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A superconducting levitation vehicle prototype

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Abstract

This paper presents a small scale MAGLEV vehicle prototype which is under development at UFRJ. The levitation is done by Y–Ba–Cu–O superconducting blocks refrigerated by liquid nitrogen in the presence of Nd–Fe–B magnets. A long primary linear synchronous motor gives the traction. Design considerations and experimental results show the characteristics and performance of this system.

Keywords: MAGLEV; Linear synchronous motor; Superconducting levitation

1. Introduction

The need of high speed and non-polluting transportation systems has drawn the world attention to MAGLEV trains, that can travel at speeds of 500 km/h and use electricity as energy source. In Brazil, for instance, more than 90% of the electric power is generated in hydroelectric power stations, that are renewable energy sources.

For more than two decades, Germany and Japan have prototypes in real scale of MAGLEV trains. Germany uses the so-called electromagnetic levitation (EML) and Japan the electrodynamic principle (EDL) as well as EML, in another project.

In the last decade, improved high temperature superconductors (HTS), such as the melt-textured Y–Ba–Cu–O (YBCO), were developed. The YBCO presents superconducting state at temperatures below 92 K, which can be achieved within a liquid nitrogen bath (77.4 K). Such cooling material is easily obtained and cheap in comparison with liquid Helium, making feasible the construction of a new conception of MAGLEV trains. The basis for the vehicle levitation is the HTS diamagnetic response causing a repulsive force that appears between such blocks and permanent magnets distributed on the rail [1,2]. The strong pinning force in these blocks leads to self-stability, as already reported [3,4], and this fact represents an advantage in comparison with the other levitation schemes, but up today there is no commercial prototype of this train in the world. This technological opportunity must be studied and analysed for practical applications.

A laboratory prototype, that reproduces in small scale such solution, is now available at UFRJ and tests are being conducted to better understand the advantages and limitations of this technology. Design considerations and experimental results are presented in this paper.

2. Levitation rail

The levitation rails under study were built in a flux concentration scheme, as shown in Fig. 1, with the YBCO superconductors levitating over a rail assembled with permanent magnets and steel plates. The permanent magnets were assembled in an opposite magnetic dipole configuration and the YBCO blocks were placed inside a container in a liquid nitrogen bath.

The initial studies used Ferrite levitation rails (Fig. 2a), but the achieved levitation force was too modest for

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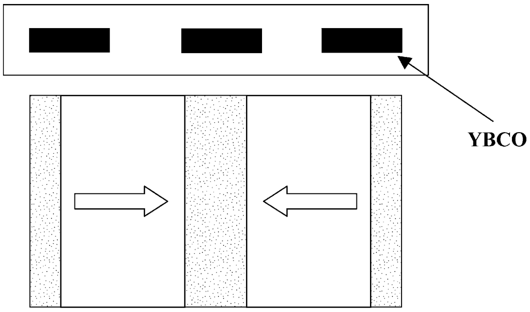

Fig. 1. Rail cross-section, showing the magnetic flux.

the proposed application. Therefore, now a levitation rail using NdFeB magnets is being considered.

Fig. 2b shows a photo of part of this new rail with two rows of $1'' \times 1'' \times 1/2''$ permanent magnets assembled in opposite dipole symmetry and separated and sided by the flux concentration scheme.

Figs. 2c and d show two other levitation rails that were studied. In Fig. 2c the steel concentrator is larger than in Fig. 2b. In Fig. 2d three rows of $1'' \times 1'' \times 1/2''$ permanent magnets were assembled.

Fig. 3 presents the measured z-component of magnetic flux density field for these configurations. As the magnetic flux and its gradient given by the configuration of Fig. 2b are the greatest ones, the levitation force will also be the biggest. Therefore this configuration was chosen for the prototype construction.

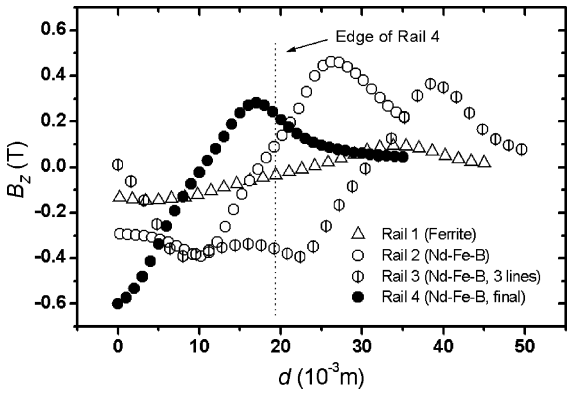

Fig. 3. Magnetic flux density.

3. Linear synchronous motor

The absence of any mechanical means for force transmission suggests the use of linear motors for the propulsion of magnetically levitated bodies. The inconvenience of sliding contacts at high speeds may be

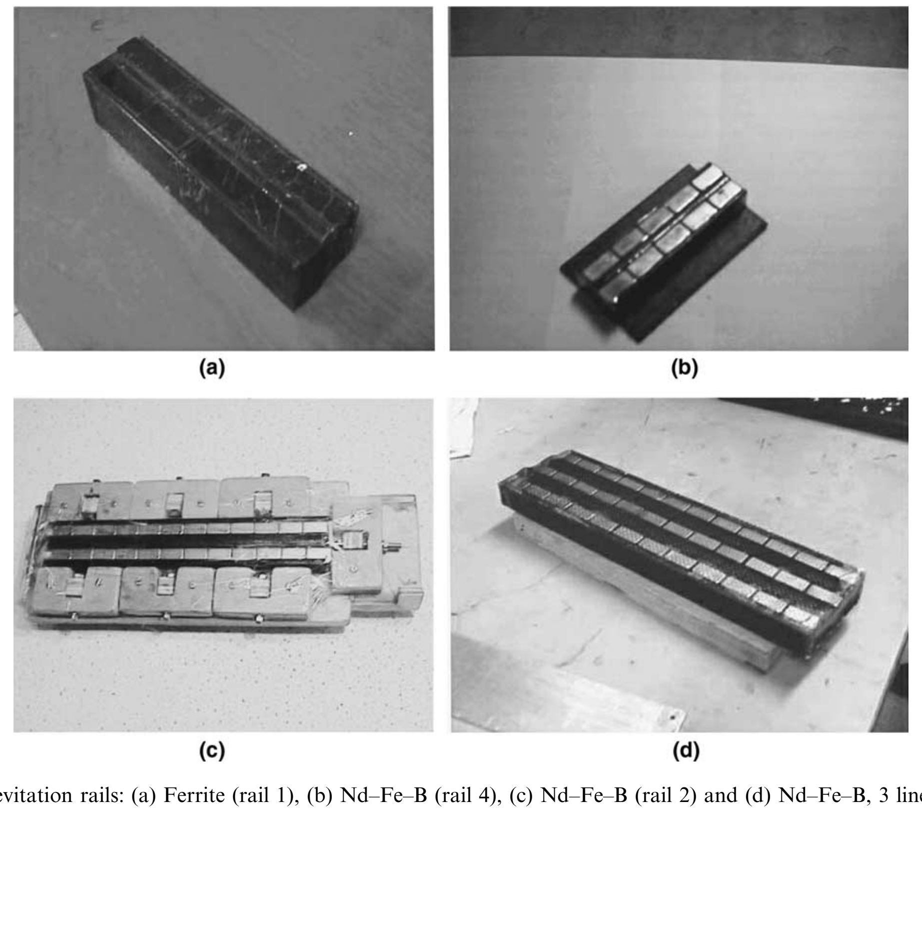

Fig. 2. Levitation rails: (a) Ferrite (rail 1), (b) Nd–Fe–B (rail 4), (c) Nd–Fe–B (rail 2) and (d) Nd–Fe–B, 3 lines (rail 3).

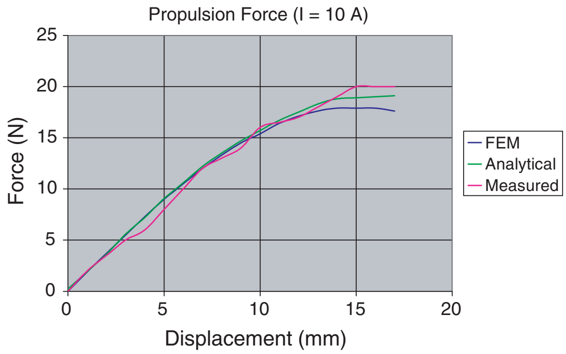

Fig. 4. Propulsion force for $I_a = 10.0$ A.

overcome with linear motors with long armature windings. After this choice, the linear synchronous motor (LSM) has advantages over the linear induction motor (LIM) since LSM can work with bigger air-gaps, is simpler to control and both have the same windings configuration.

The core of the linear motor design lies on the accurate calculation of the magnetic flux due to the armature and field windings. In this project a commercial finite element program is used [5].

A section of the rail described above, with 1 meter long armature winding and 4 poles of NdFeB permanent magnets on vehicle, was tested in order to validate the design procedures and parameters estimation through analytical expressions and calculations using the finite element method [6,7]. Measurements of traction force were made and compared with the results expected from the design equations and finite element model (Fig. 4) showing good agreement. Iron losses, saturation and air fiction were neglected. Magnet permeability was approximated to μ_0 (air).

4. Conclusion

The proposed system of a new MAGLEV train presents good technical characteristics. From an economical point of view, with the increase in production of permanent magnets and superconducting blocks, there are promising perspectives of costs decrease. In the near future, new tests will be conducted with the laboratory prototype and a convincing effort will be done for the construction of a real scale prototype.

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