THE CURRENT STATE OF THE BRAZILIAN PROJECT FOR A SUPERCONDUCTING MAGNETIC LEVITATION TRAIN

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Abstract:

The current state of the high-temperature superconducting magnetic levitation train prototype in UFRJ is described. This project has two main parts: the levitation and the traction. In this paper, the development and results of both parts are presented. Simulation and test measurements are presented. The integration of both parts will be done with a small scale laboratory prototype. These results are necessary as a convincing example for higher investments and new enrollments, necessary for the construction of a real scale prototype, the next step in our project.

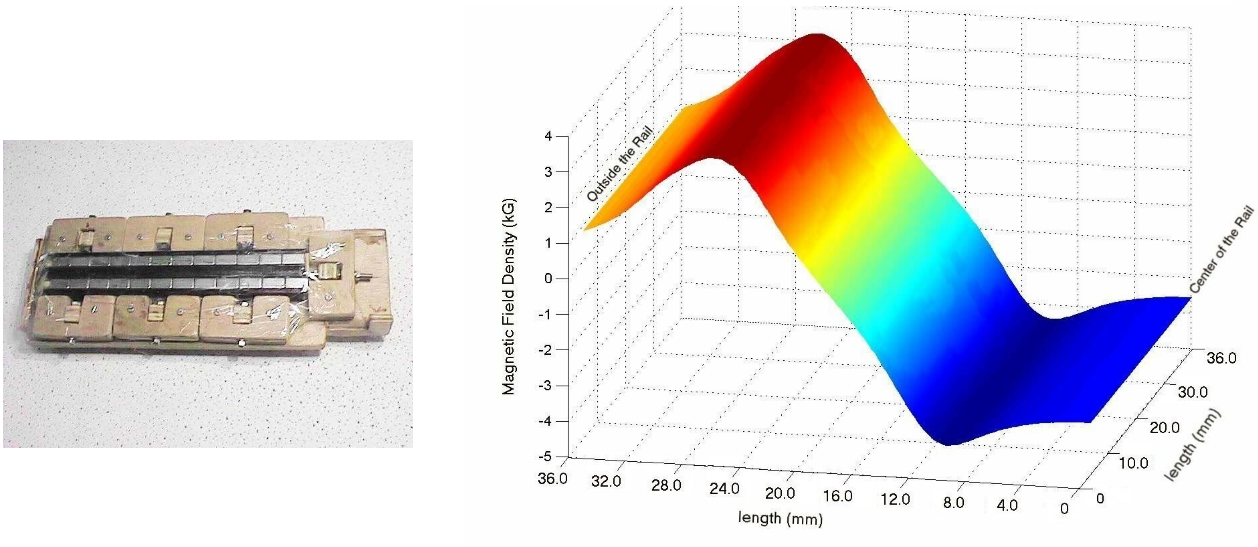
1 Introduction:

In the last decade new bulk high temperature superconducting materials, such as the $YBa_2Cu_3O_{7\delta}$ (YBCO), were developed. These ceramics present the superconducting state at a temperature of 92K, which can be easily achieved with liquid nitrogen bath (77.4K) and exhibit good performance in critical current densities and trapped magnetic fields. Those features made feasible the construction of a levitation train prototype, based on the interaction between permanent magnets and 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]. This paper describes a laboratory prototype, as the first and important step in the development of that technology.

2 Levitation Rails:

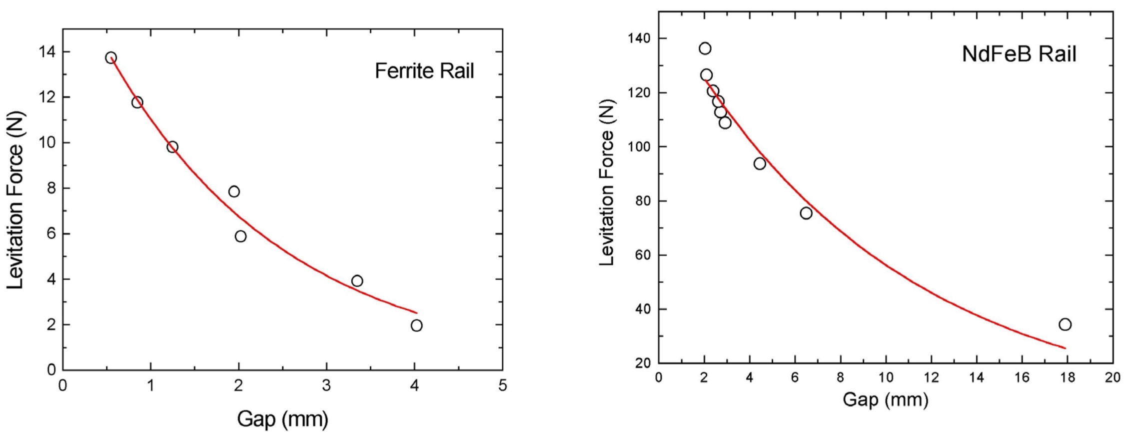
The initial studies used Ferrite levitation rails, but the achieved levitation force was too modest for the proposed application. Therefore, now a levitation rail using NdFeB magnets is being considered.

Fig. 1(a) shows a photo of part of this new rail with two rows of 1” × 1” × ½” permanent magnets assembled in opposite dipole symmetry and separated and sided by flux concentrators of steel. Fig. 1(b) presents the measured z-component of magnetic flux density field for this configuration. Fig. 2 presents the measured levitation forces of the constructed rails sections on the same superconducting blocks configuration. As can be seen, the NdFeB rail section promotes a ten times higher levitation force.



(a) (b)

Fig.1. (a) NdFeB test rail of 30 cm with two rows of magnets.
(b) Measured magnetic field profile from center to outside at 0.5 mm above the surface.



(a) (b)

Fig.2. Measured levitation forces on the same superconductor block configuration.
(a) Ferrite rail. (b) Nd Fe B rail, both mounted in opposite dipole configuration with magnetic flux concentrators (see text).

3 Linear Synchronous Motor:

The absence of any mechanical means for propulsion force transmission suggests the use of linear motors for the propulsion of magnetically levitated bodies. 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 ferrite permanent magnets distributed along the track. The prototype worked well but had the drawback of requiring sliding contacts. The inconvenience of sliding contacts at high speeds may be overcome with a contact-less energy transfer method or a linear motor with long armature winding. This section describes the design of a linear synchronous motor with a long armature winding with the field excitation provided by NdFeB permanent magnets, which are fixed to 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.3). Each one of these two rails will look like the small segment shown in Fig. 1(a) and the linear synchronous motor armature will lay in the middle of both.

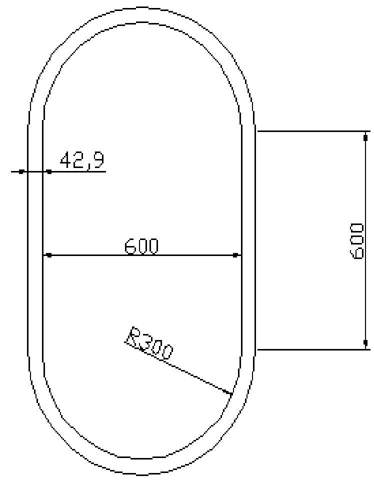


Fig. 3 - The double rail closed loop track (units in cm)

Two designs of linear synchronous motor are being studied: a double sided motor and a single sided motor with coreless armature winding (fig. 4) which is the object of this paper.

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 from a power converter. 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.

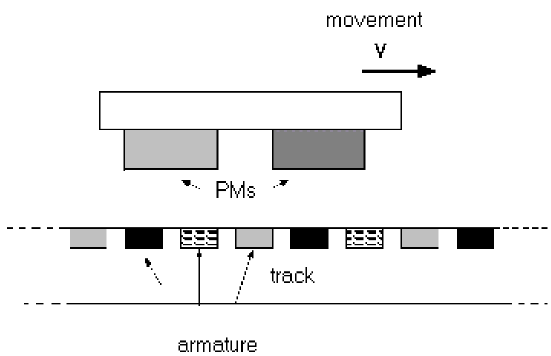


Fig. 4 - Single sided linear synchronous motor

3.1 Single Sided Motor Design

The core of the design lies on the accurate calculation of the distribution of magnetic flux density due to the armature and field windings. In this project a commercial finite element based program is used [9]. This section will present the design procedure.

3.1.1 Experimental validation

The traction and levitation arrangement imply that the motor will inherently have a variable air gap length. Therefore the first step was to calculate the magnetic flux density distribution at different distances from the permanent magnets surface. For the calculation of the By component of the magnetic flux density distribution, the geometry presented in figure 5 was used. With the aid of a Gaussmeter, experimental measurements of the normal component of magnetic flux density (B_y) were taken along the central part of the magnets, spanning the distance of two pole pitches.

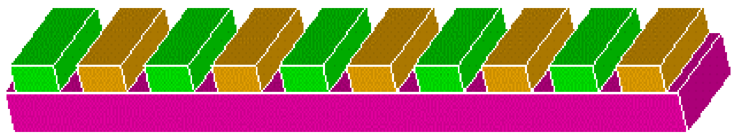


Fig. 5 - Permanent magnet poles on vehicle

At the different airgap lengths shown in Fig. 6, the results for the peak value of By are presented in Table I. For the airgap distance of 5 mm the B_y distribution along two poles is plotted on Fig. 7.

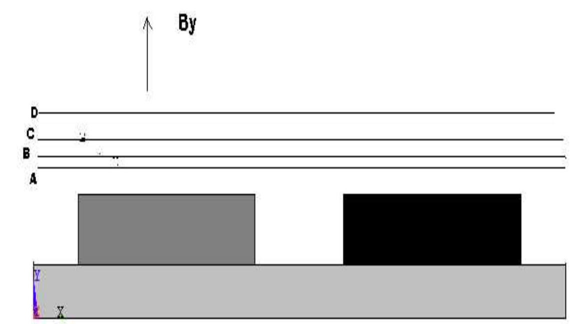


Fig. 6 - Planes for different airgap lengths

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.

TABLE I – PEAK VALUES OF MAGNETIC FLUX DENSITY

	A	B	C	D
B_y peak (T) (FEM)	0.33	0.29	0.23	0.16
By peak (T) (measured)	0.31	0.26	0.19	0.11

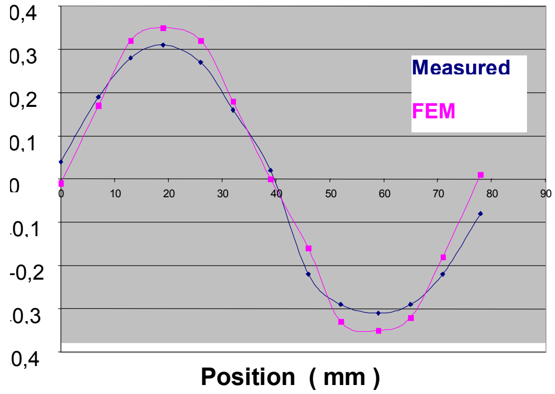


Fig. 7 - By distribution at 5 mm airgap length

The differences presented in the results above may be explained by the the fact that the simulations used the permanent magnet characteristics provided by the manufacturer. However, due to transportation limitations the permanent magnets were bought without being magnetized and were lately magnetized by a third party. The characterization of the magnetics are currently under way and the simulations will be repeated.

The same procedure was carried out for the armature winding which is shown in Fig. 8.

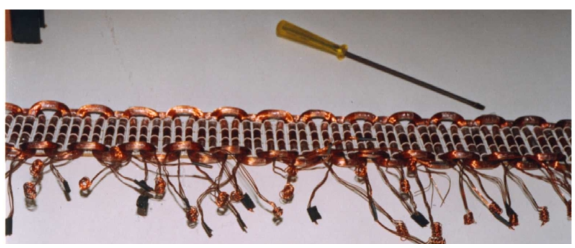


Fig. 8 - Armature winding

The measurement of the normal magnetic flux density B_y at a distance of 5 mm over a single coil, at the points indicated in Fig.9 gives the results shown in Table II. The values obtained at the same points with a 3-D FEM model (Fig. 10) are also presented.

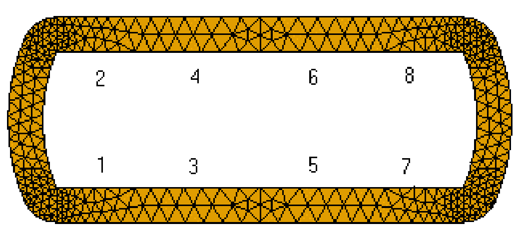


Fig. 9 - Selected points

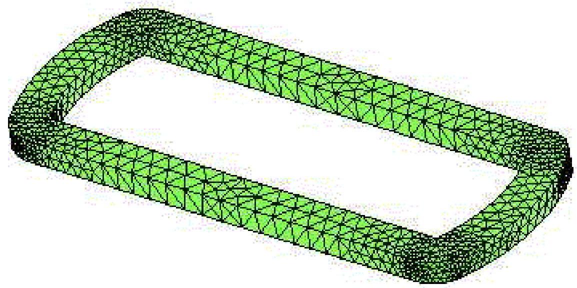


Fig. 10 - 3-D FEM model of a single coil

TABLE II –VALUES OF MAGNETIC FLUX DENSITY AT SELECTED POINTS

POINT	By (measured)	By (FEM)
1	0.40	0.47
2	0.42	0.49
3	0.37	0.41
4	0.38	0.43
5	0.41	0.41
6	0.40	0.43
7	0.42	0.47
8	0.40	0.49

3.1.2 Motor specification

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 III. 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. 11.

TABLE I II – SINGLE SIDED MOTOR SPECIFICATIONS

Data	
Number of poles	10
Frequency (Hz)	20
Synchronous speed (m/s)	1,56
Pole pitch (mm)	39
Airgap (mm)	5
Slot width (mm)	10
Tooth width (mm)	3
Number of slots/pole/phase	1
Number of turns	20
Number of phases	3
Armature resistance (Ω/m)	0.85
Synchronous reactance (Ω/m)	0.07

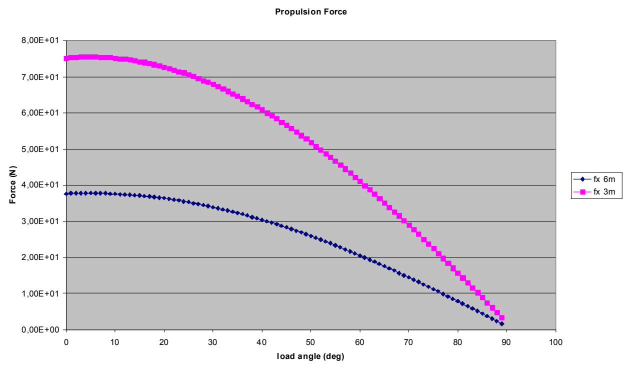


Fig. 11 - Propulsion force curves

Conclusion:

This paper presented the first steps in the development of a magnetic levitation train based on the superconducting quantum levitation principle. This prototype will serve as convincement for future financial support.

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