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Design and Fabrication of Single Sided Linear Induction Motor for CNC Machines

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ABSTRACT

Anything that requires linear motion will require a Linear Induction Motor. Linear Induction Motors (LIM) are used in many different applications, from moving sliding doors to high speed trains around the world. The main aim of this project is to design, fabricate and analyze a small laboratory sized single-sided linear induction motor (SLIM) for educational aid.

The idea of a practical LIM was first developed by an English Electrical Engineer, Eric Laithwaite around 1940.

LIM operates on the same principle as the conventional rotary motor. To understand the principle of working of a LIM let the Rotary induction motor (RIM) is cut out and laid to form the equivalent LIM. Everything remains same, only the direction of motion has been changed.

This thesis describes the design, fabrication, modeling, testing of a single sided linear induction motor. The stator winding design is particularly important.

Keywords: ***LIM, RIM, Single Sided LIM, CNC***

I. INTRODUCTION

In engineering, especially in electrical and mechanical automated structures such as industrial robots, fast manipulations and machine tools (advanced like CNC machines) linear movements are very usual. These movements are mostly obtained by using rotating motors in combination with rotation-to-translation mechanisms. However, in case where high speed and accuracy are required of these mechanisms, serious problems may arise with stiffness, mass, friction and backlash. These problems can be solved by use of linear motors where linear motion is required. Also energy can be saved up to 30%.A linear electric motor belongs to the group of special electric machines that convert electric energy directly into mechanical energy of translatory motion. These motors can be of DC, induction or synchronous type. Linear induction motors are found to be most effective and are manufactured commercially in many countries.

A linear induction motor is essentially a multi-phase alternating current electric motor that has had its stator “unrolled” so that instead of producing a rotational torque it produces a linear force along its length. It can be described as a non-contacting, high speed linear motor which operates on same principle as that of rotary, squirrel cage induction motor. This project report discusses in detail the design and fabrication of a single sided linear induction motor for use in CNC (computerized numerical control) machine.

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1.1 Objectives:

The main objective of this project is to design and fabricate a single a single sided linear induction motor for its application in CNC machine, as a curtain opener and for various machine tool drives.

This motor is proposed to have following features

- Single sided i.e. one primary a and one secondary
- 3 phase primary moving and stationary secondary as a continuous track
- Small and compact in size

The linear induction motor has been designed considering these features and the other specifications like power rating, thrust etc are used accordingly. These features and specifications are in accordance with necessity for use in a CNC machine.

The benefits provided by use of LIM in CNC machine are as follows

- Translational motion
- High acceleration and velocity
- High accuracy and speed control
- Simplicity in construction and no mechanical linkages
- Enhanced reliability
- Low maintenance and long life
- Compact in size

II. PRINCIPLE OF OPERATION

The basic principle of operation of a LIM is similar to that of rotary induction motor, however instead of producing a rotary torque a linear force is to be produced.Primary and secondary are the two main parts of a linear induction motor. The primary (or secondary depending on design) consists of a polyphase winding uniformly distributed in the slots. The primary produces a sinusoidally distributed magnetic field in the air-gap moving at a uniform speed $2\omega/P$, with ω representing the network pulsation (related to the frequency f by $\omega=2\pi f$) and P the number of poles. The relative motion between the magnetic field produced by primary and secondary (plate) induces a voltage in the secondary. The interaction of these two magnetic fields will produce a linear force. If primary is kept stationary, then the resultant force will move the secondary in the direction of the field.

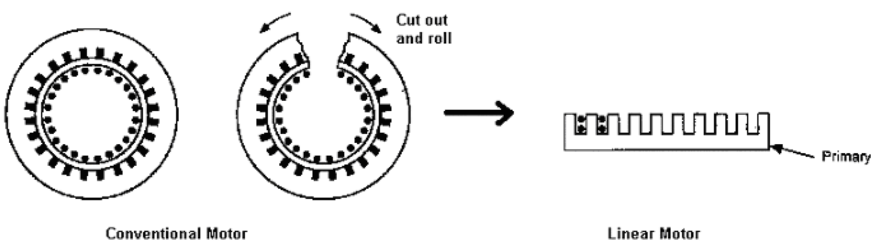

Fig. 1.1: Visualization of LIM from rotary induction motor

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According to Faraday's law of electro-magnetic induction, if flux passes through turn of coil then the emf induced, this is directly proportional to rate of change of flux with respect to time.

In equation form

$$e_{ind} = -d\varphi/dt$$

Where,

e_{ind}= Voltage induced in the turn of coil.

φ = Flux passing through the coil.

If a coil has N turns, the the voltage induced can be given by,

$$e_{ind} = -N\,(d\varphi/dt)$$

The negative sign in the equation indicates the opposition as per Lenz'z law which state that, the direction of induced voltage is such that it opposes the cause produced will oppose the original flux.

When a three phase set of voltage is applied to the stator of rotary induction motor, a three phase set of stator current flows. These currents produce a magnetic field B which is rotating in nature .The speed of rotation is given by

$$N_s = 120f/P$$

Where,

f = System frequency (Hz)

P = Number of poles.

This rotating magnetic field 'B' passes over the rotor conductors and induces an emf, which is represented by the following equation

$$e_{ind} = (V*B).I$$

Where,

V = Velocity of conductor relative to the magnetic field.

B = Magnetic flux density vector.

L = Length of the conductor in the magnetic field.

The relative motion of the rotor compared to the stator magnetic field produces induces voltage in the rotor conductors. Now, if the rotor conductors are short-circuited this would cause a current to flow. This current produces a rotor magnetic field B_R.Interaction between these two fields produces a torque which tends to line-up the two magnetic fields. Therefore, the torque induced causes rotation of the rotor (as stator is fixed). This torque in the machine is given by

$$T_{ind} = k*B_R*B_s$$

Similarly, if a balanced three phase supply is given to primary of linear induction motor, a travelling flux density wave is created that travels along the length of the primary. This traveling wave will induce current in secondary. This induced current will interact with the travelling wave to produce a translational force or thrust 'F'. Now, if the secondary is fixed and the primary is free, than the primary will move in the direction of the traveling wave.

The synchronous velocity of the traveling wave is given by,

$$V_s = 2*\tau*f$$

Where,

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τ = Pole Pitch

f = Supply frequency

It is worth to note that synchronous velocity is independent of the number of poles. The speed of LIM is determined by winding design and supply frequency. By changing the design parameters the thrust to be produced can be varied.

III. CONSTRUCTION

Primary and secondary form the main part of linear induction motor. Either primary or secondary has slots with distributed winding. The polyphase distributed winding maybe mush type, lap type or wave type. The distributed winding produces a distributed magnetic field in the air-gap travelling at a uniform speed. If the primary which is carrying distributed winding, when energized would produce a magnetic field which will interact with the secondary. This would induce voltage across it and would cause a current to flow. Thus, secondary would produce its own magnetic field. Interaction of these two fields would produce a thrust or linear force. If the primary is fixed and secondary is free to move, than the resultant force will move the secondary in the direction of the field.

IV. TYPES

On the basis of construction the linear induction motor can be classified as follows:

1) Single sided linear induction motor

Single sided linear induction motor consist of a primary (coil assembly) and a secondary (reaction plate).The coil assembly comprises of steel laminations and phase winding. The reaction plate maybe of aluminum/steel, copper/steel or steel sheet. The reaction plate faces the coil assembly. The width of the reaction plate must at least be equal to the coil assembly. A bearing system maintains the air-gap between the coil and reaction plate among the length.

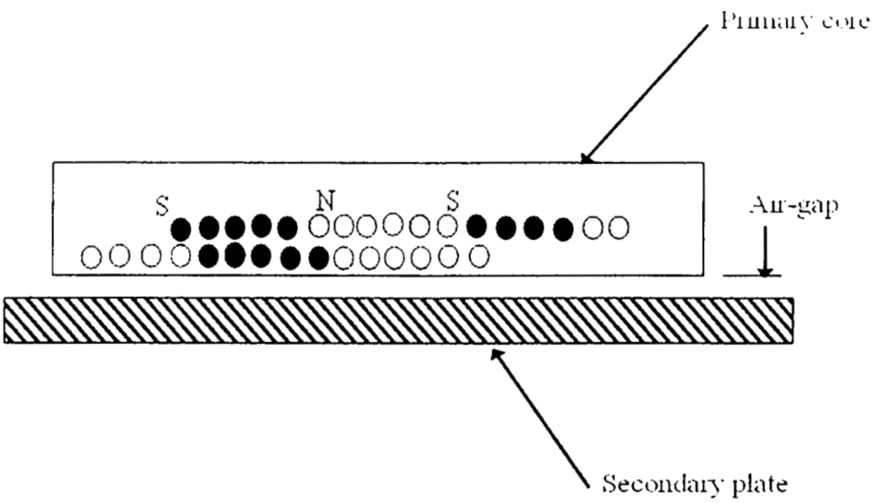

Fig. 2.2 Transverse view of single sided LIM

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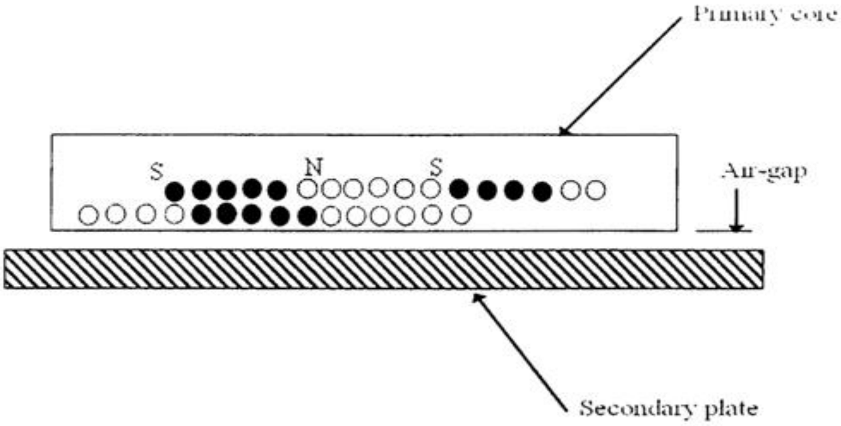

Fig.1.2: Single sided LIM

2) Double sided linear induction motor

In double sided linear induction motor the primary is duplicated and arranged in such a manner that the two primaries face each other and the secondary is in between them as shown below:

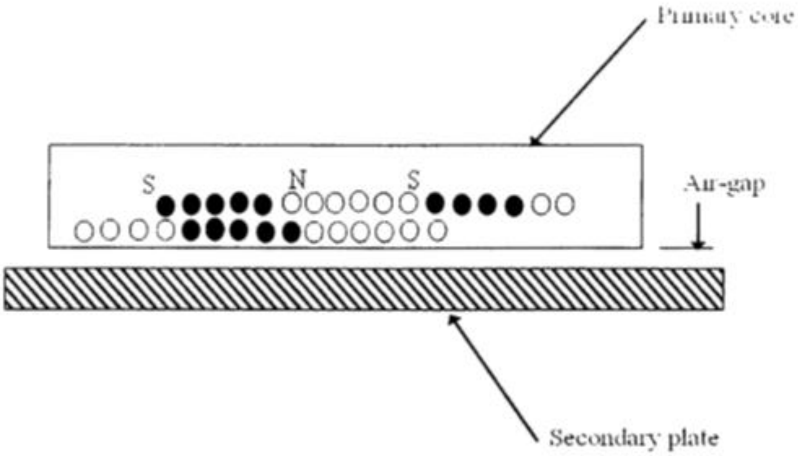

Fig. 2.2 Transverse view of single sided LIM

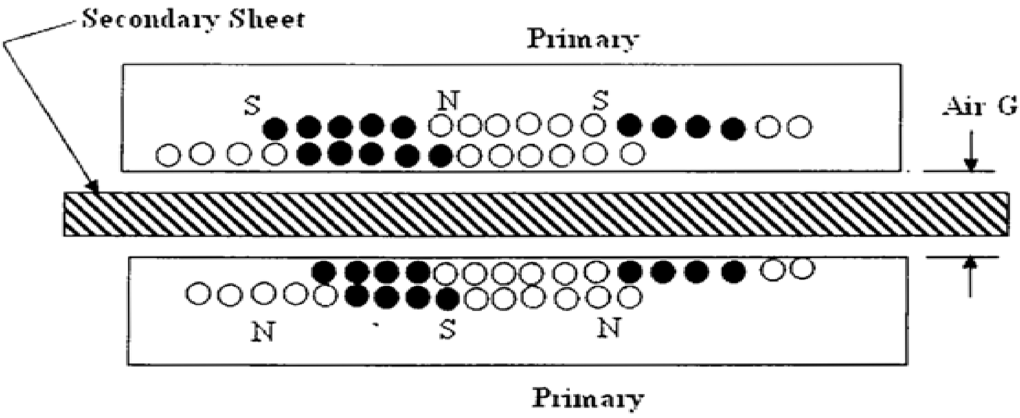

Fig.1.3: Double sided LIM

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V. FABRICATION OF LINEAR INDUCTION MOTOR

The important aspect of any machine design is practical representation of the machine in the form of a fabricated product. The fabrication of the motor gives a practical view of the characteristics of the machine that have been calculated in the design. The different characteristics that can be determined by testing the machine are speed, full load current, efficiency, power factor, output power etc.

VI. MATERIAL PROCUREMENT

The fabrication part of the motor starts with the study of the material required. The materials were chosen in such a manner that the performance of the motor will be highly efficient and there will be no hindrance in its working. The materials used for the various parts such as primary, secondary and frame are described in the table below.

Table below shows all the Material for linear induction motor

Sr. No.	Materials	Specification
1	Lamination sheet	0.381 meter sq.
2	Enameled copper conductor as per design, motor grade	34 SWG
3	MS plate for secondary	182 cm
4	Insulation paper	Class F
5	Coaster wheels small, heavy duty	4 Nos.
6	Voltmeter, Ammeter & indication lamps	(Qty 1 set)
7	3-ph, 220V, coil contactors	(Qty 3 No.)
8	Remote	(Qty 1 No.)
9	DC wire bundle (1.5sq.mm)	(Qty 1 No.)
10	Linear varnish	

Table 1: List of the materials required

- **PRIMARY STACK FORMATION**

The width of the primary stack according to design is approximately 53.3mm for which theoretically 108 laminations, each of 0.5 mm thickness were required. The actual assembly took 106 laminations keeping the stacking factor as 0.98.

Laminations of dimensions 120 mm*30mm were cut out of an aluminum sheet . This cutting of the sheet into laminations was done using bed saw machine.

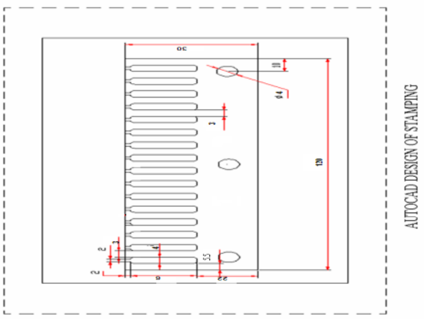

Fig1.4 : Formation of primary Stack

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This cutting into the desired size by use of bed saw machine made the cutting work easy as compared to the conventional methods which required cutting with saw, punching the desired slots for all the 106 laminations and then straightening the laminations.

The laminations obtained were perfect according the size desired but had aberrations at the edges which had to be smoothened by filling. The laminations obtained were now exact as desired and required for stacking shown below.

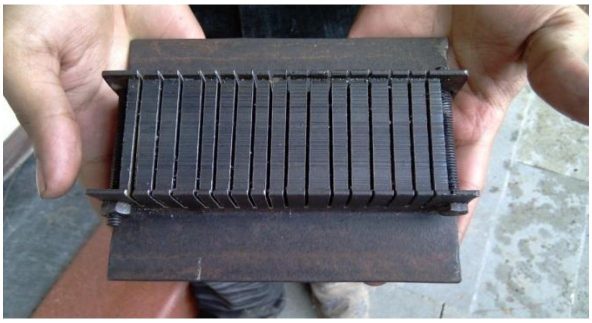

Fig.1.5: Primary stack formation with windings

- **PRIMARY WINDING**

The primary winding of the linear induction motor are made of 34 SWG copper conductor of round cross section. The conductors have enameled insulation. The coils were wound over a former as many number of times as required by the design. The slots were lined with insulation paper (class F) before the coils could be pushed into it. After this the coil sides were pushed into the slots gently with few conductors been pushed at a time. The winding is of a single layer type and hence one coil side is in each slot. After the coil was completely pushed into the slot was covered with insulation paper of 0.5 mm thickness. After the coil side was placed firmly a rectangular wedge was inserted above the coil side as to hold it firmly in place in the slot. These wedges are held by the lips of the slots. It may be mentioned that the winding is made for 3-phase supply as specified in the design. The above set process was repeated for each slot. A piece of insulating paper was inserted in between the overhang portion of each slot. The overhang is tied together with strong waxed thread.

- **SECONDARY FORMATION**

The secondary is the track of MS sheet in horizontal position, 1.8 meter long, on which the primary moves. The secondary is placed in a box shaped track. There is no use of iron bars and angles for support making the track light in weight and is handy to use. The fig below shows the secondary track.

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Fig.1.6: Secondary Track formation

VII. DESIGN STEPS OF LIM

Step 1: Input Data

- Number of phases (m) = 3 ph.
- Input voltage (V_{line}) = 415 V.
- Input frequency (f) = 50 Hz.
- Thrust (Fx) = 40 N.
- Required velocity (V) = 2 m/s.
- Slip (s) = 3%.

Step-2: Assumptions

- Flux Density (B_{av}) = 0.3 Wb/m^2.
- Ampere conductors (ac) = 12,000.

Step-3: Primary Design

- Synchronous velocity

  V_{sync} = V (mtr/s)/(1-s)
  = 2/(1-0.03)
  = 2.061 mtr/s

- Pole pitch

  τ = V_{sync}/(2*f)
  = 2.061/(2*50) = 0.0261 m.

- Output power

  P_{out} = Fx (N) * V (mtr/s)
  = 40 * 2 N-mtr/sec
  = 80 watt.

- Taking ηcosφ = 0.1875 from Power o/p Vs ηcosφ graph
- Induced emf

  E_l = 0.7 Vph
  = 0.7 * 239.6
  = 167.72 V

- Current per phase

  Iph = (Fx * V)/ (m * Vph * ηcosφ)
  = (40 * 2)/(3 * 239.6 * 0.1875)
  = 1.11 ampere

Step-4: Taking poles

P=2, Length and width of primary was calculated.

Step- 5: Primary winding design

Calculate Number of turns per phase, total number of conductors, flux/pole

Step- 6: Assumption

Current density (δ) = 30 Amp/ mm^2

- Area of conductor

$$S = Iph/ \delta = 1.11/ 30 = 0.06\ mm^2$$

- Diameter of conductor

$$d = \sqrt{[(s *4)/ \Pi]} = \sqrt{[(0.037 * 4)/\Pi]} = 0.217\ mm$$

From data sheet (d) is taken to be 0.235mm

Step -7: Calculation of area of conductor, slot-pitch and number of slots.

- **LIMIT SWITCH CONSTRUCTION TO CONTROL LIM :**

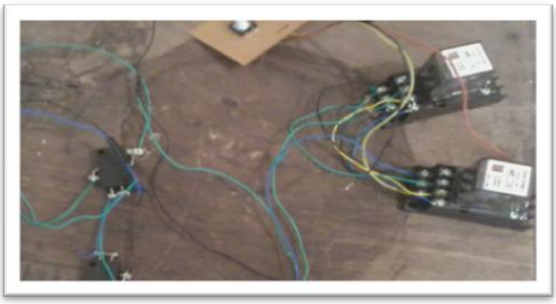

Fig.1.7: Limiting switch to control LIM

- **FINAL ASSEMBLED WORKING MODEL:**

Fig.1.8: Practical model of LIM

VIII. ADVANTAGES AND DISADVANTAGES OF LIM

- **Advantages:**

- High speed linear motor operates on the same principle as a rotory squirrel cage induction motor.
- Centrifugal forces are absent, so no chances of winding to come out.

- It is capable of higher speed.
- Used in the application where accurate positioning is required
- The noise level is very low in compare to RIM

➢ **Disadvantages:**

- Linear motor has larger slip for which secondary losses increases and efficiency decreases.
- Presence of end-effects reduces maximum thrust
- Due to larger air-gap, the magnetizing current taken by LIM is large which decreases the power-factor

IX. APPLICATIONS OF LIM

- Sliding Doors
- Baggage Handling
- Water valve operation
- Crane Drives
- Linear Accelerators
- Capsule Filling Machine
- High Speed Trains

X. TESTING OF LIM

Testing of LIM can be done using Two Watt-meter method for finding No-Load test and Blocked Primary test to find power factor, machine output and efficiency.

XI. OVERVIEW OF THE PROJECT AND CONCLUSION

The design and fabrication of the single sided linear induction motor with a remote control formed the main objective of the project. The objective was in accordance with the necessity of the use of this linear induction motor for CNC machine and other machine tool drives. The design procedure was first done analytically considering the parameters required like velocity, output power, size of motor, etc. The motor design was thus carried out systematically and desired characteristics and performance was obtained.

The next part of the fabrication was the most difficult part which required time commitment and patience. The fabrication was completed trying to achieve the design considerations.

After the fabrication motor was tested and analytical and practical parameters like efficiency, power factor, losses, etc were matched. Thus the project was completed successfully in all aspects to achieve the objective. The project was an enriching experience for all of us in terms of analytical and practical experience. The knowledge in this field gained by us is incomparably rich. It will thus remain as a knowledgeable and eventful experience period in our life.

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Thesis

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[6] J. Duncan, C.Eng, M.I.E.E.E, designed an equivalent circuit model of a LIM using RIM as a basis and is modified to account for the so called "End Effect" and is used to predict output thrust, vertical force andcouples.

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