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To cite this article: G G Sotelo *et al* 2014 *J. Phys.: Conf. Ser.* **507** 032017

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MagLev Cobra: Test Facilities and Operational Experiments

G.G. Sotelo¹, D.H.N. Dias¹, R.A.H. de Oliveira², A.C. Ferreira², R. De Andrade Jr.², R.M. Stephan²

1- Fluminense Federal University – UFF
Escola de Engenharia, Rua Passo da Pátria, 156, Bl. E, Sala 431. CEP.: 24210-240,
Niterói-RJ, Brazil.

2- Federal University of Rio de Janeiro – UFRJ
Centro de Tecnologia, Cidade Universitária, PO box 68553, 21945-970, Rio de
Janeiro, Brazil

E-mail: gsotelo@id.uff.br, dhndias@id.uff.br, raholiveira@ufrj.br, ferreira@ufrj.br,
rubens.andrade@ufrj.br, richard@dee.ufrj.br

Abstract. The superconducting MagLev technology for transportation systems is becoming mature due to the research and developing effort of recent years. The Brazilian project, named MagLev-Cobra, started in 1998. It has the goal of developing a superconducting levitation vehicle for urban areas. The adopted levitation technology is based on the diamagnetic and the flux pinning properties of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) bulk blocks in the interaction with Nd-Fe-B permanent magnets. A laboratory test facility with permanent magnet guideway, linear induction motor and one vehicle module is been built to investigate its operation. The MagLev-Cobra project state of the art is presented in the present paper, describing some construction details of the new test line with 200 m.

1. Introduction

The requirement of efficient transportation systems, silent, non-polluting and with competitive construction costs is one of the priorities of crowded cities, where nowadays great part of the world population lives. One potential solution for this problem is the superconducting MagLev technology, which is based on the diamagnetic and flux pinning properties of High Temperature Superconductor (HTS) bulk blocks of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) in the interaction with Nd-Fe-B permanent magnets. Recently, commercial cryostats with HTS were designed for levitation, contributing for the evolution of the superconducting MagLev technology [1]. Also, the development of high quality Nd-Fe-B and their optimized arrangement in a permanent magnet guideway (PMG) made possible to build linear superconductor magnetic bearings (LSMB) able to levitate high level loads, weighting more than 1 ton [2]. Groups from Brazil [2-3], Germany [4] and China [5] have given important contributions in this field. In special, the Brazilian technology, known as MagLev-Cobra, proposes a full scale vehicle with multiple short units, allowing curves of 50 m radius, ramps of 10% and velocities up to 70 km/h. The MagLev-Cobra can run silently inside cities on elevated structures. For the vehicle traction, a linear induction motor (LIM) is used, whose geometry also contributes to increase the levitation force. Some experiments for the designed LIM are presented here. Finally, this paper shows construction details of the new full vehicle prototype and the 200 meters long test line.

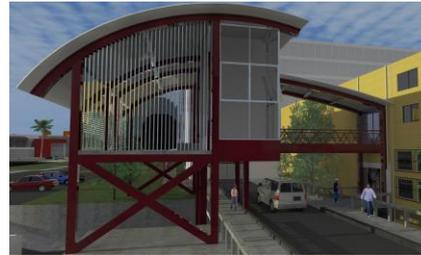


2. Vehicle design and construction

The MagLev-Cobra vehicle design consists of small modular units having 1.5 meters length and 2.4 meters width. These modules can be arranged to fit any specific necessity. The new test line is 200 m long and it is under construction to connect two buildings at the Technology Center (CT) inside the university campus. Figure 1 shows the foundations of a terminal station and Figures 2 (a) and (b) present architectural drawings of this line.



Figure 1. Foundations of a terminal station



(a)



(b)

Figure 2. Architectural drawings

The vehicle will have four modules. The perspective view of the designed vehicle is presented in Figure 3, and the actual stage of the vehicle under construction with light fiber reinforced plastic materials is presented in Figure 4. This prototype was planned to carry comfortably 30 passengers.

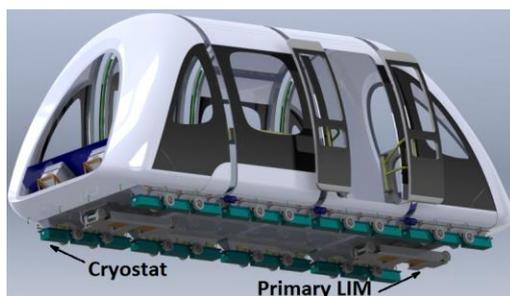


Figure 3. Designed MagLev-Cobra vehicle prototype.



Figure 4. Actual stage of construction of the vehicle.

3. Linear Induction Motor

The designed LIM windings were designed to form a double inverted C configuration (Figure 5). This configuration contributes to the levitation force, since there is an attraction between the stationary and mobile parts besides the propulsion force. The main parts of a LIM are the primary (containing the 3 phase windings) and the secondary (made by laminated iron and short-circuited conducting bars, similar to a squirrel cage rotor). Each vehicle has two short primary windings coupled to the vehicle and the secondary is distributed along the way (long secondary). This solution was chosen because of

the lower manufacture cost. The two primary modules work independently, but they are synchronized by sensors installed at the train that gives the control signals for each motor drive. To power supply the primary collecting brushes are used.

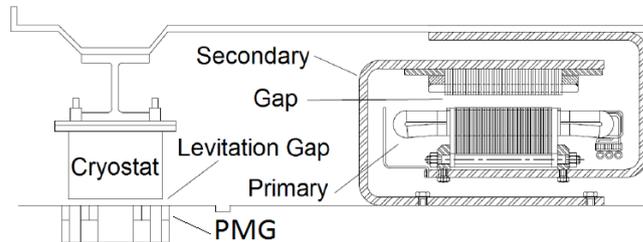


Figure 5. Cross section of vehicle bottom showing the levitation system (cryostat plus PMG) of one side and the inverted C geometry LIM.

The LIM develops a traction force (F_x), responsible for the movement, and a normal force (F_n). The traction force F_x is generated by the interaction between the induced current in the secondary with the travelling field in the air gap. The normal force existing in the LIM is the result of the magnetic flux crossing the air gap and has two components. The first component F_{na} is the electromagnetic attractive force between the primary and the secondary iron core and the second component is the electrodynamic repulsion force F_{nr} between the moving primary and secondary FMM. The repulsive force F_{nr} can be disregarded, since the vehicle operates at low speed. So, F_n improves the levitation gap during the acceleration due the inverted C configuration.

The attraction force was measured by installing a load cell between the ground and the primary of the linear motor. For this test, the longitudinal movement is blocked by a steel cable anchored in the wall. The test adopted the air gap of 8 mm. The frequency varied between 1 Hz to 5 Hz and V/f ratio was kept constant. The attractive force reaches approximately 3000 N, as presented in Figure 6.

Figure 7 presents the operational test of one vehicle module. To evaluate the levitation gap fluctuation during this operational test, ultrasonic position sensors were installed on the vehicle base. Those sensors can give the gap variation with a precision of 0.1 mm. Also, an optic sensor was used measure its velocity. In this test the vehicle was accelerated from standstill and it was brought back again to standstill. For the acceleration, the supply frequency was increased from 0 Hz to 5 Hz with a constant V/Hz relationship. The braking procedure used a combination of regenerative braking with 0.5% direct current component. The acceleration of the vehicle produces an attractive force between the secondary and primary of linear motor as expected.

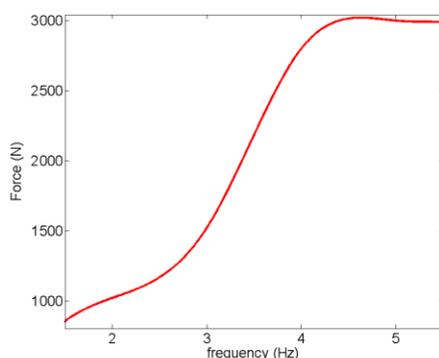


Figure 6. Static force measurement as a function of supply frequency.

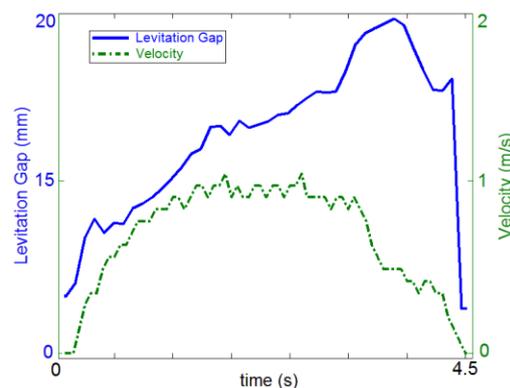


Figure 7. Levitation gap and velocity results during operational tests.

The laboratory tests have the objective to quantify the generated energy during regenerative braking. The tests were realized in a 6 m length ramp. The results were obtained for 1000 kg mass and the inclination of 15 %. The air gap for this experiment is 8 mm. Deceleration is obtained changing the frequency to lower values until stop. A frequency pattern was imposed for the operation as shown in Figure 8. These tests allow the determination of the system regenerative capacity. The DC link voltage and motor AC rms current are presented in Figure 9. It is possible to observe an increase in the DC link voltage during deceleration. The regeneration can also be observed by the DC link current, whose signal is negative during regeneration, as presented in Figure 10, that shows the negative current (in red) has low values of amplitude and duration ($\sim 7.8 \text{ s} \leq t \leq 8.3 \text{ s}$) due to the short test track (6 m).

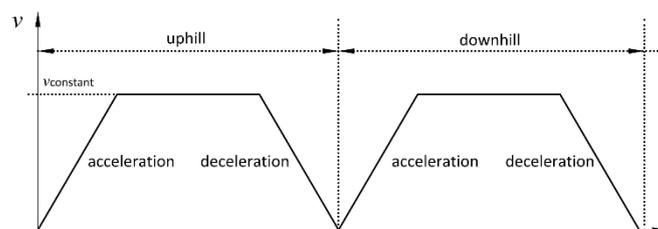


Figure 8. Trapezoidal trajectory used in the experiments.

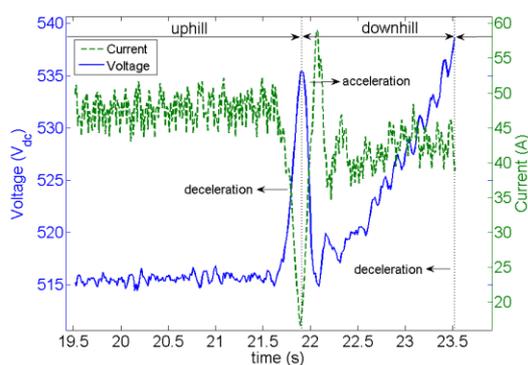


Figure 9. DC link voltage and motor current during a test with 1000kg and 15% ramp.

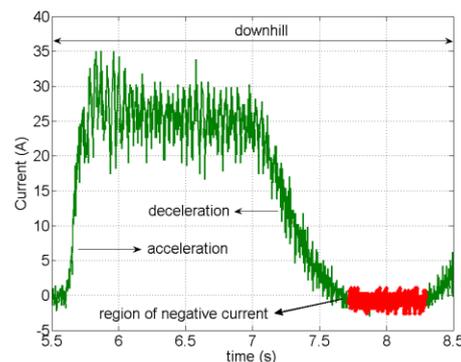


Figure 10. DC link current during regeneration.

4. Conclusions

This paper reported the state of the art of the first full scale superconducting magnetic levitation train prototype, named Maglev-Cobra. The prototype linear induction motor was tested, presenting regenerative braking and levitation gap increase during operation. The daily operation of this system in a 200 m test line is expected to start in September 2014, by the time of the 22nd International Conference on Magnetically Levitated Systems and Linear Drives.

5. References

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Acknowledgments

Authors wishing to acknowledge financial support from the Brazilian agencies: CAPES, CNPq, FAPERJ and BNDES.