LINEAR INDUCTION MOTORS

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ABSTRACT

The basic theory of Linear Induction Motors, with special emphasis on 'Goodness Factor' calculations is outlined, together with approximations which lead to the similarity to conventional machine theory. The construction of a miniature double-sided short primary machine which shows the principle of operation of LIMS is included with a few brief observations.

"Nothing in this world is so powerful as an idea whose time has come".—Victor Hugo.

LIST OF SYMBOLS

- G — Goodness factor
- l_e — Length of electric circuit
- l_m — Length of magnetic circuit
- A_e — Cross-sectional area of electric circuit
- A_m — Cross-sectional area of magnetic circuit
- ρ — Resistivity
- μ — Permeability
- W — Motor width
- g — Total air gap length
- t — Thickness of secondary
- p — Pole pitch
- V_s — Synchronous speed

1. INTRODUCTION

1.1 A Brief Historical Background

It is difficult to trace back who initiated or what led to the invention of the Linear Induction Motors (LIM). The basic idea of LIM theory is probably a good hundred years old. Way back in the late 19th century LIMs were used to drive power looms. The first large-scale LIM, called the 'Electropult' was built during World War II. The obsession for circularity ever since the invention of the wheel, has helped in no small measure to suppress this ingenious idea. However, the sudden interest that skyrocketed the LIM into electrical machine technology was Man's insatiable desire for faster modes of transport in this jet age. The last two decades have placed much emphasis on research into levitation of vehicles. The LIM method of propulsion provides by far the most powerful, silent, pollution-free mode of propulsion for the levitated vehicle. LIMs have since found many ideal potential applications wherever linear motion is required directly.

1.2 Basic Principles and Classification of LIMs

The LIM can be considered to be, basically, a conventional induction motor 'cut' radially and opened. This results in a linear stator and linear rotor, separated by the air gap (Fig. 1). The moving magnetic flux is itself now linear, and attempts to move the rotor forward. (At this stage it is desirable to switch over to a different form of nomenclature to prevent any ambiguity. The stator will be referred to as the primary member and the rotor as the secondary member). The secondary windings which are normally short-circuited in conventional induction machines, are replaced by a thin strip of conducting material. Such a machine is referred to as a *single-sided* or *open-ended* LIM (Fig. 2). If another set of primary windings are placed above the secondary, the LIM is called a *double-sided* or *sandwich-type* (Fig. 3).

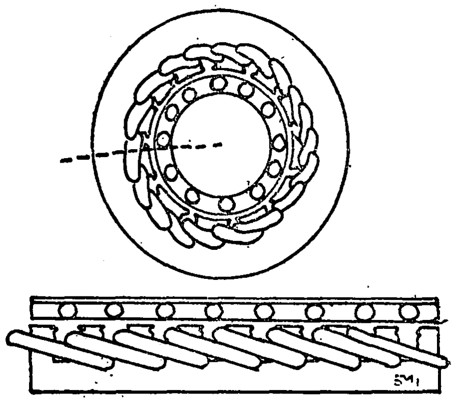

Fig. 1: The Linear Induction Motor

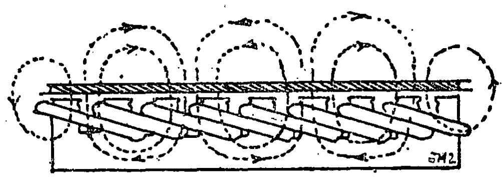

Fig. 2: Single-Sided LIM

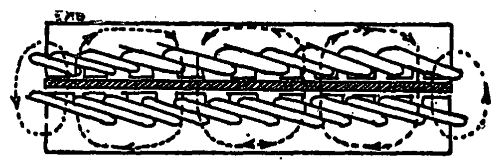

Fig. 3: Double-Sided LIM

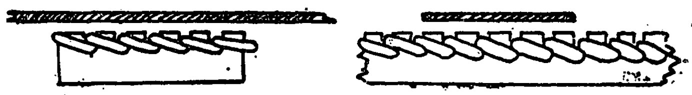

Fig. 4: Short Primary and Long Primary Motors

1.3 Essential Differences between LIMs and Rotary Induction Motors

Once the equivalent rotary machine is 'cut' and 'unrolled' to form a LIM, as described, it has two 'ends.' When the machine moves, a part of the secondary member is no longer under direct influence of the primary. Thus, to maintain continuous motion, either member will have to be extended. This yields yet another form of classification viz. Short-secondary (or long-primary) and short-primary (or long-secondary) machines (Fig. 4). Normally it is the shorter member that moves.

The travelling flux patterns of LIMs are distorted at the ends of the machine. These give rise to exit and entry edges transients, causing the characteristics to be different from conventional theory.

The other major difference in LIMs is the unbalanced magnetic pull produced on the secondary by the energized primary. In rotary machines this pull is felt around the entire periphery of the rotor and hence cancels out. However, a double-sided LIM is a closer equivalent to the rotary machine in this aspect, since both halves of the primary exert a magnetic pull on the secondary.

2.0 GENERAL THEORY OF LIMs

2.1 Goodness Factor

The general purpose of any electrical machine is to convert electrical power to mechanical or vice-versa. Thus the 'Goodness' of a machine can be considered to be its ability to convert power from one form to another. This conversion is governed by the *Current* produced by a given driving emf and the resulting *flux*. Since current and flux are inversely proportional to resistance and reluctance respectively, we may write,

$$G \propto \frac{1}{\text{resistance}} \times \frac{1}{\text{reluctance}}$$

$$\therefore G \propto \frac{A_e}{\rho l_e} \times \frac{\mu A_m}{l_m} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

But this expression gives G the dimensions of time. Hence by multiplying the right hand side of expression 2.1 by frequency, G can be obtained as a dimensionless quantity.

$$G \propto \frac{\mu A_e A_m f}{\rho l_e l_m} \qquad \ldots\ldots\ldots\ldots (2.2)$$

2.2 Goodness Factor and the Physical Dimensions of the Machine

With reference to Fig. 5

$l_e = W$

$l_m = g$ since the reluctance is almost entirely due to the air-gap.

$A_m \propto p.W$

$A_e \propto p.t$

$$G \propto \frac{\mu_o p^2 f}{\frac{\rho}{t}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

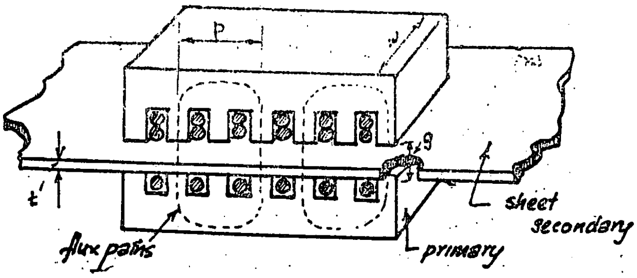

Fig. 5: Physical Dimensions

By obtaining the time constant of decay of flux set up by the secondary current, with the primary on o/c, the constant of proportionality of the expression 2,3 can be shown to be $2/\pi$.

$$G = \frac{2\mu_o p^2 f}{\pi \frac{\rho}{t} g} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Since $V_s = 2pf$. . . . .(2.5)

We may rewrite equation 2.4 eliminating p

$$\text{Then } G = \frac{V_s^2 \mu_o}{2\pi f \frac{\rho}{t} g} \qquad \ldots\ldots\ldots\ldots\ldots (2.6)$$

The above expression gives a starting point for the design process. To obtain a fairly large goodness factor, the denominator of equation 2.6 should be minimized. Assuming fixed supply frequency the only variables would be the gap dimension g, and the thickness of the secondary t, (-provided a material of lowest possible resistivity is used). Ideally t=g gives maximum goodness although practically this would mean completely filling the gap with the secondary, which is quite impossible. Also the pole-pitch dimensions governs the value of the numerator and consequently the speed of the machine or vice-versa. The V_s^2 term in equation 2.6 indicates that faster the machine the better would be its performance. Thus it is left to the ingenuity of the designer to vary the parameters of the machine and obtain the optimum values which give the best possible results desired.

2.3 Equivalent Circuits and Approximations

Conventional induction machine equivalent circuits may be applied without large errors to small LIMs. However this would mean that the transients arising from the edge effects have been neglected. Unlike in the case of conventional theory, the magnetizing current is drawn larger. The secondary being normally a sheet of conducting material, the iron loss component R_m can be neglected. The secondary leakage reactance X_2 can also be neglected, since it is very much smaller than R_2

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Hence for small LIMs with a Short-secondary, the equivalent circuit of Fig. 6 is applicable, with the elements referred to one side, as in the case of conventional theory.

3.0 THE TEST MODEL

3.1 Mechanical Aspects

The most practically feasible project was the building of a miniature double-sided, short-primary LIM capable of moving along the secondary. The two halves of the primary had dimensions of 2.5 cm x 13 cm x 1.3 cm and was made up of laminations. Each carried 10 slots 0.6 cm. wide, milled out to a depth of 1.6 cm. The halves were kept apart, maintaining the required air-gap between them, by two brass shafts. The shafts carried two wooden wheels which guided the model along the 'mono-rail' secondary. The secondary was an aluminium beading about 0.3 cm. thick, 2.5 cm. wide mounted vertically edgewise.

3.2 Electrical Aspects

The primary winding was a full pitched one-slot per pole per phase, series connected one. This arrangement called for three coils per phase in each half, making 18 coils in all. Each coil carried 50 turns of SWG23 enamelled copper wire. A reduced voltage three-phase supply was fed from one end, while the opposite end, on the other half of the primary, was star-connected.

With these specifications the following values were obtained by approximations to conventional theory:

$G = 0.62$	$V_s = 360$ cm/sec.	)
$R_1 = 0.48$	$F_{max} = 500$ gm.f	)for 30 V
$X_1 = 2.92$	Current drawn, 6 amps.	)(line to line)
$X_m = 0.15$	Power of Model = 0.013 HP	
$R_2 = 0.034$	Power Factor = 0.19	

4. OBSERVATIONS AND CONCLUSIONS

The model proved to be fairly successful as regards the basic operation of a LIM. For a 30 V (line to line) supply the observed values for current and force were 5 A. and 200 gm.f respectively.

However various minor mechanical difficulties hindered more efficient performance of the model. The inability to obtain a smaller air-gap (due to impractical machining tolerances), inherent frictional forces (mainly due to the model tipping to one side) and the difficulty in feeding power to the moving model, were some of the pitfalls.

The limitation of space for testing fair-sized models proves to be the biggest problem in projects of this nature. A phrase synonymous with LIMs is 'faster and bigger the machine the better its performance'. However the mechanical construction is far simpler than rotary machines—a milling machine being perhaps the most complicated piece of machinery required.

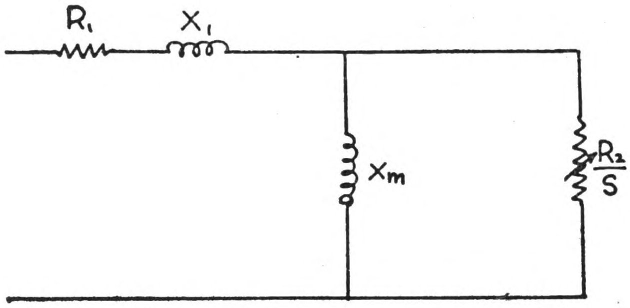
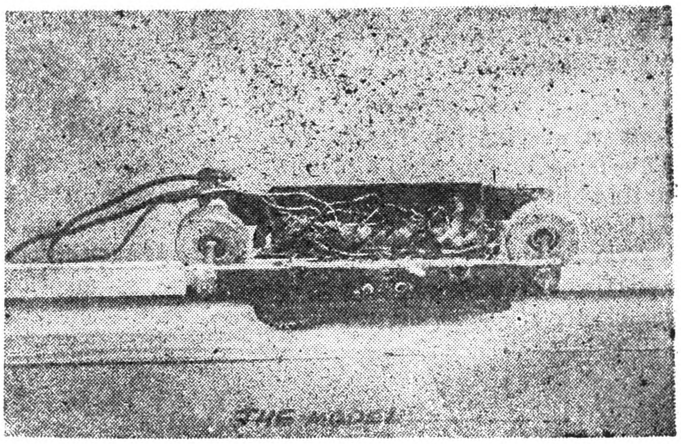


Fig 6. Approximations Equivalent Circuits for Small LIM



Bibliography

1. LAITHWAITE, E. R., (*Propulsion Without Wheels.*) London, English University Press, 1970.
2. LAITHWAITE, E. R., (*Induction Machines for Special Purposes.*) London, George Nenes Ltd., 1966.
3. BARWELL, F. T. & LAITHWAITE, E. R., (*Application of the Linear Induction Motor to High Speed Transport.*) Proceedings of the I.Mech.E., 1966-67, Vol. 181, Part G, pp. 83-100.
4. LAITHWAITE, E. R., (*Linear Electric Machines—A Personal View.*) Proceedings of the IEEE, Feb. 1975, Vol. 63, No. 2, pp. 250-290.
5. MITHTHAPALA, S. & BARNABAS, R J, (*Design and Construction of a Linear Induction Motor*)— 1976 Project Report submitted for the partial fulfilment of the Degree of the Bachelor of Science of Engineering, Katubedde Campus, University of Sri Lanka.