DESIGN OF AN ELEVATOR PROTOTYPE DRIVEN BY LINEAR MOTORS

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Abstract **– This work looks at a conception of a roped elevator prototype, using a linear induction motor (LIM) as traction machine and hence a development of a linear drive. Thus the development of a specific inverter to feed the linear motor, allows several ways to drive the elevator, through a suitable choice of the RMS voltage levels, an angular phase displacement and a fundamental frequency of the output voltage. As result tries to establish a new paradigm of the vertical conveying, through a new construction technique and arrangement of the system with counterweight allowing an increase of reliability, comfort and cost effectiveness.**

Keywords **– drives, conveyors, linear induction motor, power electronics.**

I. INTRODUCTION

Nowadays the great majority of the applications in which a translatory motion is necessary use a rotary electrical motor as motion power to convert the rotary movement into a translatory movement. Often, it is necessary to use a complex mechanical system of gears, axles and screws jacks. When used directly, these mechanical systems for energy transmission produce great losses, increasing the abrasive wear due to the friction of the mechanical parts, even using low viscosity fluids for the lubrication, increasing the operational costs, mainly those relative to maintenance. Therefore, for transport applications, the use of an electrical machine that produces the translatory motion directly would result in lower operational cost, higher reliability and less maintenance.

This work focuses on the development of a new vertical conveying system using a linear induction motor, fed by a specified converter, which takes into consideration the desired drive.

II. LINEAR MOTORS

The operating principle of a linear motor can be visualized by butting a rotary motor along its radius from the center of the shaft to the external surface of the stator core rolling it out flat, according to Fig. 1. Linear motors were first developed at the same time of other rotary electrical machines, at the end of eighteen century. Therefore, for each type of rotary electrical machine (synchronous, inductance, reluctance and direct current) there is a linear equivalent.

Difficulties in driving the linear motor restricted its use to a few applications, due to its operation characteristics as well as the problems due to the longitudinal end and transverse edge effects that exist in linear machines [1]. Initially, AC motor drives used to present fixed voltage and frequency and the increased complexity required in linear motor drives limited the use of linear machines in routine applications, turning the linear machine simply into a theoretical reference for almost all the first half of XX century.

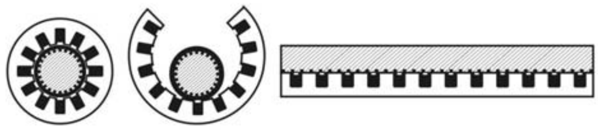

Fig. 1. Imaginary building process of a linear induction motor (LIM).

The development of power electronics associated with the microprocessor allowed speed control; adjustment of the thrust and braking control of the linear motor with efficiency and security. Thus some applications are becoming advantageous when compared with the equivalents driven by rotary electrical machines.

The perspectives of future applications of the linear machines in the industry are each time more promising, such as: pallet transportation, belt conveyors transportation of bulk material, machines tools, presses mills, separators, automated manufacturing systems, strip tensioners, textile shuttles, turntables, disc saws, military and aerospace applications, hypervelocity, ship propulsion and submarines, biomedical applications, elevators, load transport.

III. LINEAR MOTORS IN ELEVATORS

The linear motor has been studied for the vertical conveying application because its main characteristic is the translatory motion, which takes place without transformation mechanisms, increasing the efficiency and the trustworthiness of the system, besides the reduction of the machine footprint.

Since the beginning of the research for the use of the linear motor in vertical drives, the type of the electrical machine (synchronous, induction and reluctance) to be used became a great source of discussion among the researchers. Gieras suggested [2] [3] some arrangements can be made for the elevator structure, such as: the motor does the work of dislocating all the traveling weight or to use a rope with counterweight decreasing thrust supplied for the motors.

Thus the use of the linear motor as a vertical drive offers:

- Performance comparable to that of rotary motors;
- Smooth operation and high comfort of riding;
- Greater adaptability to the environment (building), e.g. penthouse machine room is not required, reduction of overhead space, etc;
- Possibility of using the linear motor as a brake;
- Linear motor action not only as a driving device but also as part of the counterweight;

- Energy saving and reduction in power capacity

IV. DESIGN OF A COUNTERWEIGHT ELEVATOR PROTOTYPE USING A LINEAR MOTOR DRIVE

To prove the concept here presented, an elevator prototype with the double-sided induction drive was projected, that would serve as traction machine and counterweight. Due to the height conditions of the laboratory (GPAR) of the Department of Electric Engineering, where the prototype was installed, the linear motor had a reduced size. Having defined physical limitations, an assessment of which linear motor topology would have to be used for the project was carried out. First the linear motor dimensions were established and then, the mechanical structure of the elevator. After that, the drive inverter was designed and finally the control unit was programmed in a microprocessor and a digital signal processor (DSP).

V. DESIGN OF A DOUBLE-SIDED LINEAR INDUCTION MOTOR

The motor to be constructed must have low speed due to the short path of 3m, thus the maximum speed was limited to 1,2m/s for a frequency of 20 Hz and a thrust of 200N, for a supply of 220 volts.

With the specified parameters the motor was designed according to [2, 4], using oriented silicon steel sheets to assembly the primary core. To use all the sheet extension (450x100mm), the primary core has 12 magnetic poles. Due to the mechanical constructions restrictions, the wires lodging in the slot and limited polar pitch due to low speed, was chosen, by opened rectangular slots.

The mechanical structure of the elevator prototype was designed for 3m path, with two car stops throughout the path and a useful car load of 50kg. For the design, the following equations were used:

$$L_\tau = (2.p.\tau + wc + c_1) \qquad (1)$$

where Lτ is the length of the primary core, τ is pole pitch, p is number of poles, wc is coil pitch and c1 is the width of a tooth,

$$h_{1y} = (0,3...0,5).\tau.Bm \qquad (2)$$

where Bm is the magnetic flux density in the primary yoke (0,7- 1,2T) and h1y is the height of the yoke of the primary stack,

$$L_i = \frac{A}{L_\tau} \qquad (3)$$

The dimensions of the primary core were obtained and are shown in Table 1.

TABLE I
Size of the primary core

Quantity	LIM	Unit
Length of primary core	450	mm
Effective width of primary core	70	mm
Height of primary core	60	mm

The primary slots have 5mm width dimension, given by:

$$t_1 = \frac{2.p.\tau}{z} \qquad (4)$$

where t1 is the slot pitch and z is number of slots, and with 30mm of depth. The tooth width has the same depth slots, and length of the primary stack has 32,5mm width. The primary core has 39 slots.

The winding of the primary core was projected as:

$$z = p.m.q \qquad (5)$$

where m is the number of phases and q is the number of slots per poles per phases, to have a three-phase configuration of 12 poles to a greater thrust, having a double-layer distribution in the thirty three central slots and a mono-layer in the six slots at utmost point, being three in the entrance slots and three at end of exit slot, as shown in Fig. 2.
5)

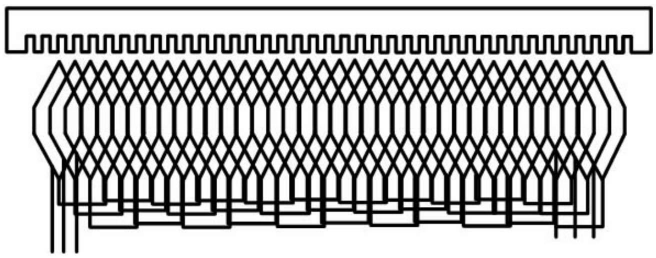

Fig. 2. Winding of primary core.

This configuration of winding together with length extension of the primary stack, try to reduce the longitudinal end effects.

The winding of the primary core has 100 turns of wire n. 22AWG (0,33mm2) obtained by:

$$N_1 = \frac{(A_{my}.\tau.p)}{3.\sqrt{2}.I_1} \qquad (6)$$

where N1 is the number of turns per phase, Amy is line current density and I1 is phase current, and by:

$$N_{sl} = \frac{N_1}{p.q} \qquad (7)$$

where Ns1 is the number of conductors in each slot, with 3 cm of polar pitch.

The winding and the primary core final result of the linear motor projected are depicted in Fig. 3.

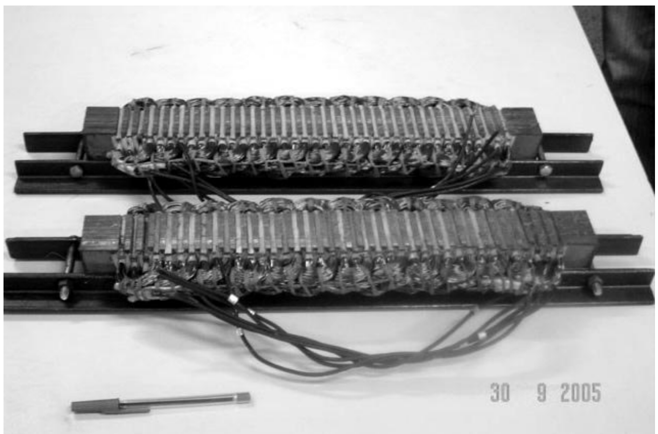

Fig. 3. Linear motor projected.

VI. MECHANICAL STRUCTURE

In this prototype the secondary core is assembled of aluminum sheets with 3000x5.6x12mm, due to the good magnetic current conductivity and the poor magnetic conductivity, the aluminum makes the same service of the traditional squirrel cage motor.

For the mechanical structure development, the linear motor was thought as a counterweight due its mass characteristics. Hence it was thought a traction elevator with counterweight, being the counterweight the traction machine.

In Fig. 4, it can be observed that the primary core structure can has a gap regulation in both primary cores, thus obtains a high precision regulation of the gap between the primary cores.

In Fig. 5, we have the final structure built. All the structure is shaped by T section angles and square tube sections of 1020 steel and ¼ in. For future designs, the mechanical structure projected will be opened, allowing small adjustments to be made.

VII. DOUBLE THREE-PHASE BRIDGE VOLTAGE SOURCE INVERTER DRIVE

This research presents a new topology of three-phase inverter, its making necessary to use a topology which supplies to the motor unbalance currents, different operation frequency with a higher supply voltage. Therefore the inverter will be the double-bridge inverter as shown in Fig. 6, supplying the motor unbalance currents required [5].

Thus the double three-phase bridge gives a 320Vrms output voltage and a 20Hz rated frequency.

The inverter specifications are presented following the Table 2. Several feeding conditions (different RMS voltage levels and angular phase displacement) of the LIM were considered.

TABLE II
Specifications

Output power	5400VA
Supplied voltage	380Vac
Rated output voltage	220Vac
Supplied frequency	60Hz
Switching frequency	7500Hz
Output voltage frequency	20Hz

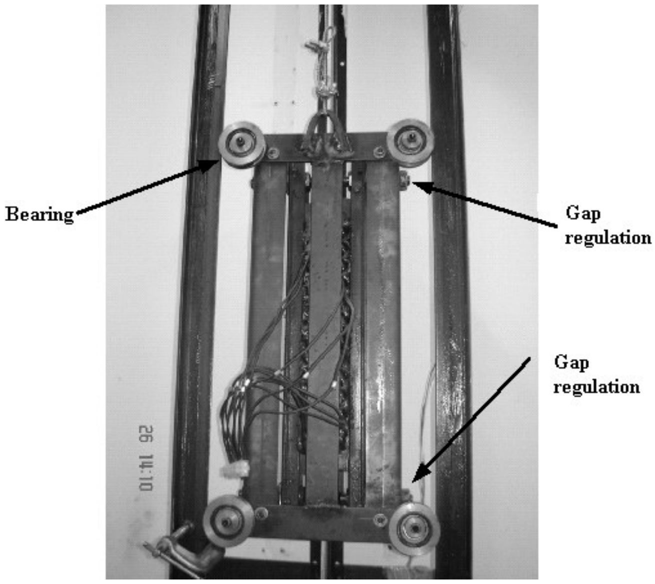

Fig. 4. Primary core structure.

Fig. 5. Elevator structure designed.

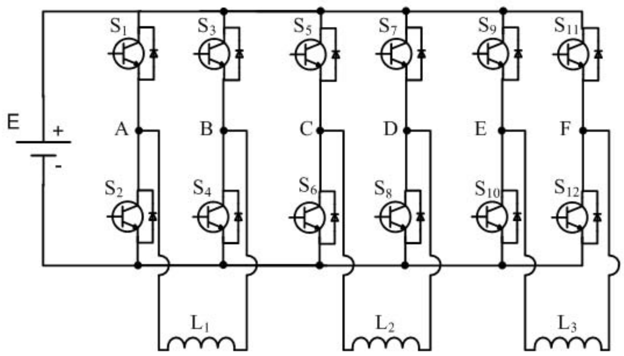

Fig. 6. Double three-phase bridge basic circuit.

VIII. SPEED CONTROL

The choice of the speed control strategy is very important in the determination of the main performance characteristics in a drive.

In this research, it is used the open loop speed control of the linear induction motor operating with a adjustable frequency, therefore the elevator prototype has as requirement a soft-start and smooth break (acceleration and deceleration).

The strategy chosen for the accomplishment the acceleration and deceleration of the elevator were the scalar v/f control technique, because it is commonly used for open loop PWM inverter (without speed feedback).

The control system has been implemented using a Digital Signal Processor (DSP) TMS320F2812 Texas Instruments®, which had its high-speed processing, high memory capacity and accomplishment of mathematical instructions using a numerical representation of fixed or floating point.

The DSP makes a complete digital control of the output voltage frequency and the rated output voltage from the inverter, as also it controls the acceleration and deceleration of the elevator.

In order to keep the primary core flux constant, a digital V/f curve was programmed in the DSP allowing the reduction of the speed and keeping the ratio between the magnitude voltage and frequency constant.

IX. EXPERIMENTAL RESULTS

Fig. 7 shows the output current waveforms, Fig. 8 shows the output voltage waveforms supplied to the linear induction motor projected for the elevator, for 220 RMS voltage, 20Hz output frequency and 120 degrees angular displacement.

From the scalar v/f control technique, an algorithm in the DSP was implemented, so that the motor achieved approximately 1,5s acceleration time.

The Fig. 9 and Fig. 10 show the current waveforms of the designed LIM, for acceleration and breaking, with an output voltage reference changing following the pattern 0-220-0V and the output frequency changing as 0-20-0Hz and 120degree angular displacement.

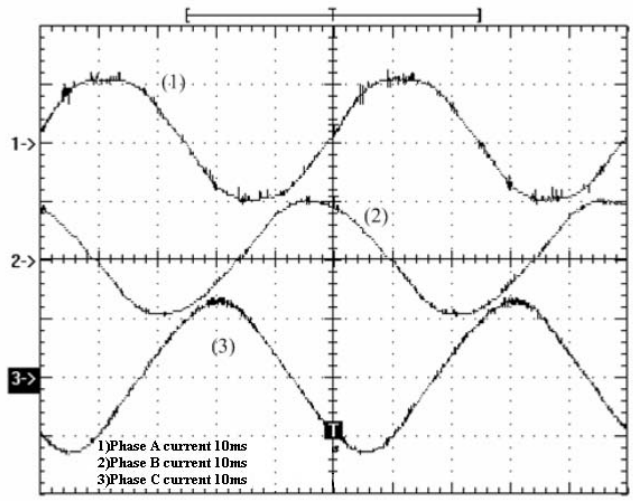

Fig. 7. Output current waveform 1)=2)=3)10A/div; 10ms/div.

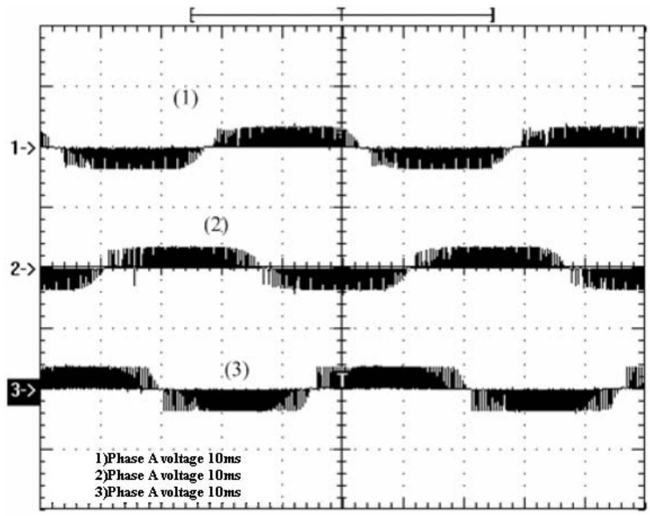

Fig. 8. Output voltage waveform 1)=2)=3)1kV/div; 10ms/div.

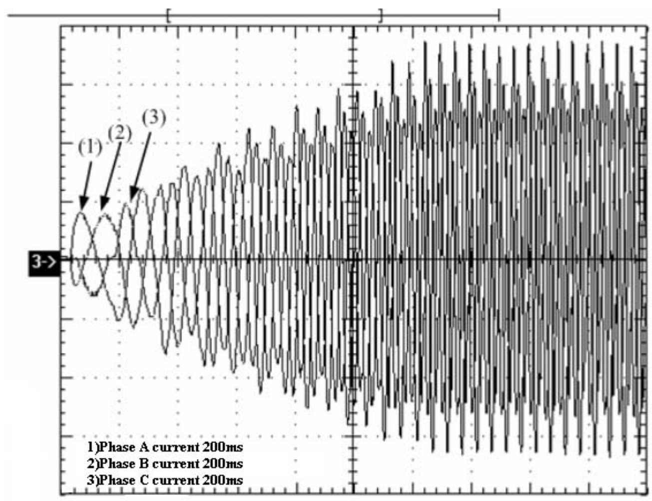

Fig. 9. Output current waveform for a soft-start. 1)=2)=3)5A/div; 200ms/div.

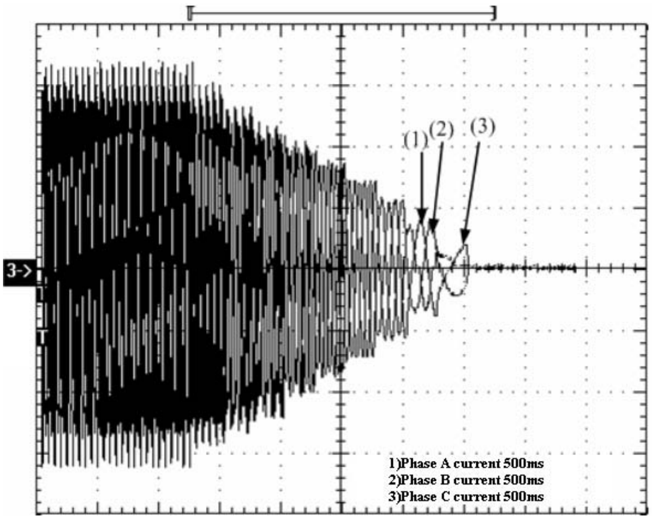

Fig. 10. Output current waveform for braking. 1)=2)=3)5A/div;

X. CONCLUSION

In this work the theoretical and experimental study of a counterweight elevator using a linear induction motor were presented. An elevator prototype using a LIM was built and experimentally tested, consisting of the mechanical structure of the elevator, the electromagnetic brake system, the drive and control unit.

As the double-bridge inverter is equivalent to three full-bridge inverters, the DSP can control independently each one of them, that is, to impose output voltage levels, angular displacement and output frequency separately. Thus its use for linear motor drive becomes a tool to impose different feeding conditions for future analysis.

With the use of this technology, a paradigm break may occur due a new way of elevator construction, not existing in the standards.

Thus with the use of the linear motor in elevators the passenger may have smooth operation, better comfort in the ascent and descent, due to the velocity control made by the inverter, easier maintenance and inspection access, as the motor topology gives this facility, penthouse machine room is not required, being able to save civil construction materials, save energy, power reduction, because of the optimization load to the motor and high speeds due to the linear motor characteristics in the project of its nominal speed, without modifying the motor thrust or use of gear-reductions.

The application of this technology aims the markets where there are distribution storage centers of the retail sector, the port sector, industrial applications or commercial elevators.

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