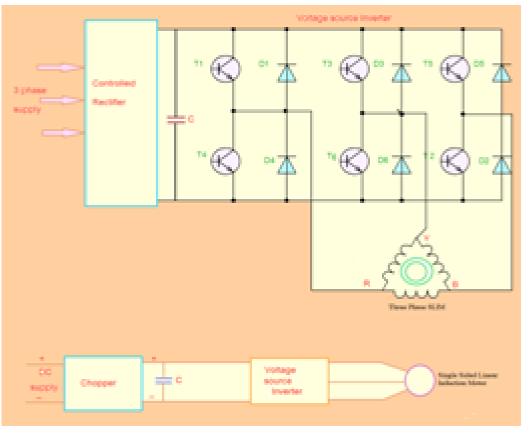


Fig.14. VSI Control of SLIM.

The circuit for VSI fed SLIM motor is shown above. It consists of voltage source Inverter i.e. the combination of transistors and diodes which provide variable frequency control to the Induction motor. The terminal voltage kept constant when the load is varying. The output voltage is square wave hence the inverter is named as variable frequency or square wave inverter.

- The frequency is varied by changing the triggering pulses switching times across the transistor.
- The magnitude of output voltage is controlled by controlling DC supply and frequency is controlled by Input wave time period.
- The above figure shows the two different operations one with three phase AC supply and other with DC supply

There are two techniques to get desirable outputs
1. Controlling the inverter voltage by PWM technique
2. Connecting the DC chopper in between rectifier and inverter.

A VSI is a self or separate control feeding Induction motor. Open loop and closed loop operation is possible. The stator current drawn by the motors when fed to VSI has sharp peaks and is rich in harmonic content which causes additional losses and heating. This technique is used for high and medium speed applications.

## V. CONCLUSION

It can be concluded that the air-gap plays a very important role in the performance of the SLIM. The air-gap needs to be as small as possible to have a better thrust. Another crucial design parameter is the thickness of rotor outer layers which are aluminum and Iron sheet. As the thickness of the aluminum sheet increases thrust also increases along with the length of magnetic air-gap which is undesirable. Hence, care should be taken in choosing the best value for aluminum thickness which yields maximum thrust.

So, from the parametric evaluation which is performed in previous chapters, it can be concluded that the input parameters like the length of physical air-gap, the thickness of aluminum sheet and the number of poles play a vital role in the performance parameters, thrust. Therefore, care should be taken in choosing these parameters. Based on our target values of rotor velocity and thrust, these parameters should be chosen which gives the best possible thrust force closest to the targeted value. The principle and operation of SLIM is same as conventional induction motor. So, the controlling methods of conventional induction motor are also applicable to SLIM, which will have effective control in terms of the efficiency and performance.

## REFERENCES

[1]. Building code requirements for structural concrete (ACI 318-11) and commentary, American Concrete Institute, Farmington Hills, MI, 2011.

[2]. State-of-the-Art Report on High-Strength Concrete, ACI 363R-11, ACI Committee 363 Report, American Concrete Institute, Detroit, 2011-1992
[3]. Nawy, E.G. Fundamentals of high performa3nce concrete, Essex, Eng: Longman 1996 Caldarone, M.A High Strength Concrete. Taylor & Francis (2009)
[4]. Shah and Ahmad. Properties of high strength Concrete (1994)
[5]. Neville, A.M. Properties of Concrete. 4th edition. Prentice Hall, (2005)
[6]. ASTM C 1240, Standard Specification for Silica Fume Used in Cementations Mixtures.
[7]. Burg and Ost, Structure and Performance of Cements, 2nd edition, New York: Spoon Press (1992),
[8]. Malhotra et al, Yajun et al (2004), Study of the reactivity of cement/silica fume. Aitcin, 'Aggregate bond and modulus of elasticity', ACI Materials (1997) 71–74.

[9] Aitcin, Mehta. Effect of coarse aggregate characteristics on mechanical properties of high strength concrete. ACI Mater J1990;87(2):103–7.
[9]. ASTM C150/C150M-16 Standard Specification for Portland Cement
[10]. Binici, H., H. Temiz and M. M. Köse (2007). "The effect of fineness on the properties of the blended cements incorporating ground granulated blast furnace slag and ground basaltic pumice." Construction and Building Materials 21(5): 1122-1128.
[11]. Çetin, C., S. T. Erdoğan and M. Tokyay (2016). "Effect of particle size and slag content on the early hydration of interground blended cements." Cement and Concrete Composites 67: 39-49.
[12]. Givi, A. N., S. A. Rashid, F. N. A. Aziz and M. A. M. Salleh (2010). "Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete." Construction and Building Materials 24(11): 2145-2150.
[13]. Karataş, M., A. Benli and A. Ergin (2017). "Influence of ground pumice powder on the mechanical properties and durability of self-compacting mortars." Construction and Building Materials 150: 467-479.
[14]. Moufti, M. R. and K. Németh (2016). Geoheritage of Volcanic Harrats in Saudi Arabia, Springer.
[15]. RILEM, C. (1984). "11.3. Absorption of water by immersion under vacuum." Mater Struct 17(101): 391-394.
[16]. Supit, S. W., F. U. Shaikh and P. K. Sarker (2014). "Effect of ultrafine fly ash on mechanical properties of high-volume fly ash mortar." Construction and building materials 51: 278-286.
[17]. Zeyad, A. M., M. A. M. Johari, B. A. Tayeh and M. O. Yusuf (2017). "Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete." Journal of Cleaner Production 144: 511-522.
[18]. Zeyad, A. M., M. M. Johari, B. A. Tayeh and M. O. Yusuf (2016). "Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties of high-strength concrete." Construction and building materials 125: 1066-1079.
[19]. Zeyad, A. M., M. A. Megat Johari, B. A. Tayeh and M. O. Yusuf (2016). "Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties of high-strength concrete." Construction and Building Materials 125: 1066-1079.