Design and Fabrication of Linear Induction Motor

PROJECT REPORT

Submitted in Partial fulfilment of the
requirements for the award of the Degree of
BACHELOR OF ENGINEERING IN
ELECTRICAL AND ELECTRONICS ENGINEERING
of the Bharathiar University
Coimbatore-641 046.

BY :

R. M SUBRAMANIAN
S. KUMAR
R. SRIDARAN
K. MALARVIZHI

1992 - 93

Under the guidance of :

Mr. S. KUMAR, M.E.,

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY
COIMBATORE - 641 006

KUMARAGURU COLLEGE OF TECHNOLOGY
COIMBATORE-641006

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

CERTIFICATE

This is to certify that the report entitled

DESIGN AND FABRICATION OF LINEAR INDUCTION MOTOR

has been submitted by

Mr. R.M. SUGA[illegible]
Mr. R. SRIDHARAN
Mr. S. KUMAR
Miss. K. MAL[illegible]

in partial fulfilment for the award of
Bachelor of Engineering
in Electrical and Electronics Engineering
branch of Bharathiar University,
Coimbatore-641046, during the academic year 1992-93.

S.Kumar 2/4/93
GUIDE

Dr. K. A. PALANISWAMY, B.E., M.Sc. (Engg), Ph.D., M.I.S.T.E., C.Eng.(I), F.I.E.,
Professor and Head
HEAD OF THE DEPARTMENT
Department of Electrical and Electronics Engineering,
Kumaraguru College of Technology,
Coimbatore 641 006

Certified that the canditate with University
Register No. ....
has been examined on ....

....
Internal Examiner

....
External Examiner

DEDICATED TO OUR FRIEND

Late S.MURALI

ACKNOWLEDGEMENT

We are greatly indebted to our Guide Mr. S.KUMAR, M.E., for his able guidance and keen interest shown in completion of this project.

We extend our heartly thanks to Dr. K.A.PALANISWAMY, M.Sc.(Engg.), Ph.D., MISTE, C.Eng (I)., FIE, Professor and Head of the department for his constant interest and help for the successful completion of this project.

We wish to thank Prof. CHRISTIAN PAUL, M.E., M.I.S.T.E., for inspiring us to take up this project and for giving us a lot of valuable help in finishing it.

We wish to thank the Principal Major T.S. RAMAMURTHY, B.E., MISTE for providing the facilities to carry out this project.

We wish to thank Dr. M.RANGASAMY, M.Sc.,(Engg.) Ph.D., Assistant Professor of E.E.E., Government College of Technology, Coimbatore, for his guidance and help in completing this project. We also thank other members of staffs of our department for their cooperation.

SYNOPSIS

Although one can date the concept, albeit in embryo form, back to the end of the last century, linear induction motors have not really been studied until the last thirty years. Since then researches in this domain have continued to gain momentum, encouraged by the importance of applications in the domain of transport, notably for aerodynamically, magnetically or electrodynamically suspended vehicles.

This project work basically involves construction of a quarter H.P, three phase, 140 volts, 50 Hz single sided Linear Induction motor model. To be more precise, out of serveral configurations of LIM this is a Short movable primary-long fixed secondary type of SLIM. This model helps us in getting acquainted with several principles related to linear induction motors.

CONTENTS

CONTENTS

CHAPTER - 1

INTRODUCTION

A linear machine can be regarded intially as resembling a normal rotating machine, cut and opened out flat. Of the two elements derived respectively from the stator and rotor, either may move. The member connnected to the supply is called the primary, the other the secondary. In use, either member is fixed as the stator, while the other becomes the movable runner.

The idea of associating power conversion with LM dates back to the early 1830s, when Faraday attempted to generate electricity by utilising the streaming water of the Thames river as the active conductor, the geomagnetic field as the field excitation, and the dangling wires as the electrodes. Other significant dates were 1841, when Wheatstone built the first LIM ;1905, when linear propulsion was first proposed for ground transportation; and 1946, when a 400ft long wound-round IM was constructed at westing house for the purpose of catapulting small seaplanes from the deck of a ship. Soon thereafter, Professor E.R.Laithwaite of the Imperial College in London initiated his pioneering work on the LIM and the recent popularity of this machine is largely due to his promotional effort. However, LIMs faced a relatively dormant period until the 1960s. It is only over the last three decades that we have seen a resurgence in the field of LMs.

In recent years, attempts to develop new means of high speed, efficient transportation have led to considerable world-wide interest in high speed trains. This inturn has generated interests in high-speed trains. This inturn has generated interests in the LIM which is considered to be one of the most suitable propulsion systems for super-high-speed trains. Research and experiments on LIMs are being actively pursued in a number of countries, among them Japan.

Linear proplusion relates to a novel type of electric drive for ground transportation systems. In such a scheme, the motor is split into two parts, of which one is carried by the vehicle and the other lies straight long the track. The force of interaction between these two structures is utilised directly as tractive effort, without the need for intermediate transmission or gear.

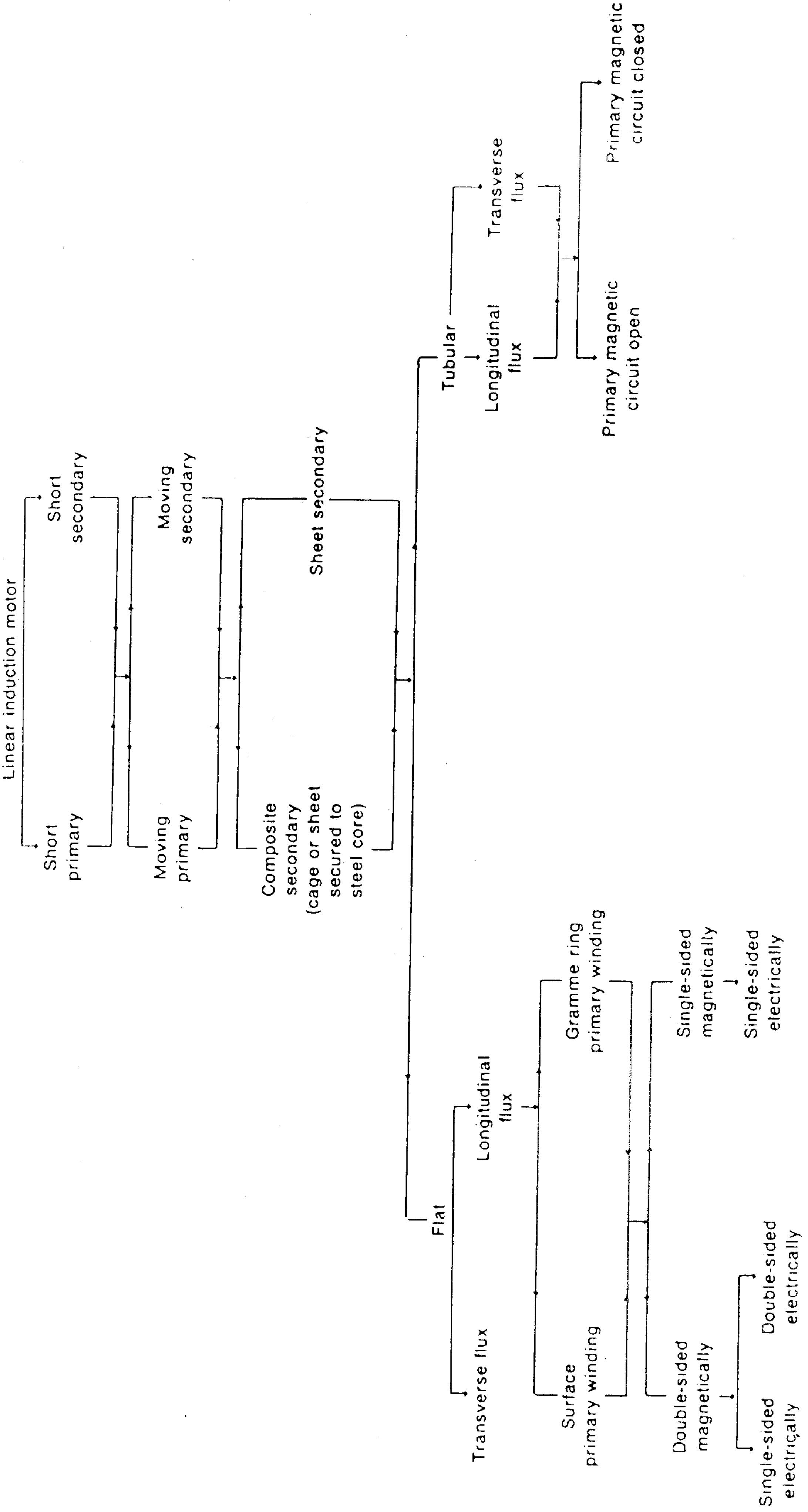
The diffrence between the LIM and the ordinary rotating IM is basically due to the diffrence in their air gap. The LIM has an open air gap with an entry end and an exit end, while the rotating IM has a closed air gap. It is the open endness of the air gap that gives rise to the peculiar characteristics of the LIM. Other constructional features, such as larger air-gap length and a secondary conductive sheet, are not peculiar to the LIM.

Just as a common (rotary) electric motor produces rotary motion, a LEM produces linear motion, or motion in a straight line. If we look around, we will find numerous examples where a conventional rotary motor is used to produce reciprocating (back-and-forth) motion, such as in a vibrator or a reciprocating compressor. Gears, worm screws and other mechanisms convert rotary motion into linear motion. Using linear motors for applications requiring motion in a straight line eliminates gears and other mechanisms, with the added benefits of quietness and reliability. A LM is not necessarily the best choice for every application involving linear motion. Although almost a century old, linear motors are in a stage of infancy in development.

Some practical applications include : robotics, biomedical engineering, Computer controlled machining and machine tools, printing pertaining to the computer industry, material handling, conveyor systems, induction pumps, cranes, short-stroke devices, stirring, high-speed trains etc.

The basic operation of the LIM is similar to its rotating counterpart. The currents flowing in the energized winding or primary, set up as electromagnetic wave that travels backward with respect to the vehicle at synchronous speed Vs, when the vehicle speed V differs from Vs, the reaction rail or secondary, slips with respect to this traveling wave. The motion-induced voltage then generates a system of alternating currents which interact with the impressed electromagnetic wave to produce a net thrust. There also develops a repulsive force which, however, is counteracted by a force of attraction, whenever the secondary conductor is backed by ferromagnetic material. In both cases the LIM can provide levitation and guidance in addition to propulsion.

In this report, the second chapter deals with the topological aspects of LIM. The design and fabrication details of LIM are elaborated in chapter three and four repspectively. The (commercial) applications of LIM are listed in the fifth chapter. The report is then concluded in the final chapter.


Linear induction motor
Short primary
Short secondary
Moving primary
Moving secondary
Composite secondary (cage or sheet secured to steel core)
Sheet secondary
Flat
Tubular
Transverse flux
Longitudinal flux
Surface primary winding
Gramme ring primary winding
Double-sided magnetically
Single-sided magnetically
Single-sided electrically
Double-sided electrically
Single-sided electrically
Longitudinal flux
Transverse flux
Primary magnetic circuit open
Primary magnetic circuit closed

TOPOLOGICAL ASPECTS

TOPOLOGICAL ASPECTS

In simple terms, the LIM can be thought of as a conventional rotary machine which has been cut along an axial plane and " unrolled " to give a flat structure capable of producing motion in a straghit line, without the use of a crank or other mechanism for converting rotary to linear motion.

There are two basic diffrences which occur in a structure designed to be the exact equivalent of the rotary machine.

(i) The cage of rotor bars of fig.2.1 has become a conducting ladder in slots in an iron structure of fig.2.2.

The "unrolling" process results in changes in operating principles.

The first distinguishing phenomenon in the LIM is that the magnetic forces try to pull rotor and stator iron blocks toward each other, like a compressive mechanical stress, in addition to the IM action producing electromagnetic forces that try to slide one over the other like a shearing stress. In a rotary machine, apart from trying to stretch the rotor radially, there is no other magnetic effect (other than electromagnetic forces which cause rotation) provided the machine is perfectly symmetrical.

In case of linear machine the whole of the surface is subjected to magnetic pull and this is likely to impose restrictions on the manner in which the motor is mounted and constrained to move. Rolloing rather than sliding action is usually required and if the rollers or wheels are too far apart, either the stator or rotor is liable to bend under the magnetic stress. For this reason, if the rotor conductor be separated from the iron, the latter held stationary, so that the rotor consists of the conductor only, the magnetic pull between rotor and stator is entirely eliminated. The stationary iron, as an improvement can contain slots, and be wound in a similar manner to the other iron member, and become a second stator or primary member.

(ii) The second diffrence exhibited by fig.2.2 is that (the linear machine) it represents the equivalent of the rotary machine of fig 2.1 until the rotor moves. As soon as movement takes place a part of the rotor of a linear motor leaves the influence of the stator at one end whilst a coresponding length of rotor has run free of the stator at the other end. If this situation is to be prevented, then either rotor or stator must be extended such extentions leading to two main classes of linear machines termed,

(a) Short primary machine being machine in which the secondary is longer than the primary as shown in fig.2.3.

(b) Short secondary machine in which the primary is longer than the secondary as shown in fig.2.4.

The edges of the shorter member in either type of machine give rise to transient effects which can make the characteristics of the motor very diffrent from those predicted on the basis of conventional theory.

Another way of classifying LIM depends on whether the stator occupies either single side or both sides of the rotor, the rotor taking the form of simple conducting sheet.

In single sided machine shown in fig 2.5. the flux is forced through long airpaths and the rotor consists simply of a slab of conductor. The magnetic circut of such a machine is very poor, but quite useful properties can be obtained. With the addition of a second stator block as in fig.2.6. the thin sheet rotor has stators or primaries on both sides, and hence becomes a double-sided machine. N-pole faces S-pole and the flux is forced through the sheet.

A double sided machine in which N-pole faces N-pole may be made, in which the rotor should necessarily contain iron to carry the opposing fluxes, axially along the rotor.

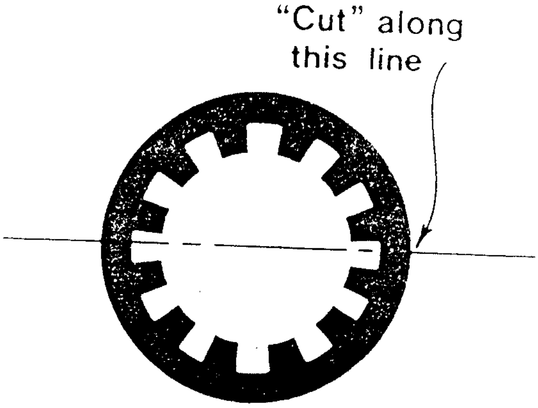


Fig 2.1
Stamping of Rotary machine

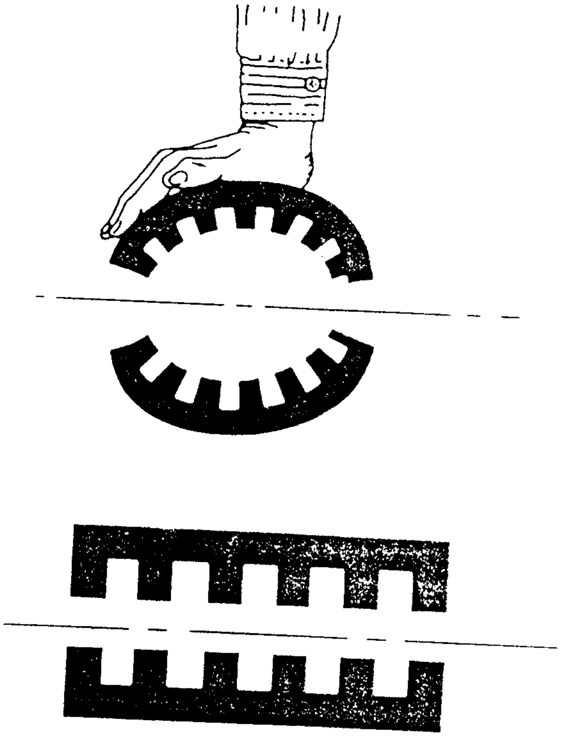


Fig 2.2
Stamping of Linear machine.

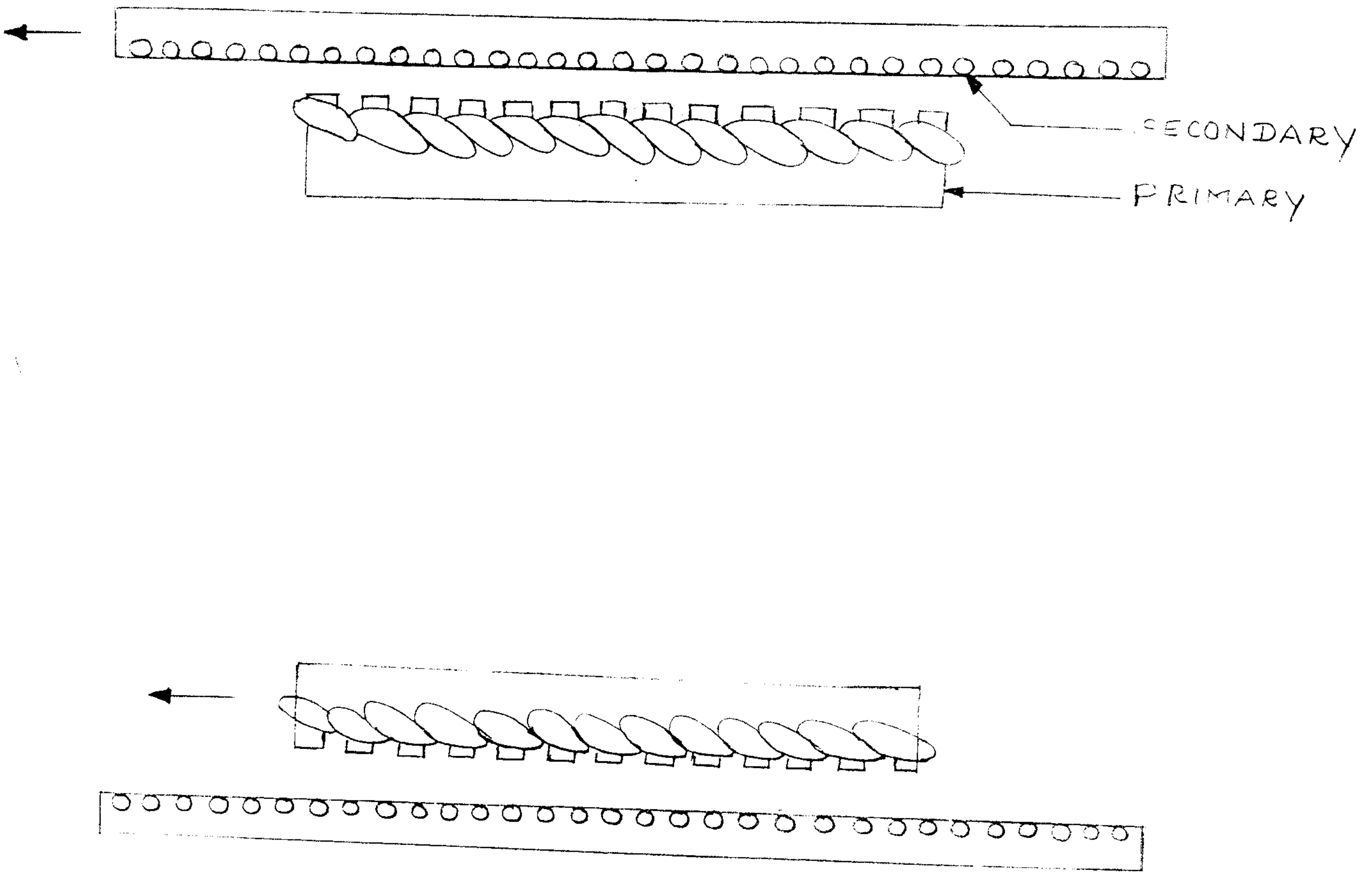


Fig 2.3

SHORT PRIMARY- LONG SECONDARY MACHINE

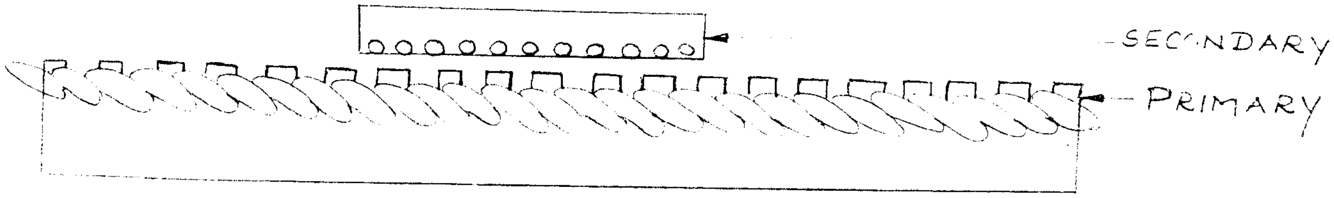
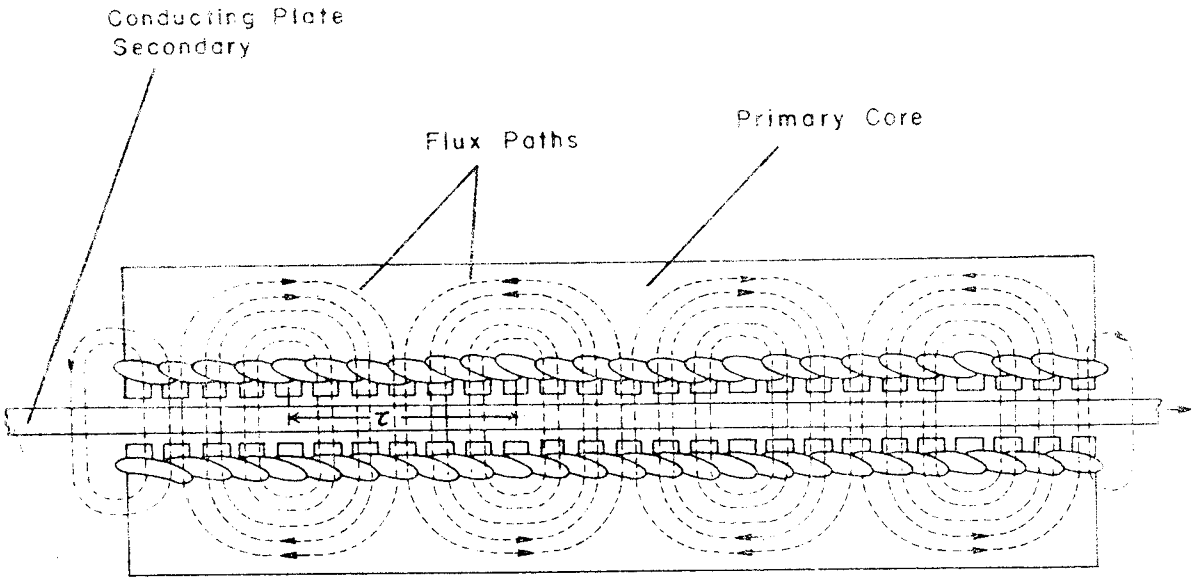


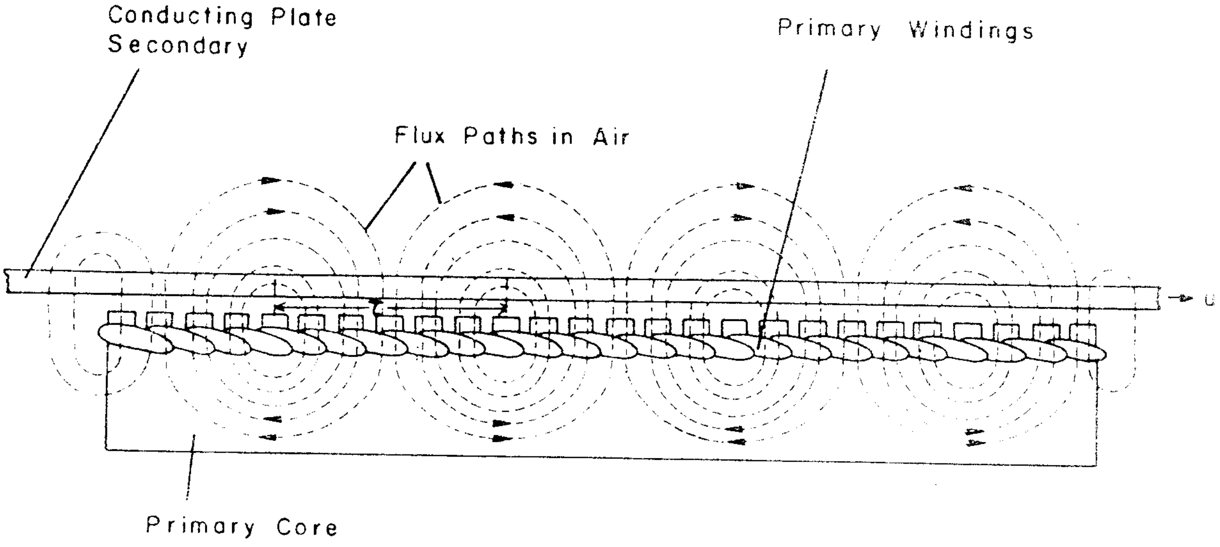
Fig 2.4

LONG PRIMARY - SHORT SECONDARY MACHINE



DOUBLE - SIDED LINEAR INDUCTION MOTOR

Figure 2.5



SINGLE - SIDED LINEAR INDUCTION MOTOR

Figure 2.6

CHAPTER - 3

DESIGN CONSIDERATIONS

DESIGN CONSIDERATIONS

Having presented a discussion of the LIM, we now summerise some design aspects of LIMs. The design of a LIM involves many parameters that can be varied to affect the performance of the machine. The effects of varying some of the parameters are oulined below.

THE GOODNESS FACTOR: The goodness factor is a convinent measure for assessing the quality of a LIM. The concept of goodness factor is helpful in designing a LIM and is a measure of performance of LIMs in general.

3.1 AIR GAP

The length of air gap is a very important parameter in machine design. A large air gap requires a large magnetizing current and results in a lower power factor. In the case of a LIM exit-end zone losses increases with a larger air gap. Also output force and efficiency are decreased when the design incorporates a large air gap. The goodness factor G is inversely proportional to the air gap.

Using the goodness factor concept, machine design can be optimised, as for a low speed LIM, to a certin 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.

3.2 POLE PITCH :

For larger goodness factor, the pole pitch should be as large as possible. The pole pitch is squared in the expression for G. However too large a pole pitch results in increased back iron thickness, which could tremendously increase the weight of the LIM. Also as pole pitch increases, effeciency 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 connection. These 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 :

$$Vs = 2 \times freq \times pole\ pitch \qquad \ldots\ldots. (1)$$

Thus for a given frequency (eg. 60 Hz) 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.

3.3 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 loss between them, resulting in a better performing machine. Thus, it would be advantageous to have a machine with large number of poles.

From equation (1), we realize that for a given synchronous speed and given frequency, the LIM may be very long unless a compromise in the number of poles is made.

3.4 OVERHANG CORRECTION FACTOR :

From the construction of a LIM, we know that the secondary overhangs beyond the width of the primary stack. To account approximately for this overhang, a correction factor k known as the Russell-Norsworthy factor is introduced in the expression for goodness factor.

The secondary thickness and the material play significant parts in the performance of a LIM.

The thicker the secondary, the larger the goodness factor. In the case of a nonferrous secondary, a thicker material results in a larger airgap, which is undesirable. For nonferrous secondaries, then, the thickness must be small, but strong enough to withstand the forces present. In ferrous secondaries the airgap is independent of material thickness. However a thicker secondary results in larger starting currents. As a result, the thickness chosen depends on starting current limitations rather than the desired increase in the goodness factor.

With regard to secondary resistivity, lower resistivity improves the goodness factor. Low resistivity also gives less secondary I^2R loss. But low resistivity results in a slower decay of the end-effect traveling wave, which reduces the output. Again, a compromise between goodness factor and secondary resistivity is necessary. Of the two homogeneous materials, ferro magnetic material has the advantage of high permeability, which means less magnetizing current, but a disadvantage is the strong magnetic pull between the primary and the secondary. A nonferrous but electrically conducting material reduces this large magnetic pull, but when permeability across the airgap is low, magnetizing currents are very large. A composite secondary of both ferrous and nonferrous materials combines the advantages of each (high permeability and reduced magnetic pull) and appears to be the best secondary electromagnetically.

3.5 PRIMARY CORE :

The variation in stator core design also affects the performance of a LIM. Given a constant cross-section 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 reactances that result in a smaller secondary time constant. A smaller time constant produces an end-effect traveling 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.

Table 3.1 summarizes the effects of the above mentioned parameter variations. For example, increasing the airgap results in a larger magnetizing current and larger exit-end loss. On the other hand, decreasing the airgap yields an increase in goodness factor, output force and efficiency.

TABLE 3.1 Effects of Parameter variation

Parameter	Increase	Decrease
Airgap	Larger magnetizing current Larger exit and losses	Larger goodness factor Larger output force Larger efficiency
Pole pitch	Larger goodness factor increase back iron thickness	Larger number of poles
No. of poles 2p	Smaller end effects	Larger secondary leakage reactance
Secondary thickness	Larger goodness factor Larger starting current	Larger secondary leakage reactance
Secondary resistivity	Smaller end effects	Larger goodness factor Larger secondary I^2R loss
Tooth width W	Larger leakage reactances	Larger force Larger efficiency

3.6 STEPS IN DESIGN :

Steps in the design of the LIM are the same as those for a conventional induction machines. With computer-aided design, the design procedure consists of the following steps:

1. Set the required specifications for the desired performance and the conditions for selecting one machine if more than one meets the requirements.

2. Establish factors to be varied, the extent to which each should be allowed to vary and the permissible increments of variation.

3. Assume an initial design from the available primary and seconday variables.

4. Make a design analysis consisting of :
   (a) The calculation of parameters and currents in the equivalent circuit.
   (b) Calculation of the performance of the machine.

5. Compare the calculated performance with the desired performance.

6. (a) If a design does not meet the desired performance, change some factor, within its specified limits, and continue iteration until the desired performance is met or until it is determined that the desired performance cannot be met under the given tolerances.

(b) If a design does meet the desired performance, continue the program and iteration process to determine whether any other design also meets the desired performance. If other machines do meet the requirements choose with respect to the predetermined conditions the best machine. Finally, prepare the design sheet.

7. If the desired condition cannot be met, one would conclude that the desired machine cannot be designed under the given allowances to meet the specifications.

3.7 SPEED :

The speed of a LIM is associated with the synchronous speed V_1, which is given by V_1=freq x wave length. the wavelength is the length of a double pole-pitch. The actual speed V differes from V_1 because of the slip. If wave length = 1m and the supply frequency is 50Hz, then V_1=50 m/sec. =

180 Km/hr (110 mile/h). For lower translational speeds on a 50 Hz supply it is necessary to shortern the wavelength. But if it is less than about 0.2m, corresponding to $V_1 = 10$ m/sec. = 36 Km/h, the performance is impaired because the pole pitch is short compared with the gap length. The effect is most significant in machines with an open magnetic circuit. Much better low-speed performances can be achieved if a low frequency supply is available. In some cases in which starting from rest at high translational force is sought, a primary with a graded pole pitch may be of advantage; alternatively the frequency can be raised during the starting period if the method can be economically justified.

TYPES

Basically there are 3 types of SLIM models.

(i) Fixed long primary - movable short secondary

(ii) Fixed short primary - movable long secondary

(iii) Movable short primary - fixed long secondary

The first model i.e. fixed long primary movable short secondary is costlier because of the lengthy primary core and a large amount of copper for winding. But it reduces the trouble of giving supply to the movable part.

The second model is the fixed short primary movable long secondary is mainly used in conveyor systems and sliding doors. In conveyor systems using LIM, the short primary is fixed and secondary is in the forms of sheet which rolls in pulleys. In case of sliding doors the primary is fixed on the top and the secondary reaction plate is attached to the door top.

The third model is the movable short primary-fixed long secondary. This is used for propulsion purposes. The secondary is laid in between the tracks. The primary is fitted with wheels to move on the track. Our model belongs to this type.

3.8 DESIGN DETAILS :

In this project it is proposed to design a 3 phase, 0.25 H.P., 140 volts, 50 Hz Linear Induction motor.

Design Calculations :

The speed of the equivalent rotary LIM is taken as 1500 rpm.

Assumptions :

The following assumptions are made based upon the ratings of this model.

Specific magnetic loading, Bav = $0.3\ \mathrm{wb/m^2}$

Specific magnetic loading, ac = 11,000 A/m

Ct. density, = $4\ \mathrm{A/mm^2}$

The ratio, L/pole pitch = 1.15

Efficiency, = 70%

Power factor = 0.7

Winding factor Kw = 0.955

Slot space factor = 0.3

DESIGNING :

MAIN DIMENSIONS

Synchronous speed $= \dfrac{1500}{60} = 25$ rps

No. of poles $P = \dfrac{2F}{\text{Pole pitch}}$

$= \dfrac{2 \times 50}{25} = 4$ poles

Output coefficient, C_o

$= 11\ Kw\ Bav\ ac \times 10^{-3}$

$= 11 \times 0.965 \times 0.3 \times 11{,}000 \times 10^{-3}$

$= 34.66$

$$\text{KVA i/p,} = \frac{H.P \times 0.746}{eff \times Pf}$$

$$= \frac{0.25 \times 0.746}{0.7 \times 0.7}$$

$$Q = 0.38\ \text{KVA}$$

$$D^2L = \frac{Q}{Co_{n_s}} = \frac{0.38}{34.66 \times 25}$$

$$= 4.38 \times 10^{-4}\ m^3$$

We have $\frac{L}{\text{Pole pitch}} = 1.15$

or $\frac{L}{D} = 1.15 \times \frac{3.14}{4}$

$$\frac{L}{D} = 0.9$$

$$L = 0.9\ D$$

Therefore $0.9\ D^3 = 4.38 \times 10^{-4}\ m^3$

Therefore $D = 0.078\ m$

Now $L = 0.9\ D = 0.9 \times 0.078$

$$L = 0.07\ m$$

Therefore for LIM

When the rotary machine is cut open we get linear machine. The circumference of the rotary machine becomes the length of linear machine and the length of rotary machine becomes the width of linear machine.

Therefore length = 3.14 D

= 3.14×0.078

= 0.25 m

Length = 25 cm

Width = L

= 0.07 m

= 7 cm

WINDING

$$\text{Flux/pole} = B_{av}\ L\ \frac{D \times 3.14}{P}$$

$$= \frac{0.3 \times 0.07 \times 0.25}{4}$$

$$= 1.3125 \times 10^{-3}\ \text{wb}$$

$$\text{Stator voltage/phase} = 80\ \text{volts}\ \left(= \frac{140}{(3)^{1/2}} = 80\right)$$

Stator turns/ph T_s = $$\frac{E_s}{4.44\ f x(flux/pole)\ K_{ws}}$$

$$= \frac{80}{4.44 x 50 x 1.3125 x 10^{-3} x 0.955}$$

$= 287.49$

Taking it as 300,

We have, stator turns as 300 turns/ph

Slots

For open type of slots,

Slot pitch should be 15 to 25 mm.

Take 20 mm ie 25 cm, ie slot = 1cm

tooth = 1 cm

Taking slots per pole per ph = $q_s = 1$

Total no. of stator slots S = 1 x 4 x 3

= 12 slots

Stator slot pitch, Y_s $$= \frac{3.14\ D}{S} = \frac{0.25}{12}$$

= 0.02 m

= 20 mm

Conductors/slot $= \frac{Z}{S} = \frac{1800}{12}$

$= 150$

Current density, $= \frac{Iz}{az}$, we have

$= 4\ A/mm^2$

Therefore area of conductor $a_z = \frac{Iz}{\text{current density}}$

$= \frac{1.52}{4} = 0.38\ mm^2$

Therefore $3.14\ r^2 = 0.38\ mm^2$

Therefore $r = 0.35$ mm

Therefore $d = 0.7$ mm

Therefore diameter of copper wire = 0.7 mm

ie 22 SWG wire (dia = 0.71 mm)

Slot space factor = 0.3

Therefore slot area $= \frac{\text{Area of conductor in slot}}{\text{Slot space factor}}$

$= \frac{150 \times 0.38}{0.3} = 190\ mm^2$

$= 1.9\ cm^2$

Width x depth = 1 cm x depth

= $1.9\ cm^2$

Therefore depth = 1.9 cm

= 2 cm

WINDING DETAIL :

For small machine like this a single layer winding placed in open slots is used, in single layer winding each coil occupies 2 slots.

Therefore no. of coils = $\frac{12}{2}$ = 6 coils

No. of coils/ph = $\frac{6}{3}$ = 2 coils

PHASE CURRENT :

No. of conductors Z = no. of phase x [2 x turns/ph]

= 3 x 2 x 300

= 1800

Iz Z = D x ac

Iz x 1800 = 0.25 x 11,000

Therefore Iz = 1.52 A

Phase current = Iz, as there is only one circuit/phase.

(I) DESIGN OF PRIMARY CORE :

A flat LIM is obtained by an imaginary process of "cutting" and "unrolling" a rotary IM. In practice the primary of a LIM consists of a rectangular block of slotted structure formed from a stack of steel laminations.

Within the slots of the primary blocks are laid the polyphase (often three-phase) windings to produce the linearly traveling magnetic field, just like the rotating magnetic field in a rotary IM, produced by the polyphase stator windings.

The primary core of this model consists of a stack of 6mm thick mild steel plates of length 25cm and height 4cm. The thickness of the stack is about 7cm ie 11 such plates are bolted together to form the stack. 12 slots are milled in the stack to accommodate a simple 3-phase single layer winding. The width of the slot is 1cm and its depth is 2cm.

For mobility, wheels are provided by welding two shafts at the ends of the core. Wheels are fixed to the shafts by means of bearing. The bearing used is Ball Bearing Number 115. The inner diameter of wheel is 2cm. The primary core employed in our model is shown in the figure 3.1.

(II) WINDING DESIGN :

Many winding configurations for LIMs have been proposed. They resemble, to some extent, those of rotary IMs. Among them four are of practical interest. These are:

1. One layer windings with an even number of poles.
2. Three layer windings with an even number of poles.
3. Two layer windings with an odd number of poles and half-filled end slots.
4. "Economic" windings for very low-power LIMs.

The advantages and disadvantages of these windings are related to manufacturing costs and the capacity for producing an airgap field distribution approaching a purely forward travelling wave. The airgap field of the windings shown in figures 3.2, 3.3 & 3.5 with open secondary, exhibits notable pulsating components besides the travelling wave because of the open character of the magnetic circuit. Also it has been found that the winding in fig. 3.4 develops a purely travelling wave airgap field in the central zone [(2p-1) poles in length, p being the number of pole pairs] whereas pulsating components occur only along the marginal, half-wound poles. Thus, in high-thrust applications, this winding is most suitable. Also, the windings in the figures 3.2, 3.3 and 3.4 make better use of the magnetic core. By reducing the end connections, the windings in figures 3.3 &

3.5 utilize copper better and in some applications this asset prevails.

As expected from fig. 3.5, the economic winding produces pronounced space harmonics in the airgap field and its winding factor is rather poor, but for very low thrust levels (up to 20 to 30 N), the copper weight and mounting room savings prevail, provoking the use of this winding. Because the magnetic circuit of a LIM has a beginning and an end (unlike that of a rotary motor), the slots of the primary of the LIM are not always completely filled. In such a case, we endup with half-filled end slots (fig. 3.4).

Our model has single layer, 3 phase winding with even number of poles. Here the number of poles = 4;

The number of slots = 12
Pole pitch = 3 slots (or) 6 cm.

The copper wire gauge used is 22 SWG. There are 150 turns in each coil. Totally there are 6 coils, (ie) 2 coils per phase. The winding diagram is shown in the figure 3.2. The 3-phases are connected in star and the 3 terminals are brought out for external supply connections.

(III) DESIGN OF SECONDARY :

In most cases, the secondaries of LIMs are made of aluminium or copper plates. Longitudinal cross-section of a DSLIM and a SLIM are shown in figures 2.6 & 2.5 respectively. These figures also show the paths of the magnetic fluxes produced by the primary windings. The fluxes tend to be dissymmetric at the ends of the primary, although the primaries are wound to have four poles. Also figure 2.5 shows that much of the flux path is through air consequently, the magnetic circuit of the SLIM shown in figure 2.5 is very poor. In order to improve the magnetic circuit,the secondary is backed by either solid or laminated iron. In numerous applications, such as in material handling, the object to be moved may itself constitute the secondary of the LIM.

In general, the secondary of flat LIMs may be of an aluminium (or copper) sheet with or without a solid back iron plate. Also in special cases a laminated slotted core with a ladder secondary may be used.Configurations of figure 3.6(a) and (b) are less expensive but have poorer energy conversion performance in comparison with configuration (c). The ladder secondary is worth considering when high thrusts are required, as in conveyors.

In this model, the reaction plate is a moulded aluminium bar embedded with iron strips in a skewed manner. The dimensions of aluminium bar is 45 x 7 x 1.5 cm. Three such bars form the secondary. The bars are placed inbetween the iron tracks. The track and the aluminium bar are supported by thick iron base plate. The figure 3.7 shows the aluminium reaction plate embedded with iron strips.

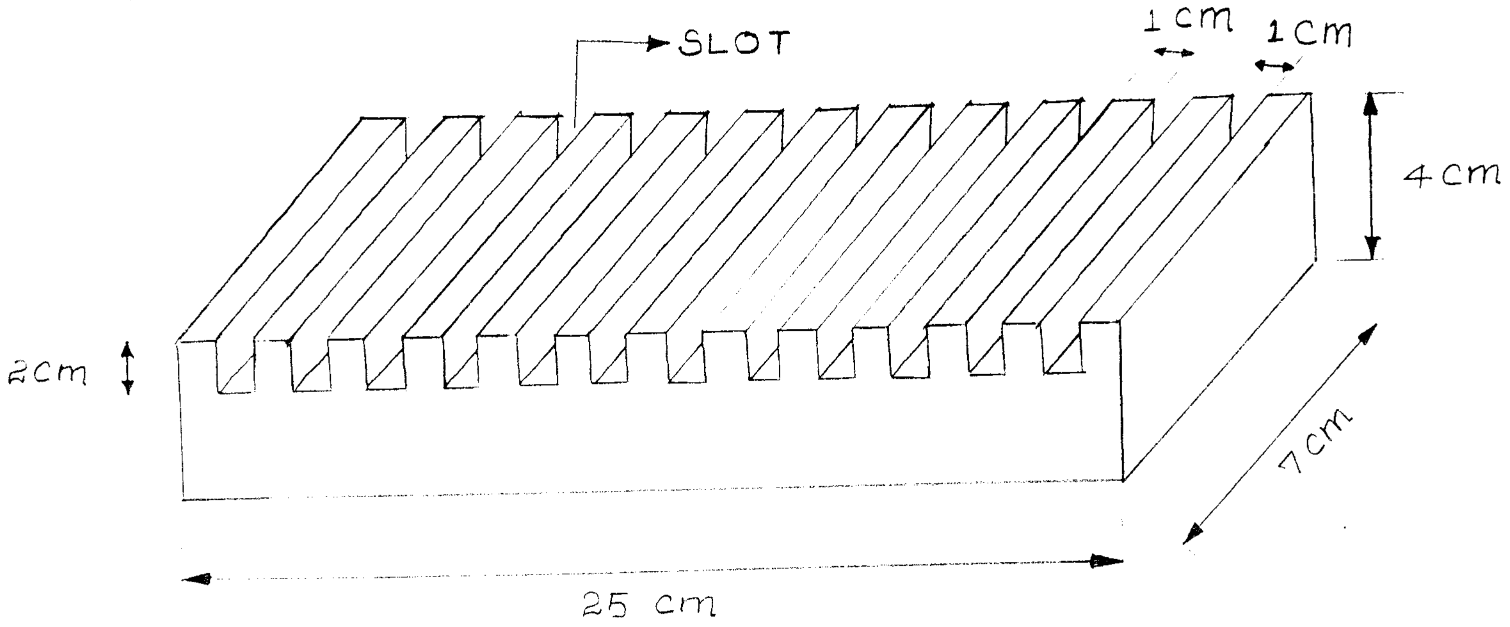


Fig 3·1

PRIMARY CORE

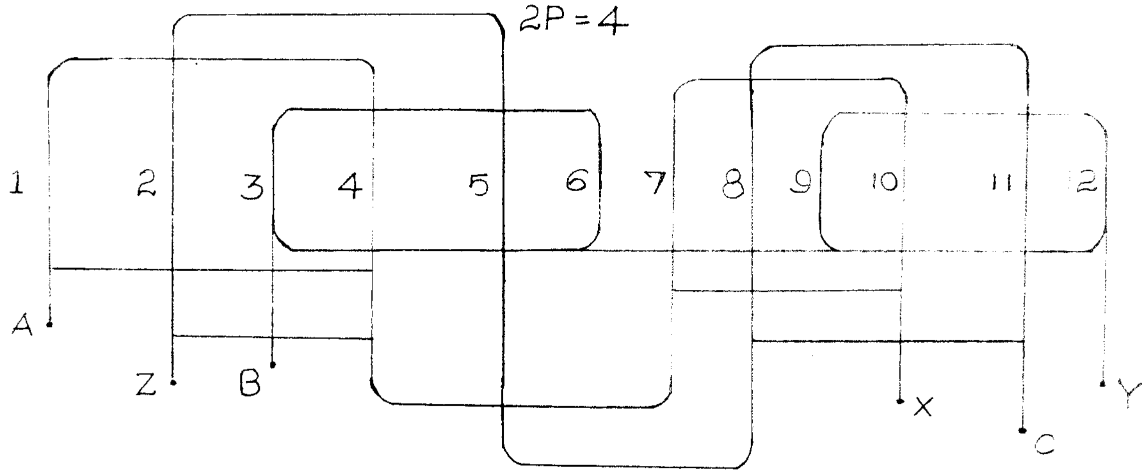


Fig 3.2

WINDING EMPLOYED IN THIS MODEL

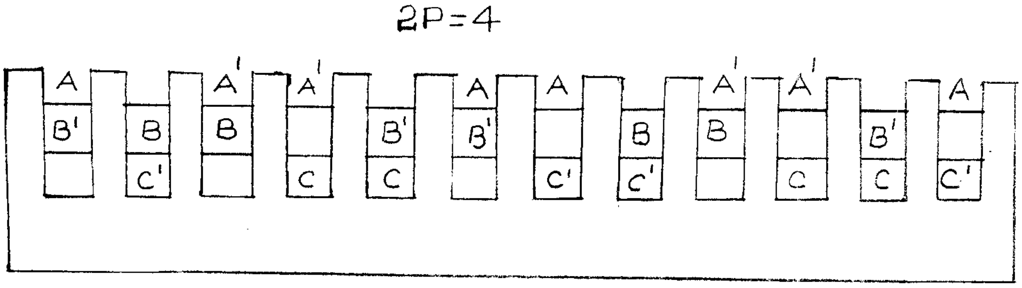


Fig 3.3

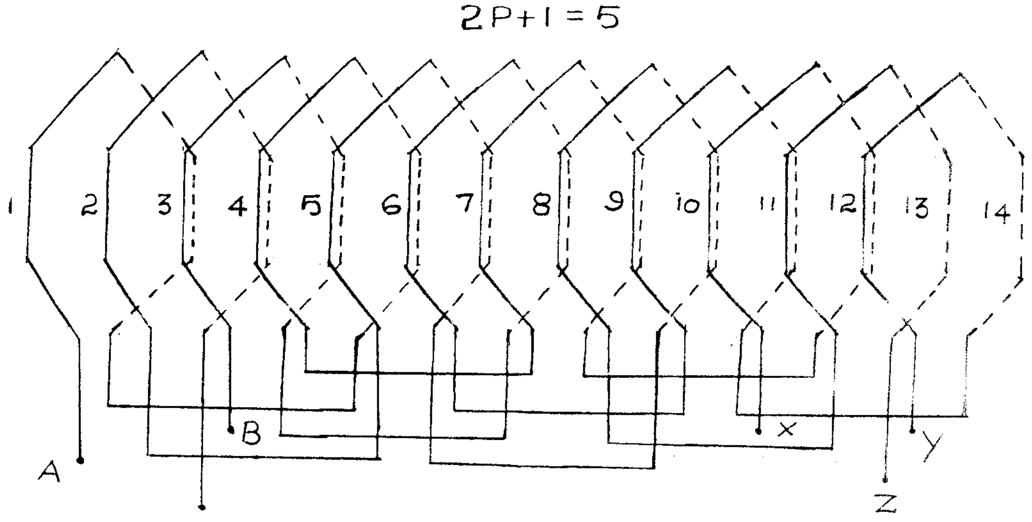


Fig 3.4

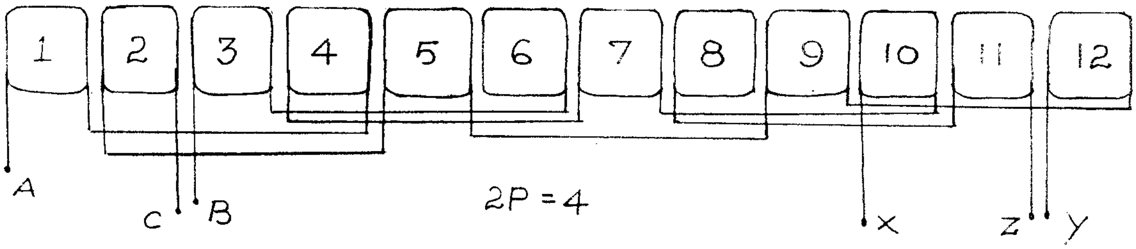


Fig 3.5

OTHER WINDING CONFIGURATIONS

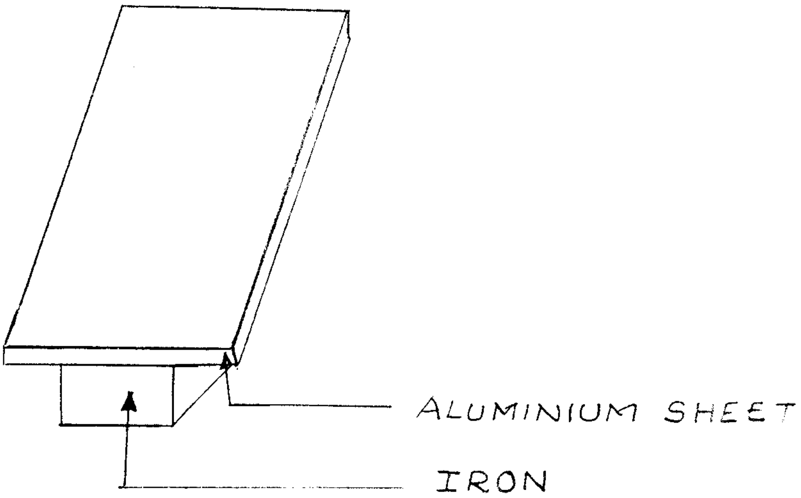


Fig 3.6 (a)

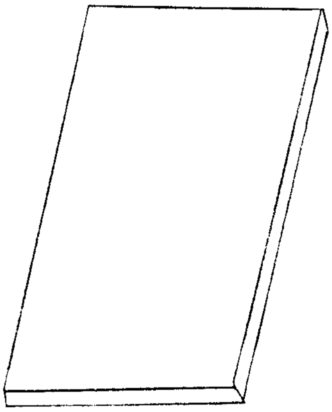


Fig 3.6 (b)

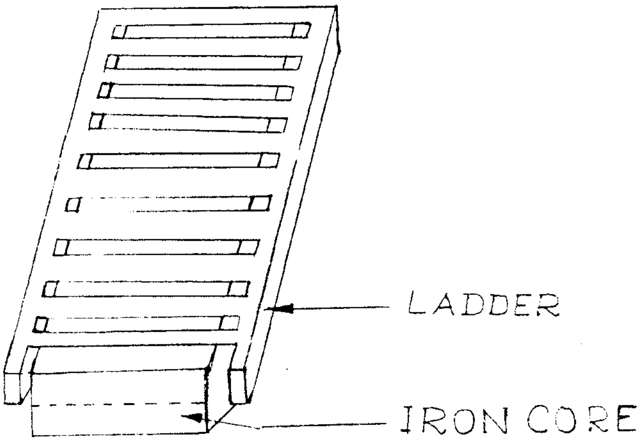


Fig 3.6 (c)

VARIOUS FORMS OF SECONDARIES

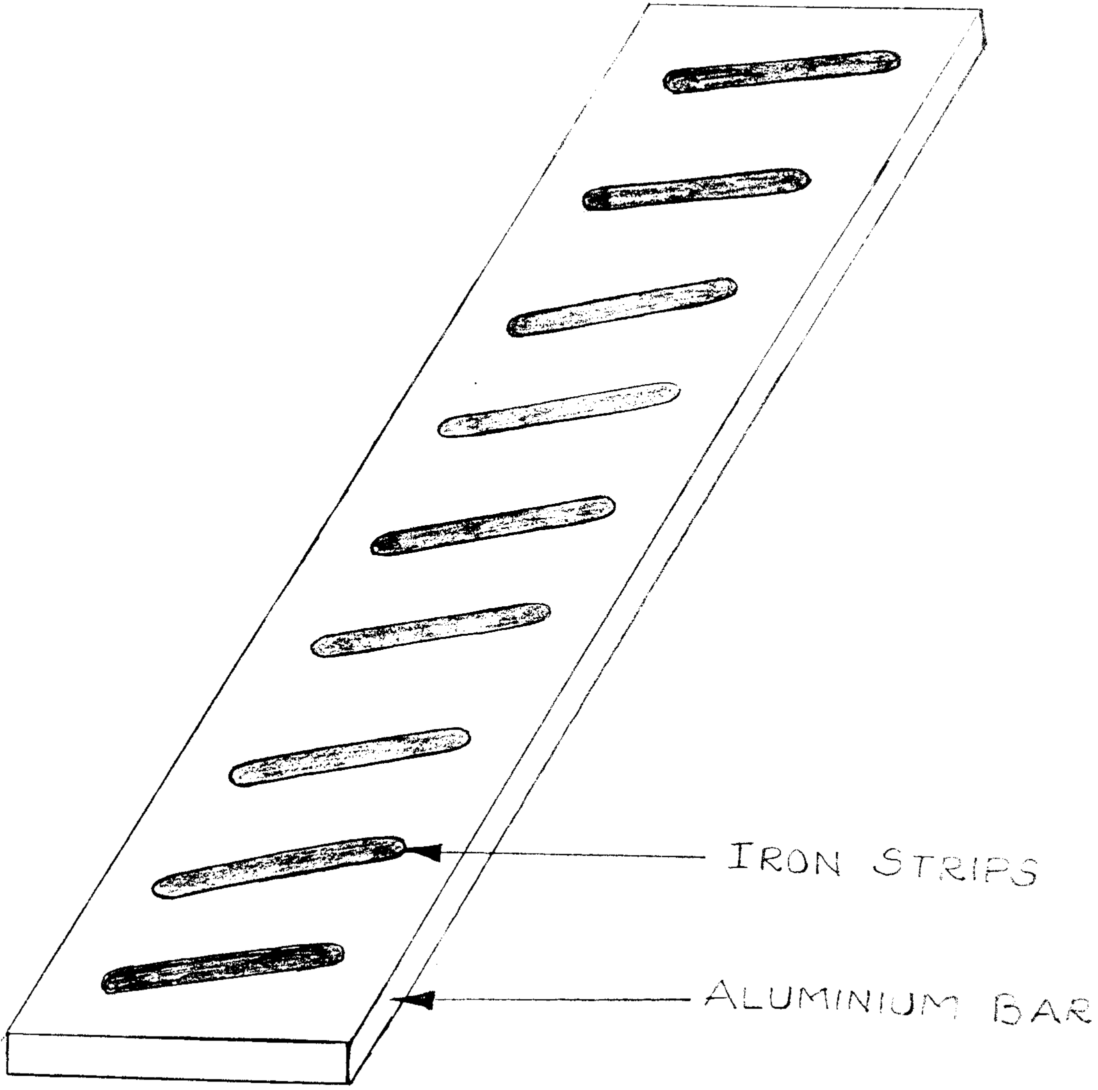


Fig 3·7

SECONDARY EMPLOYED IN THIS MODEL

CHAPTER - 4

CONSTRUCTION

CONSTRUCTION

In this chapter various details regarding the fabrication of the model are discussed. For clear description the construction of the model is classified into the construction of (i) primary core (ii) winding (iii) secondary.

4.1 PRIMARY CORE :

The primary core is a stack of mild steel plates. For this, a 12 feet long mild steel plate of thickness 0.6cm and height 4cm is cut into 11 strips, each of length 25cm. The slots have to be cut in these strips. Slots of open type are cut using a milling machine. Vertical milling type is made use. As the designed slot width is 1cm a tool (end mill cutter) of diameter 095cm is made use. The depth of the slot is 2cm 12 such slots are cut in each strip. The designed width of each tooth is 1cm. So each strip with 12 slots and 13 teeth totally measures 25cm. Holes are drilled below the end teeth at the two corners of the strips for the provision of bolt and nuts. The 11 slotted strips are alligned and are bolted togethe tightly. This forms the stack. Then the faces of the core are grinded well to get a smoother surface. The interior of the slots are made uniform by filing.

If the primary core is made of laminations, eddy current losses could be minimised and the efficiency could be improved. But the lack of commercial access of such stampings for linear type of motor, laminations could not be used. Since hundred such stampings are required to form the core of this model, mannual cutting of the stampings was also not possible. Hence mild steel plates stack for the primary core was preferred. This being a demonstrative model, eddy current losses could be tolerated.

The stack thus formed has the dimensions 25x7x4cm. Then two thick iron sheets of size 7x4cm are welded to the two ends of the core.

In this model, the primary, a movable member which is to move on a pair of rails, between which the secondary is placed. For mobility wheels have to be provided to the primary core. For this, two shafts are welded on the either sides of the core ie on the thick iron sheets that are already welded to the core. The shafts and the four wheels of inner diameter 2cm are turned in a lathe, where a step is provided in the wheels so that no derailing occurs. These wheels are fixed to the shaft by means of ball bearings. The size of ball bearing is number 115. The construction of the primary core is thus complete.

4.2 WINDING :

A 3-phase single layer winding is to be provided in the slots of the primary core. As per the design, a 3-phase single layer winding is wound and placed in the slotted core. There are six coils in total-2 coils per phase. Each coil is of 150 turns. The copper wire used is 22 SWG gauge wire. It took 1kg of copper for the entire winding. Adequate insulations are provided in between the phases and also between the winding and the iron core. the number of poles is 4 and the pole pitch is 3 slots or 6cms. Other types of winding as shown in fig. 3.3, fig. 3.4 or 3.5 are also applicable. But the winding as shown in fig. 3.2 is employed because of its simplicity and economy. The 3-phases are starred and the other three terminals are brought out for external supply. These three terminals are connected to a connector which is affixed on the top of the primary. The connector has four inputs and four outputs. To three of the inputs and outputs, the three phases of the supply and winding are connected respectively. The star point of the winding and the neutral of the supply are connected to the fourth output and input respectively.

4.3 SECONDARY :

The secondary of the SLIM model can be fabricated using ferrous or non-ferrous material or combination of both. When the secondary is backed by ferromagnetic material, repulsive forces that are developed are counteracted by a force of attraction.

The non-ferrous materials that are commonly used are aluminium and copper. In this model, aluminium is used. The secondary is designed to have the dimension as length 135cm widht 7cm height 1.5cm.

The aluminium bar forms the secondary with iron strips embedded on it in a skewed manner. Thus designed secondary is obtained by moulding. The designed length of the secondary and the skewed arrangement of iron strips makes the moulding tough and tedious. So the desired length of the secondary is segmented into 3 equal pieces.

MOULDING - A pattern for the segment, is set with the iron strips half burried inside it in a skewed manner. The molten aluminium is then poured into the pattern carefully so that it does not wash away the iron strips. It is then allowed to cool, hence gets solidified. Three such segments are moulded.

The secondary is to be rigidly fixed on a platform. Holes are drilled on the moulded segments for fixing them on the platform. The platform has a base plate of thick iron sheet. This sheet is rested on rigid L-angled iron plates. The track (a prallel pairs of rails) is constructed by welding two iron strips on the iron sheet. Two parallel strips are kept apart a distance, so that the primary moves on it freely. The three aluminium bars are linearly placed end to end inbetween the rails and are bolted to the base plate. The three bars are fixed at proper height so that the airgap between the primary and secondary is minimum. The steel portion of the platform is painted white.

4.4 TEST SET UP :

The test set up comprises of the SLIM model, a 3-phase auto transformer and a 3-phase supply. A 3-phase supply is given to the primary of the LIM through an autotransformer. This is depicted in the fig. 4.1. A photograph of the model is also put up.

The primary is placed over the rails with the secondary in between the rails. The primary is placed on the middle of the track, such that it can move in any direction. The primary is connected to 3-phase supply through the autotransformer. The supply is switched 'ON'. Then voltage is applied gradually by the use of autotransformer. After a certain voltage the primary starts to move slowly in a particular direction. When the voltage is further increased the primary runs faster and reaches the corner of the secondary. Now the supply is switched 'OFF' and any of the two phases to the primary are interchanged and the above procedure is repeated. This time the primary runs in the opposite direction. As the length of the secondary is limited the supply voltage is gradually increased using an autotransformer.

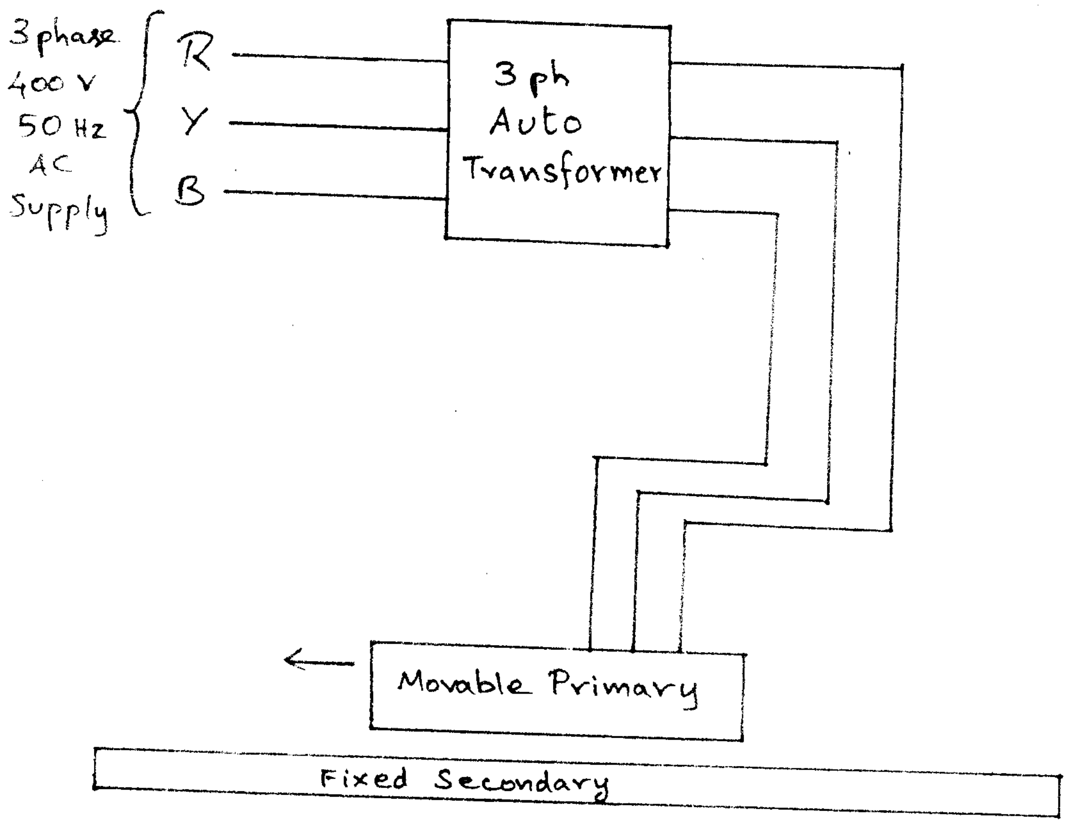


Fig 4.1
Test Set-up, Block Diagram.

APPLICATIONS

In many applications, linear motors are special purpose devices in that, unlike their rotary counterparts, linear motors are tailored to specific needs. Whereas a rotary machine or a rotary motor interfaces with the mechanical system through the shaft, a linear motor often interacts with the moving member (or the "rotor"), which is the mechanical system itself. This feature of linear motors diversifies and broadens their scope of applications considerably.

The major practical limitation on the performance and applications of linear motors is the inherently large airgap. Furthermore, in many instances, especially in very long motors, it is extremely difficult to maintain a uniform airgap over the length of the motor. The second limiation is imposed by the length of travel of the moving member of a linear motor. For example, in a conveyor system, formed as a travelling loop of the secondary of a linear motor, the fabrication of the belt poses a very difficult problem. It is envisaged that linear motors will find applications requiring a limited length of travel and as reciprocating or oscillatory motors have also been used in low (or medium) - speed and heigh-speed ground transportation systems. Some of the growing uses of linear motors are in actuators for automatic equipment, such as numerically controlled machine tools, packaging and handling equipment and aircraft. With advances in power semiconductors, digital electronics and high-energy permanent magnets, linear motors are expected to find novel and unique applications.

Linear motors potentially have unlimited applications. LIMS alone have found applications in the following general areas; 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. LSMs are being used in high-speed "bullet" trains in Japan. Before the advent of linear motors, rotary motors with rotary-to-linear converters of some kind were used to produce linear motion. The most obvious advantage of a linear motor is that it has no gears and requires no mechanical rotary-to-linear converters. Thus compared with rotary motors having mechanical gears and similar devices, the linear motor is robust and more reliable. Some of the other advantages of linear motors over rotary motors are as follows :

1. High acceleration and deceleration and less wear of the wheels and the track where acceleration and deceleration take place.

2. Mechanical and electrical protection and the ability to withstand a hostile environment.
3. Ease in maintenance, repair, and replacement.
4. Ability to exert thrust on the secondary without mechanical contacts, as well as convenient control of thrust and speed.
5. Existence of the normal force, which can be advantageous in levitation machines.

To review some of the possible applications of linear motors, it is convenient to divide LEMs into the following categories from an applications standpoint:

1. Force machines
2. Power machines
3. Energy machines

Based on this classification, force machines are short-duty machines operating essentially at standstill or at very low speeds, and efficiency is not a major consideration with regard to overall performance. These machines are most medium or high speeds and are continuous-duty machines; they must have high efficiencies. Energy machines are short-duty machines and have found applications as accelerators and impact extruders.

The high-speed applications of LEMs are mainly as propulsion and levitation systems for high-speed ground transportation. Rotary motors are a poor choice for use at speeds above 250 Km/hr. because of adhesion and other mechanical considerations. On the other hand, a linear motor offers a means of propulsion that is ideally suited for speeds exceeding 250 km/hr. For speeds at which mechanical constact is undesirable, it has been proposed to use a levitation machine for a magnetic suspension systems. For both propulsion and suspension of HSGT vehicles, test vehicles having linear motors have been designed and tested in the United States, Great Britain, West Germany, France and Japan.

The linear Motor for a HSGT vehicle may be either a LIM or a LSM. The short-primary LIM on the vehicle with on-board power sources with an aluminium reaction rail (or track) as the secondary has been tested and seems to be one of the solutions. A SLIM, with a short primary on the vehicle and a secondary of aluminium with back iron has also been proposed for high-speed applications. But no large-power test vehicle is reported to have been built.

Some full-scale test vehicles have been made using LIMs for propulsion, LSM- propelled vehicles have proved to be more promising for HSGT. Super conducting magnets on the vehicles are used for field excitation of the LSM, and the track consists of an air core polyphase armature. This form of LSM may be used to develop thrust as well as levitation force. On the other hand, a levitation machine can be used to provide the suspension of a high-speed vehicle. A levitation system may be either (a) repulsion type or (b) attraction type. An attraction-type suspension system has been successfully tested in West Germany. The force of attraction between the on-board electromagnet and the steel guide rails provides lift and guidance. A gap of 15MM can be maintained between magnet and rail with a power expenditure of about 2KW per ton of suspended weight. A feedback system monitors the gap and adjusts the current in the electromagnet to overcome the inherent instability of an attraction system. The repulsion-type suspension system is also considered.

The preceding discussions indicate that in high-speed applications, linear Motors provide the thrust and/or levitation force to suspend the vehicle. In some instances the linear Mmotor is used for propulsion only, and the vehicle may be supported either by rail or aircushion. To ensure propulsion, the linear motor must provide sufficient thrust to (a) balance the drag of the vehicle at constant speed (b) accelerate the vehicle from zero to cruising speed, and (c) help brake the vehicle. For HSGT, the large power requirements make it obvious that high efficiency, power factor and voltage as well as low specific weight and volume are important considerations in the choice and design of linear motors. The power factor has a major impact on the power conditioning subsystem.

The SLIM is the widely used linear motor.The secondary of the SLIM is either sandwich type or steel. The sandwich secondary consists of aluminium strips 3mm thick, attached to mild steel plates that are 6mm thick.

SLIMs with steel secondaries have found applications in the speed range of 0.7 to 1.5 m/sec. in the field of Mechanical handling equipment, for example, such a SLIM has pronounced (normal) attraction force between the Primary and the Secondary. The normal force of attraction may be as high as 10 times the thrust.

Another application of an LIM, is a linear disk motor. This is useful in achieving the traction motion of an overhead crane. The low shaft speed of 150 to 200 rpm enables a single gear reduction of 4:1 between the motor and the crane-wheels to be fitted. The linear disk motor also can be used in ship propulsion.

For horizontal applications carrying steel stock sections, SLIM primaries placed at intervals, depending on the length of material handled, give a simple drive thrust, with variable speed if desired. For a coal-carrying conveyor, a number of LIM primaries may be spaced about 3m apart; the airgap is about 0.5cm and the primary is fed at 10Hz for a speed range of 2 to 5 m/sec. The LIM has a starting thrust of 8.4 KN and a continuous thrust of 4 KN.

A flat linear motor about 21cm long and 9cm wide, used as an automatic door operator. A flat LIM can serve for pipe-lifting beam in steel works, and tabular LIMS can be employed as actuators in mechanical handling. Other applications of linear motors range from turn tables driven by linear motors to aerodynamic reading heads in a computer and from induction stirrers for molten metals to shuttle propulsion and package winding in the textile industry.

One of the earliest LIM applications was an energy machine to launch aircraft. The machine was called an electropult. The primary winding was mounted on a carriage, and the secondary consisted of a winding in slots in a ferromagnetic structure. Two full-scale tracks were built, one 5/8 mile long, the other just over a mile and the primary unit on the runway. Current collection was by means of brushes running in the slots alongside the secondary members. In an aircraft attached to the primary unit by a sling, the motor developed 10,000 hp and attached speeds exceeding 225 mph. A 10,000-lb jet aircraft was accelerated to 117 mph is a 540-feet run in 4.2 sec from rest. The system was usually abandoned on the grounds of high critical cost.

Other applications of LIMs as energy machines include accelerators for very high velocity projectiles and actuators in high voltage circuit breakers. LIMs have also been used to simulate the conditions of a carcrash. An LIM capable of accelerating vehicles weighing as much as 10,000-lb to any speed up to 40 mph has been used as the primemover (to drive the vehicle). A typical impact barrier for a car-crash indoor facility, and a view of the LIM track are illustrative. The aluminium alloy reaction rail or seconday stands vertically in a pit. The reaction rail is approximately 2.5cm thick and 75cm high with steel flanges top and bottom.

The primary has an inverted U-frame containing the two winding blocks one on either side of the secondary. Current is fed to the primary by means of carbon brushes that run along collector rails mounted on insulators on the walls of the pit. At the floor level, on top of the moving component, is a coupling to which the test vehicle is attached. Cams at the ends of the track (or secondary) trigger the coupling to release the vehicle. Another interesting application of the LIM as an energy machine has been proposed for impact extrusion.

Primaries of energy machines are used to cold-form conducting metal into its final shape. For example, silver fusible links of large current-limiting fuses are bonded to the fuse ferrule by magnetically shrinking the ferrule around the barrel, with the ends of the links in between cable shields are clamped to connector shields with a similar process.

The posibilities of the industrical application of linear motors are enormous. Linear motors being simple in construction, are inexpensive and very reliable, will find more and more applications in situations in which mechanical gears and rotary-to-linear converters are undesirable.

Linear motors are not practical for many drives. At one end of the scale is the simple screw-jack that is used for lifting houses off foundations. Also, the automobile gear-shifting transmission is efficient and has cost features that cannot be matched by linear motors. On the other end of the scale is the precision-positioning task in numerically controlled machine tools. Stepper motors are used for these applications.

In the design of linear motors, there are a large number of parameters that can be varied to meet a given set of specifications. For example in conveyor application, the major performance criteria are (1) the speed, (2) the thrust (3) the thrust per unit surface area, (4) the figure of merit as measured by thrust per square root of input power for comparing various motors, we assume reasonably well-designed motors having an airgap flux density of 0.2T (or 2000 gauss) and an electrical loading of 2.25×10^5 A/m (or 5715 A/in).

CONCLUSTION

A SLIM demonstrative model has been fabricated successfully. When the supply is given, the primary moves over the fixed secondary and the model works satisfactorily. Here as the secondary, the aluminium bar is embedded with iron strips, (a ferro magnetic material) in addition to the propulsion of primary it is also guided.

As an extension of this project, the primary of this model can be fixed and an aluminum sheet belted over a pair of pulleys, the sheet would move over them if the winding of the primary is energised.

The urge for high speed and efficient transportation have generated world wide interests in LIM as it is considered to be one of the most suitable propulsion system. But still this field has not been properly exploited in our subcontinent and it is hoped that LIM would get the due recognition in the technical arena in the coming years.

REFERENCES

1. NASAR AND BOLDEA - LINEAR ELECTRIC MOTORS, PRENTICE-HALL, INC ENGLEWOOD CLIFFS, NEW JERSEY - 1987.

2. MICHEL POLOUJADOFF - THE THEORY OF LINEAR INDUCTION MACHINERY CLARENDON PRESS, OXFORD, 1980.

3. A.K. SAWHNEY - A COURSE IN ELECTRICAL MACHINE DESIGN DHANPAT RAI & SONS 1991 EDITIONS

4. BHATIA (SL) - HAND BOOK OF ELECTRICAL ENGINEERING WILEY EASTERN LIMITED, 1987

5. 13th EDITION M.G. SAY - ELECTRICAL ENGINEERS REFERENCE BOOK BUTTERWORTH & CO (PUBLISHERS) LTD, 1973.