Long Armature Linear Synchronous Motor for a Magnetically Levitated Vehicle

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***Abstract* – The traction force produced by linear motors are exclusively due to the electromagnetic interaction between the vehicle and the track. Therefore, no friction is necessary and this is naturally the best choice for the propulsion of magnetically levitated trains. The choice of a linear synchronous motor with long armature [1] is imposed by the inconvenience of sliding contacts at high speeds. This paper presents the design of a linear motor for a magnetically levitated prototype, which will run on a 30m track, that is being constructed at UFRJ [2]**

I. INTRODUCTION

Brazil is the fifth country in the world in surface (8,5 million square meters) with a population of approximately 160 million inhabitants and the Brazilian Gross National Product (GNP) is the tenth in the world. The two major Brazilian metropolitan regions, namely Great São Paulo and Great Rio de Janeiro, are 400 km apart. The corridor between both cities has economical and population densities comparable to the Central Europe. Currently, the passengers flow between these two cities is done basically by bus or car (6h trip) or by plane (40 minutes flight). However, due to the high concentration of population and economic activities, there is an intense people dislocation between both cities and a rapidly increasing demand for faster connection. This demand could be fulfilled with a magnetic levitation train linking these economic poles.

For more than two decades, Germany and Japan have prototypes in commercial scale of levitation trains. The former uses electromagnetic levitation (Transrapid) and the latter the electrodynamic levitation principle (MAGLEV train).

In the last decade new high temperature superconducting materials, such as the $YBa_2Cu_3O_{7-\delta}$ (YBCO), were developed. This ceramic presents the superconducting state at a temperature of 92K, which can be achieved with liquid nitrogen. This made feasible the construction of a levitation train prototype, based on YBCO blocks prepared by top-seeded-melt-texturing technique. The basis for the vehicle levitation is the superconductor diamagnetic response causing a repulsive force that appears between such blocks and the permanent magnets located on the rail [3]-[4]. The development of seeded-melt-texturing technique raised the critical current of YBCO blocks and the consequent levitation force. The strong pinning force in these blocks leads to self-stability, as already reported [5]-[6]. There is until today no commercial prototype in the world of this train and this is a technological opportunity for Brazil. This paper describes the traction part of a laboratory prototype, a step before the commercial one. The levitation design is described in another paper [7].

As the traction force produced by linear motors are exclusively due to the electromagnetic interaction between the vehicle and the track, no friction is necessary and this is naturally the best choice for propulsion of levitation trains. The inconvenience of sliding contacts at high speeds suggests the choice of a contactless energy transfer method as the linear transformer proposed for the Swissmetro project, that will use a homopolar linear motor, or a linear synchronous motor with long armature as described in this paper.

II. THE PROTOTYPE

In order to validate the combination of linear traction and magnetically levitation using superconductor blocks, a first prototype was built [8]. The prototype consisted of a 7 meters straight double rail track and a linear synchronous motor with the armature winding in the vehicle and the field winding composed of NdFeB permanent magnets distributed along the track. The prototype worked well but had the drawback of requiring sliding contacts. Therefore, the next step of the project is the design of a synchronous linear motor with the armature winding distributed along the track and the field winding in the car. In order to test the performance of both traction and levitation systems when operating at higher speeds, the train will run in a double rail closed track with an oval-like perimeter of 30-meters (Fig.1).

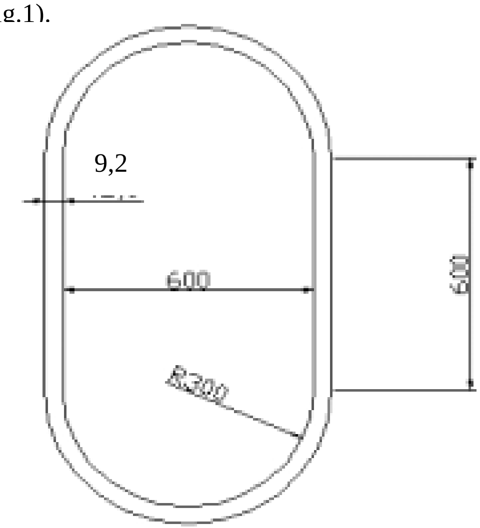

Fig.1 The double rail closed loop track.(units in cm)

Two designs of linear synchronous motor are being studied:

1) Single sided motor with coreless armature winding (Fig. 2);

2) Double sided motor (Fig. 3).

In both designs special care is taken in order to avoid attraction forces between the car and the track which would impair the successful operation of the levitation system. Both designs use NdFeB permanent magnets as the field excitation.

In either case, the motor will be supplied by a power inverter. For the first prototype a commercial inverter with V/f control was used. Initially this arrangement will also be used in the new prototype. The next step will be to explore the use of a vector control scheme and compare the performance of both schemes. Also the use of a segmented rail, where each part will be fed from a different inverter, will be explored and strategies to insure the synchronism of the machine when changing from one segment to another will be investigated.

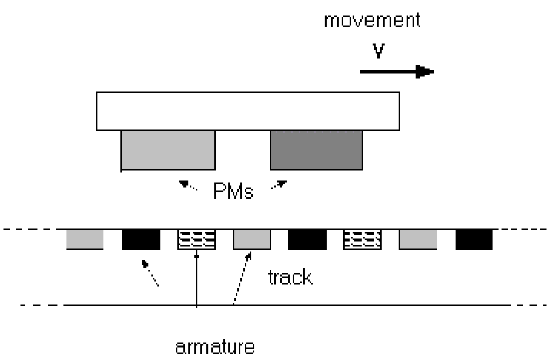

Fig. 2 Single sided linear synchronous motor

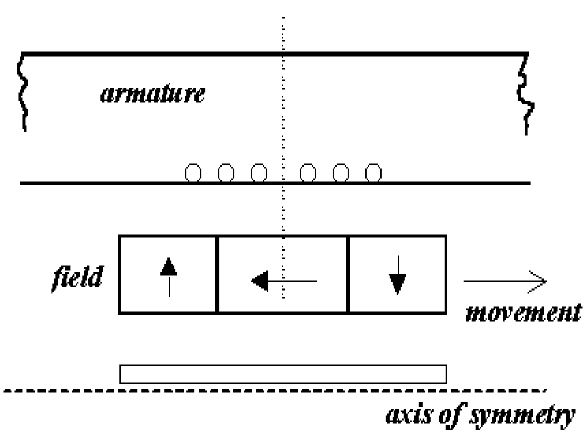

Fig 3. Double sided linear synchronous motor

III. SIMULATION RESULTS

The core of the design of both motors lies on the accurate calculation of the distribution of magnetic flux density due to the permanent magnet. In this project a commercial finite element based program is extensively used [9]. This section shows some results of these calculations.

A. *Single Sided Linear Synchronous Motor*

The traction and levitation arrangement implies that the motor will inherently have a variable airgap length. Therefore the first step was to calculate the magnetic flux densities at different distances from the permanent magnets surface as indicated in Fig. 4, where:

A –5mm from the permanent magnets surface;
B –7mm from the permanent magnets surface;
C –10mm from the permanent magnets surface;
D –15mm from the permanent magnets surface.

Fig. 5 shows flux lines distribution for the geometry presented in Fig. 4. This geometry can be recognized as a pair of poles of a multi-pole field. Figs. 6 to 9 show graphs of magnetic flux densities at the planes shown in Fig. 3. The peak value of flux densities at different airgap length are presented in Table I.

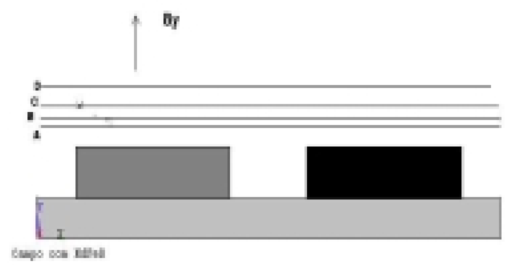

Fig. 4 - Field winding arrangement (two poles shown)

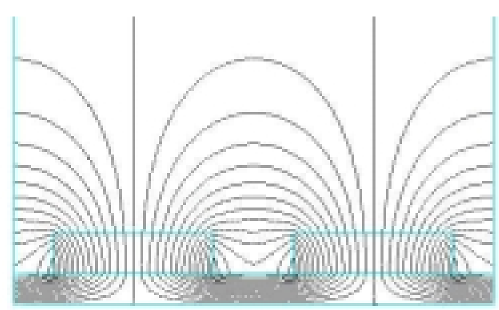

Fig. 5 - Magnetic Flux Lines

TABLE I – PEAK VALUES OF MAGNETIC FLUX DENSITY

	A	B	C	D
B_y peak (T)	0,33	0,29	0,23	0,16

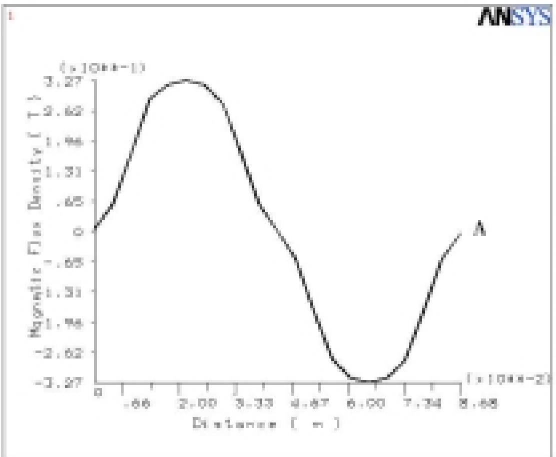

Fig. 6 - B_y component of magnetic flux density at Plane A

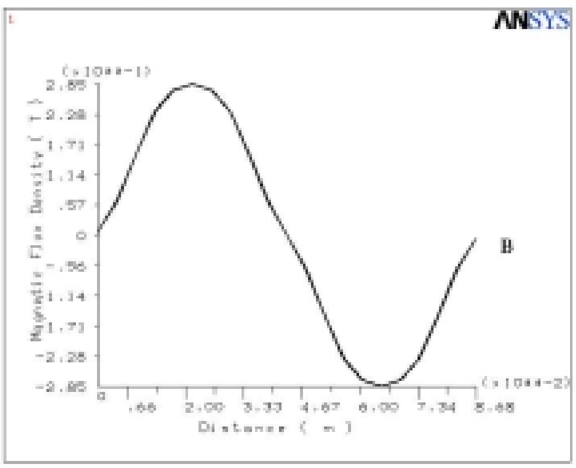

Fig. 7 - B_y component of magnetic flux density at Plane B

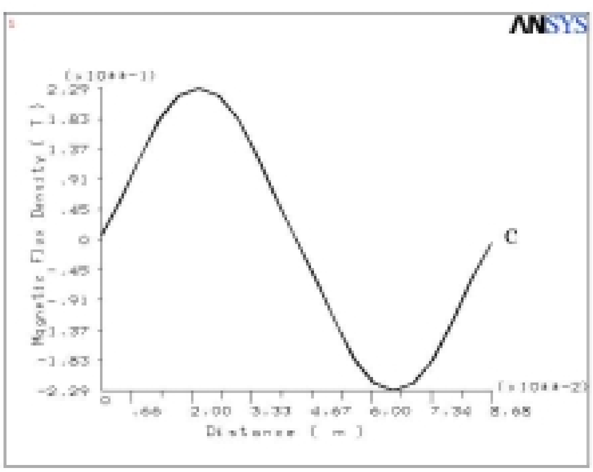

Fig. 8 - B_y component of magnetic flux density at Plane C

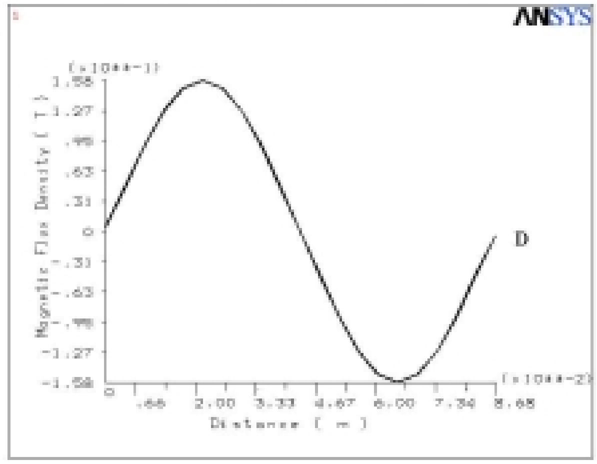

Fig. 9 - B_y component of magnetic flux density at Plane D

The results above were used together with classical formulary [1] to investigate design configurations. The specifications of a preliminary design of the single sided motor are presented in Table II. Two possible arrangements are considered using the V/f inverter to feed the track. In one case, a whole section of 6 meters is fed in series configuration, and in the other, two track sections of 3 meters are fed in shunt configuration. The estimated propulsion force curves for each case are shown in Fig. 10.

TABLE I I – SINGLE SIDED MOTOR SPECIFICATIONS

Data	
Number of poles	10
Frequency (Hz)	20
Synchronous speed (m/s)	1,56
Pole pitch (mm)	39
Airgap (mm)	10
Slot width (mm)	10
Tooth width (mm)	3
Number of slots/pole/phase	1
Number of turns per phase	40
Number of phases	3
Armature resistance (Ω/m)	7,8
Synchronous reactance (Ω/m)	0,3

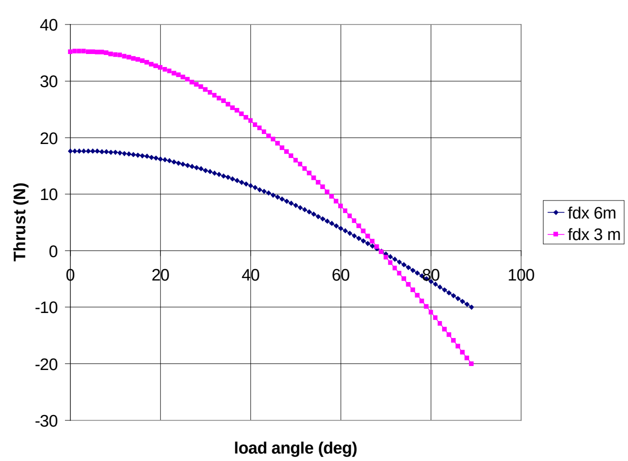

Fig. 10 - Propulsion force curves

B. *Double Sided Linear Synchronous Motor*

In this design an attempt is made to increase the field flux by using an Hallbach Array arrangement as shown in Fig. 3. The simulations use a 3D representation as shown in Fig. 11 where every degree of symmetry is explored.

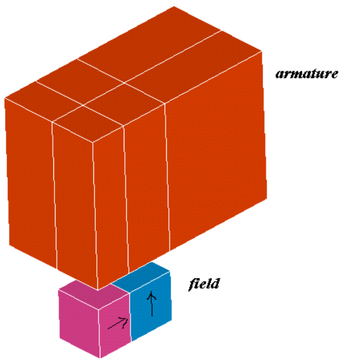

Fig. 11 - 3D representation of double-sided linear synchronous motor

Fig. 12 presents simulation result showing the normal (y) component of the magnetic flux density distribution at a plane lying on the armature winding plane. A future paper will explore the design of a double-sided linear synchronous motor using a Halbach Array arrangement.

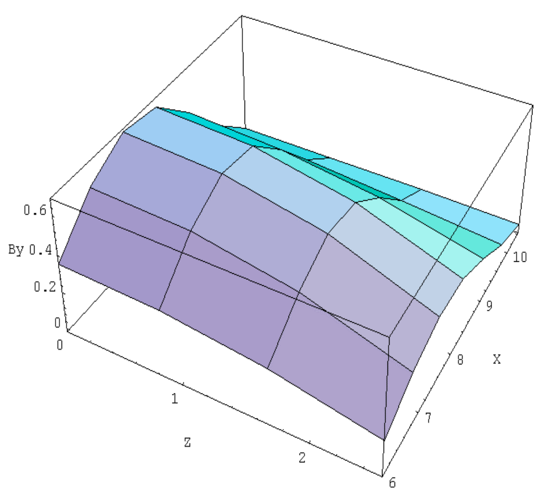

Fig. 12 - Magnetic flux density at armature winding (T)

IV. CONCLUSION

This paper has presented two configurations of a linear synchronous motor to be used in the study of a magnetically levitated train prototype. It has also been shown how a commercial program for magnetic field calculation can be used for the design.

V. ACKNOWLEDGEMENT

To CNPq and FAPERJ for the financial support.

VI. REFERENCES

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