# Construction of Three Phase Linear Induction Motor

## Construcción de Motor Lineal Trifásico de Inducción

Sebastián Ocampo Gutiérrez[1], Roberto Largo Taborda[2], Nicolás Toro García[3], Fredy E. Hoyos Velasco[4]

**ABSTRACT**

This paper explores the construction process of a linear induction motor (LIM), the basic concepts behind key aspects of linear induction machines construction and the testing process of a working prototype. Making use of three phase systems, fundamental devices are used to produce a machine governed by means of electromechanical forces, based on varying magnetic fields and energy propagation all generated by three phased systems. The prototype developed is characterized in its mechanical configuration and subsequent tests are performed to address energy usage efficiency in different coil arrangements, varying key parameters which rule the movement generated by it, equivalent circuit analysis are employed. Automation circuits are implemented, rudimentary solving problems of directional movement, enabling the LIM to perform changes in direction.

Keywords: Three Phase Systems, Linear Induction Motor, Electromagnetic Devices, per-phase equivalent circuit.

RESUMEN

Este artículo explora el proceso de construcción de un motor lineal de inducción (LIM), los conceptos básicos tras los aspectos más importantes en la construcción de máquinas de inducción linear, y el proceso de pruebas, diseño y desarrollo de un prototipo funcional de un motor lineal. Haciendo uso de sistemas trifásicos se produce una máquina gobernada por procesos electromecánicos basados en inducción, a partir de los cuales se genera una respuesta mecánica que se traduce en desplazamiento. Se caracteriza mecánicamente el dispositivo desarrollado y se realizan pruebas para verificar fenómenos de uso de energía en diferentes configuraciones posibles de sus componentes, variando parámetros fundamentales que controlan el movimiento generado. Se exploran circuitos equivalente. Sistemas básicos de automatización son usados para permitir el cambio de dirección del motor generando finalmente una plataforma para pruebas de sistemas más complejos directamente relacionados con el análisis de señales y sistemas.

Palabras clave: Sistemas Trifásicos, Motor Lineal de Inducción, Dispositivos Electromagnéticos, Circuito Equivalente por Fase.

1 Engineering Physics Student, Department of Physics, Universidad Nacional de Colombia, Medellín, Colombia., socampo@unal.edu.co

2 Engineering Physics Student, Department of Physics, Universidad Nacional de Colombia, Medellín, Colombia. rlargot@unal.edu.co

3 Ph. D. Engineering Industrial Automation, Department of Electrical, Electronics and Computer Engineering, Grupo de Investigación en Recursos Energéticos (GIRE), Universidad Nacional de Colombia, Manizales, *Bloque Q, Campus La Nubia, Manizales, 170003, Colombia*. ntoroga@unal.edu.co

4 Ph. D. Engineering Industrial Automation, Scientific and Industrial Instrumentation Research Group, Universidad Nacional de Colombia, Medellín, Calle 59 A N 63-20, Medellín, 050034, Colombia.. fehoyosve@unal.edu.co



VIII Simposio Internacional sobre Calidad de la Energía Eléctrica 2015 SICEL

Noviembre 18, 19 y 20 Valparaíso Chile

## Introduction

A motor can be defined as a device that transform electric energy into mechanical energy. A traditional motor usually transform this energy intake into a rotatory movement (it generates torque) even if that is changed afterward into other forms of movement [1].

A linear motor works under the same principles as a rotary motor, given only a different characteristics form its designed conception, making it more task-specific right from its core fundamentals: A LIM is tailored to generate force, generate linear momentum instead of angular momentum [2].

For virtually every rotary electric machine, there is a linear motion counterpart. So is also the case with induction machines, they are called linear induction machines (LIMs), which directly develop an electromagnetic force, called thrust, along the direction of the travelling field motion in the air gap [3].

From a comparison view, a LIM operates as its rotary counterpart does, changing concepts and functions like thrust instead of torque and linear speed instead of angular speed, based on principle of travelling field in the air gap, described by de physics distribution of constitutive elements [3].

Induction motors are widely used as actuators in industrial applications because of the simplicity in construction, lack of maintenance and low cost. Using LIMs for industrial applications which require linear motion suppress the need for gears and other motion conversion mechanisms, hence fast acceleration and deceleration is feasible, they are also capable of working in hostile environments facilitating thrust and speed control. Furthermore, size is diminished, as more common motion mechanisms tends to use a bigger volume for its operation; put pulleys and chain systems in contrast to induction machines.

Even though a LIM presents an interesting dynamics not always considered for designing devices [4].

A comparison to the LIM counterpart is in order to understand the working principle of the devices:

- The main differences between the natures of this devices lies in the rotary nature and linear nature of them. Which is vastly self-explanatory.
- Both work under an induction principle, which can be described as the generation of an electromotive force whenever a conductor in subjected to a varying magnetic field.
- This devices use three phase AC input to generate its varying magnetic field, running through coils.

Linear induction machines are being actively investigated for use in high-speed ground transportation. Other applications including liquid metal pumps, magnetohydrodynamic power generation, conveyors, cranes, baggage handling systems, as well as a variety of consumer applications that have contributed to an upsurge in interest in linear induction machines.

Unfortunately, analysis of a linear induction machine is complicated by the so-called "end effect". In a conventional round-rotor induction motor the behavior of the machine need to be calculated only over one pole pitch. The solution for the remaining pole-pitches can then be simply obtained by symmetry.

However, the symmetry argument cannot be used for a linear induction machine since the electrical conditions change at the entrance and exit, be it the edge borders or mover ends in the LIM [5].

All the differences between linear and rotary IMs suggest the main merits and demerits of LIMs, which are summarized in table [3].

| MERITS | DEMERITS |
|---|---|
| Direct electromagnetic thrust propulsion; no mechanical transmission or wheel adhesion limitation for propulsion | Due to large air gap to pole pitch (g/τ) ratios–g/τ > 1/250 the power factor and efficiency tend to be lower than with rotary IMs. |
| Ruggedness; very low maintenance costs | The efficiency is to be compared with the combined efficiency of rotary motor + mechanical transmission counterpart |
| All advanced drive technologies for rotary IMs may be applied without notable changes to LIMs | Efficiency and power factor are further reduced by Longitudinal end effects. |
| Precision linear positioning (no play (backlash) as with any mechanical transmission) | Additional noise and Vibration due to Uncompensated normal force, unless the latter is put to use to suspend the mover (partially or totally) by adequate close loop control. |
| Easy topological adaptation to direct linear motion applications | |

This work presents and experimental assembly of a three phased LIM with a nominal voltage of $208V_{line\text{-}line.}$ The developed platform work as a basis for further study, applying fundamental concepts in the area of signal analysis and manipulation. First section places a mathematical basis given to further understand the LIM behavior, analyzing the per-phase equivalent circuit, Eddy Currents diagram and Automation Systems developed and implemented.

In the second section a comprehensive prototyping summary is treated, listing the design processes and problems encountered while development.

## Linear Induction Motor Modeling.

In a conventional round-rotor induction motor the behavior of the machine is only needed to be calculated over one pole pitch. The solution for the remaining pole-pitches can then be obtained by symmetry.

However, the symmetry argument cannot be used for a linear machine since the electrical conditions change at the entrance and exit.

The imaginary process of cutting and unrolling the rotary machine to obtain the linear induction motor (LIM) is by now classic (Figure 1.1 [3]).

The primary may now be shorter or larger than the secondary. The shorter component will be the moving part, hence the longer will stay stationary. A LIM can either be Single-Sided (Figure 1.1.e) or Double-Sided (Figure 1.1.d)

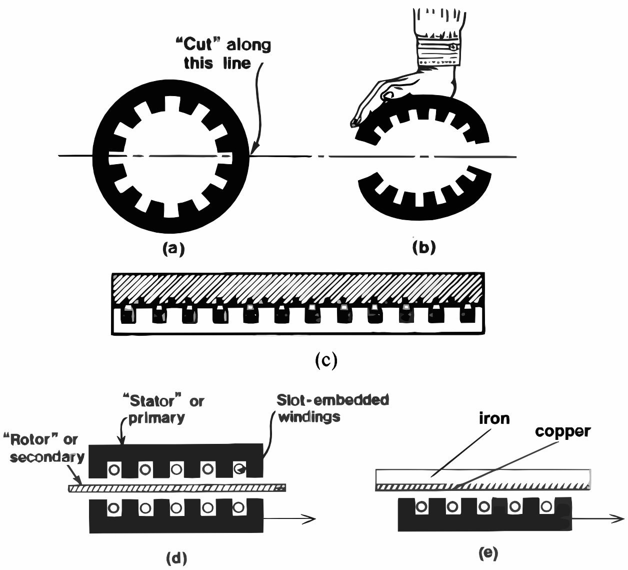


Figure 1.1. Unrolling process from RIM to LIM [3]

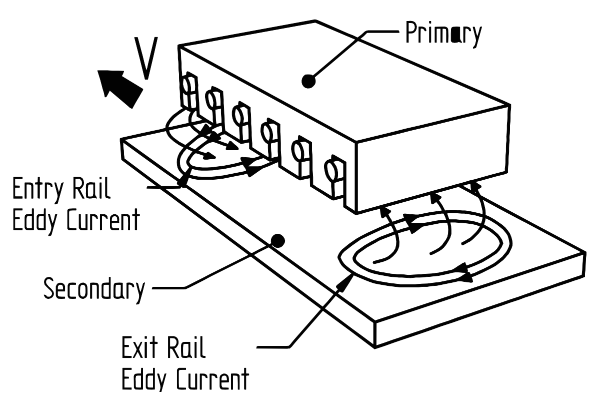


Figure 1.2. Eddy current generation at the entry and exit of the air gap when the primary coil moves with velocity V.

As stated, in a linear machine electrical conditions change at the entrance and exit level [6], as shown in Figure1.2, where eddy currents form along the primary, inducing the static element.

## Equivalent Circuit for LIM.

When working with induction machines, it is always a good strategy to take it apart in chunks by mathematical means to develop models that take into account more details in the designing process. As shown in figures 2.1 and 2.2, a basic per-phase circuit can easily be expanded to span the full phases working principle of a LIM, enabling handling of mathematical model in a more compact way.

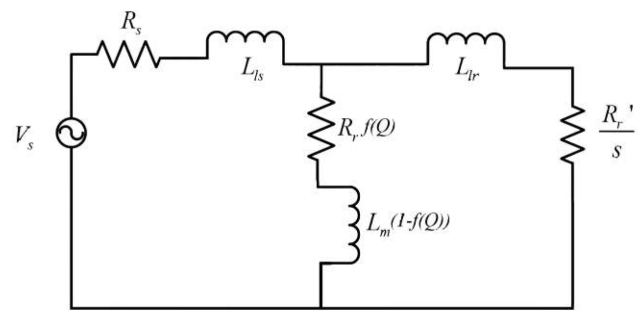


Figure 2.1. per-phase equivalent circuit of a three-phase LIM

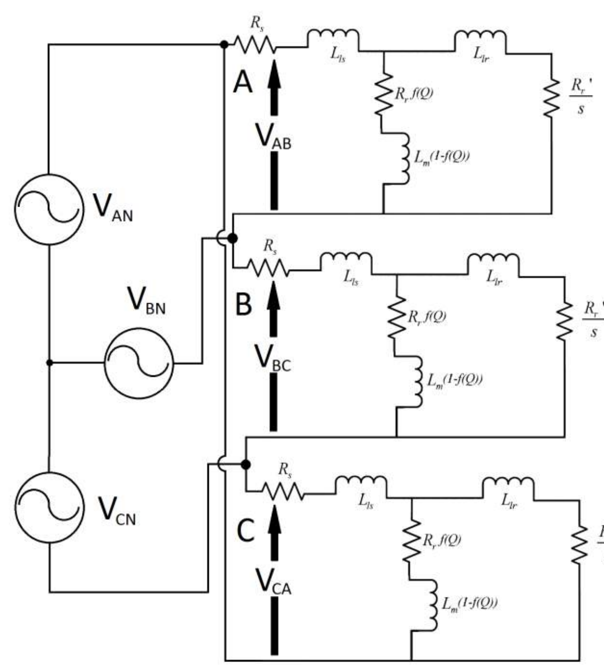

Figure 2.2. LIM three phase equivalent circuit

## Automation Control

As a need to ease the behavior of the prototype, and expanding its capabilities, a conveyor belt design was implemented. However, a longitudinal distance displacement in one direction must be automatically and autonomously inverted for longer operating time.

For this purpose, a rather rudimentary, yet effective system was implemented, making use of basic electrical devices, such as relays and contactors.

The control circuit design is presented in figure 2.3 and represents a limit switch control interface, actioned by the LIM itself after completing a full extend travel to either side of the conveyor belt.

Some thought when into unravelling a problem encountered with pushbuttons enabling both contactor during direction change status, solved al shown in the Control Circuit diagram on figure 2.1

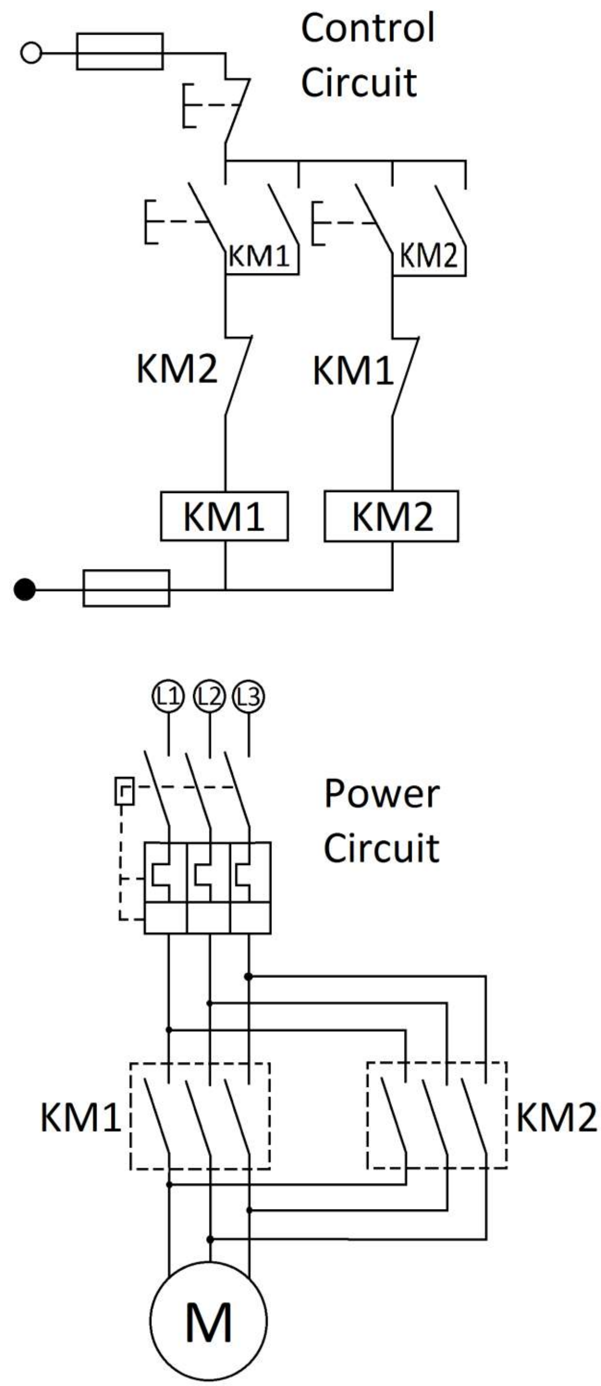


Figure 2.3. Automation drive circuit for LIM three phase

**Prototyping.**

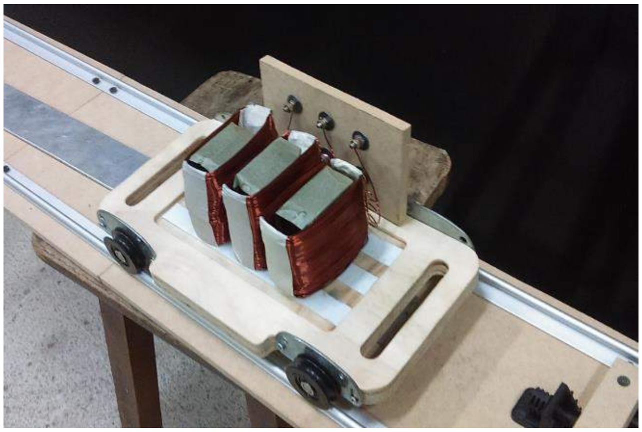

Figure 3.1. Second Iteration Prototype

After taking in consideration the design objectives and the mathematical background, prototyping is the next step. The available three phase connection provided 110V RMS, having ~208V phase to phase.

The first designed LIM was made by putting 9 coils, each one had 50 turns of 18:5 gage copper wire, in line over a core made out of silicon steel 40mm*240mm*0.5mm stripes layered to avoid eddy currents on the coils cores. In this first arrangement of coils they were permanently connected in Y configuration, where the first, forth, and seventh coil were connected to the first phase, the second, fifth, and eighth coil were connected to the second phase, and the third, sixth, and ninth coil were connected to the third phase.

As it is a Y configuration all three coil series systems were connected finally to a neutral line, this neutral line doesn't need to be connected since in Y configuration with the same load in every line the neuter has 0A current. This first design worked properly but generated little, and barely noticeable, force.

Table 1. Preliminary Design Especifications

| Preliminary Design | | |
|---|---|---|
| | **Material** | **Dimensions** |
| **Coils** | **Copper** | **50 turns 18.5 AWG** |
| **Core** | **Laminated Silicon Steel 0.5 thickness** | **40mm*70mm*12mm** |

An automation solution is given in the connection present in Figure 2.3 for the lead a, b, and c, allowing it to change direction by limit switching instead of manually switching lines.

Here KM1 and KM2 are contactors, each one having three Normally Open (NO) switches and one Normally Closed (NC). The NC switch from the contactor is connected in series with the opposite contactor coil, avoiding short disabling one contactor when the other is active.

There are three limit switches, one connected in series at the beginning of the Control Circuit, being a NC limit switch: pushing on it de-energizes all the circuit.

The other two present limit switches are NO, pressing them energizes the motor in either direction, alternating them.

The second design was formed by only three (3) coils also made of 18,5 gauge copper wire, but with a massive difference: each one of these new tree coils has 250 turns. This second design of LIM was mounted into a little wagon and rails to allow it to move, and onto the wagon were also mounted some banana female connectors for each coil terminal to allow changing between Δ and Y configuration easily.

Table 1. Final Design Especifications

| Final Design | | |
|---|---|---|
| | **Material** | **Dimensions** |
| **Coils** | **Copper** | **250 turns 18.5 AWG** |
| **Core** | **Laminated Silicon Steel 0.5 thickness** | **40mm*70mm*12mm** |

Having all this into account, this working prototype specifications are:

- Adjustable air gap to a maximum of 15mm.
- Usable railing length of 1.0 meters.
- Maximum voltage of 120$V_{line.}$
- Maximun current 1,5A.
- 250 turns per coil.
- Power 0,1kW

## Conclusions

A linear induction motor was designed and constructed. Two attempts were made and tested using Y and Δ configurations. The first design worked properly but generated little, and barely noticeable, force. A better performance under Δ configuration was obtained in the Single-Sided LIM prototype.

An Automation drive circuit for LIM three phase was given allowing to change direction by swapping two of the three feeding lines, using a limit switching instead of manually switching lines.

Flexibility for experiments allowing different configurations for behavioral studies is one of the most important features of the LIM proto-type In addition an easy method for LIM construction, permits to obtain a very cheap prototype for labs in technical schools.

## Acknowledgements

This work was supported by the Universidad Nacional de Colombia Sede Manizales with the research group on energy resources (GIRE- COL0144229) and The Universidad Nacional de Colombia Sede Medellín (Instrumentación Científica e Industrial-COL0037917) with research project HERMES 30115.

## References

[1] A. Fitzgerald, S. Umans and C. Kingley, Electric Machinery, McGraw-Hill Education, 2013.

[2] P. C. Sen, Principles of Electric Machines and Power Electronics, John Wiley & Sons Inc, 2013.

[3] I. Boldea and S. A. Nasar, The Induction Machine Handbook, CRC Press LLC, 2002.

[4] N. T. García, Dynamical Analysis of Three–phase Systems Controlled by ZAD-FPIC Techniques, Manizalez: Universidad Nacional de Colombia, 2012.

[5] T. A. Lipo and T. A. Nondahl, "Pole-by-pole d-q model of a linear inductuion machine," *IEEE Transactions on Power Apparatus and Systems,* Vols. PAS-98, no. 2, p. 629, 1979.

[6] J. Liu, F. Lin, Z. Yang and T. Q. Zheng, "Fiel oriented control of linear induction motor considering attraction force and end-effects," in *International Power Electronics and Motion*, 2006.