Linear Superconducting Magnetic Bearing for Urban Transportation

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Abstract

This paper describes the evolution and perspectives of the Superconducting Magnetic Levitation (SML) method, based on High Critical Temperature Superconductors (HTS) and Rare-Earth Permanent Magnets, to reach commercial application for urban transportation. All the results showed in this article were obtained by tests made on the Maglev-Cobra track at the Federal University of Rio de Janeiro (UFRJ).

Keywords: *Magnetic Levitation, MagLev, Superconducting Magnetic Levitation, Urban Public Transportation.*

1. Introduction

The same magnetic forces that allow the construction of Magnetic Bearings of rotating machines can be applied for linear movements and transportation systems. But the physical arrangements and propulsion alternatives deserve special attention, justifying a dedicated research area.

There are three levitation methods applied in Magnetically Levitated (MagLev) vehicles: Electrodynamic Levitation (EDL), Electromagnetic Levitation (EML), and Superconducting Magnetic Levitation (SML) (Moon, 1994). The EDL method uses repulsion forces and is well fitted for high-speed operation (> 500 km/h) and not for urban transportation. The EML method is based on the attraction force between an electromagnet and ferromagnetic materials. The resulting system requires feedback control to achieve stable operation. Five urban EML-MagLev systems are already in commercial operation: Nagoya, Japan, since 2005 – Seoul, South Korea, since 2016 – Changsha, China, since 2016 – Beijing, China, since 2017 - Hunan, China, since 2022. But there is no SML Vehicle in commercial use, which opens an opportunity for innovation in Urban Public Transportation.

The present paper describes the efforts to turn the SML-MagLev Technology into a commercial product applied to urban mobility. Since nowadays more than 50% of the world population live in cities, and in many countries of Europe, South and North America this share is higher than 80%, there is a promising potential market.

2. The Superconducting Magnetic Levitation (SML) Vehicle MagLev-Cobra

The SML method depends on High Temperature Superconductors (HTS) and Rare Earth Permanent Magnets. These materials were developed at the end of last century and made commercially available only at the early 2000. The main advantage in comparison with the EML method is the stable operation, which increases the reliability and simplicity, opening great opportunities for urban transportation. The SML MagLev-Cobra project (Stephan and Pereira, 2020) reached Technology Readiness Level TRL07 (European Association of Research and Technology Organizations, 2014) in 2019, but COVID-19 imposed a development gap (Fig. 1).

The evolution of the MagLev-Cobra Project is registered in papers published since year 2000 in the International Conference on Magnetically Levitated Systems and Linear Drives (MAGLEV), a worldly recognized conference devoted to the subject (Nicolsky, et al., 2000, 2002; Motta, et al., 2008; Stephan, et al., 2004, 2006, 2008, 2011, 2016, 2018, 2022).

The step to reach TRL08 in October 2023 and the plan to reach TRL09 by 2025 will be described in the following.

2.1 A Reliable Vehicle

An industrialized vehicle, with reliable operation, including doors, air conditioning, comfortable seats, energy supply, emergency breaking and exits belong to the fundamental components of a commercial product. To reach these demands, a partnership has been established with Aerom, a company that has large experience in the fabrication of wagons for urban mobility. Figure 2 shows some details of the new vehicle.

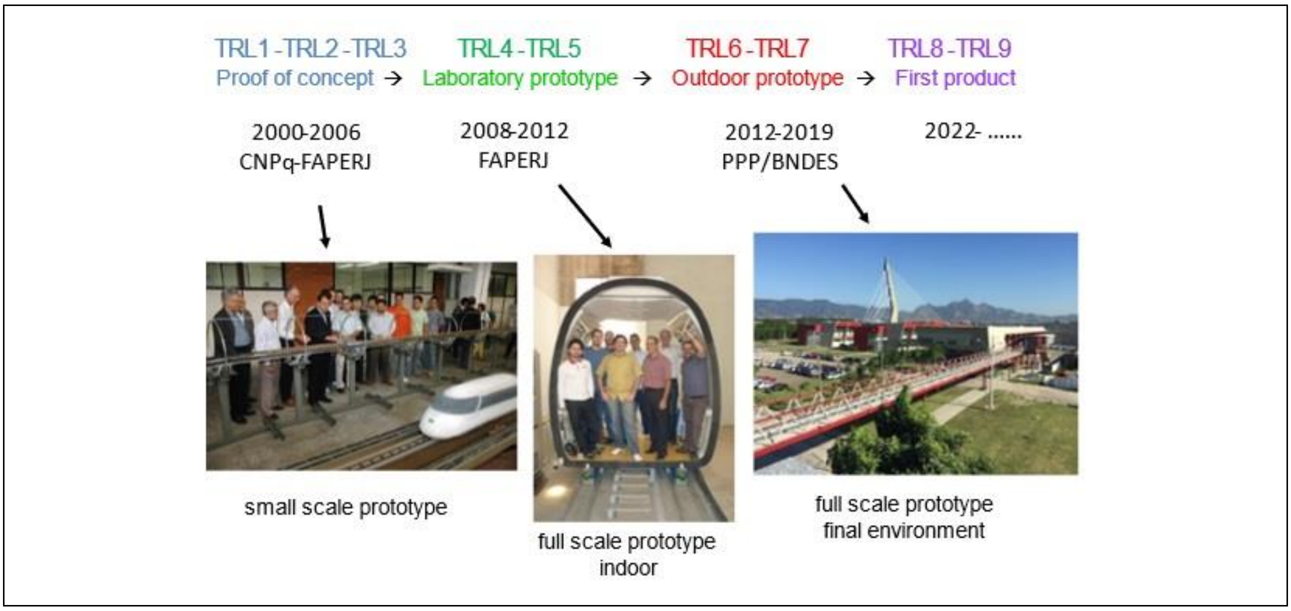

Figure 1 The MagLev-Cobra project measured with the TRL scale.

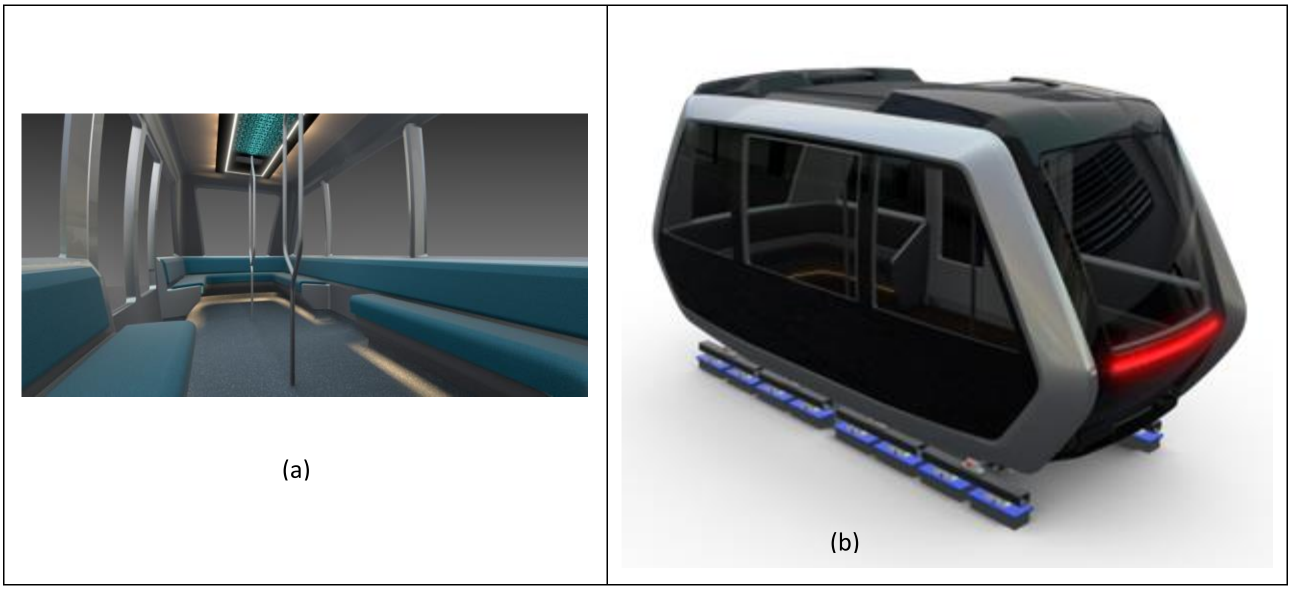

Figure 2 The new MagLev-Cobra design: (a) internal view (b) external view.

The new vehicle proposal is aligned with a modern design and the technological appeal that this technology deserves. The commissioning of the new MagLev Cobra is scheduled to the beginning of October 2023. After that, a fully automated operation will be delivered to the University (UFRJ). This will be the first in the world to offer regularly this kind of transport (SML-MagLev) for employees, students and visitors.

2.2 An Adequate Traction System (Linear Motor)

The linear motor was also improved following Oliveira's (2020 a, 2020 b) Ph.D. research thesis. It is a short primary linear induction machine with aluminium conducting sheets and back iron secondary. The primary is installed under the wagon while the secondary lays along the track (Figure 3).

The new configuration has turned the motor easier to produce and cheaper than the first one, overcoming the upper limit on the vertical movement imposed by the C configuration of the former linear motor (Oliveira 2020 a, 2020 b).

2.3 A Protected Magnetic Rail Infrastructure

One of the main problems observed during 5 years of external operation (TRL 06 – 07) was the oxidation of the magnetic rails. As the magnets weren't completely protected against rain and sun light exposition, micro cracks allowed the penetration of water inside the rails, giving environment conditions for oxidation. To overcome this difficulty, a protective painting based on Zn was successfully applied, but some magnets had already suffered a magnetization loss from circa 0.4 T. This reflected on the levitation height, as will be seen with the measurement results. A new magnetic rail is under development, this time fully protected against water.

2.4 An Automated Operation

The vehicle operation must be autonomous. This is practically the standard of urban transportation that plays a crucial role in modern cities, providing means for people to move around efficiently and effectively. The transportation system must be reliable and able to handle the volume of people using it, without causing significant delays or overcrowding. This can be achieved by optimizing routes and schedules, ensuring that buses, trains, and other modes of transportation arrive and depart on time. An autonomous system is under development and planned to be fully tested by the end of this year.

Figure 3 The new Induction Motor 200 meters long secondary made with Aluminium sheets and back iron.

3. Measurements

For the reliable operation of MagLev vehicles, the levitation height is an important information to ensure some safety level and reliability once the vehicle does not touch the ground. In the case of SML, since there is no closed loop control of the levitation height, and the system regulates itself as result of the interaction between the refrigerated superconductor materials and the magnet rails, this information plays an important role. Therefore, for each wagon, four ultrasonic type position sensors were installed, as shown in Figure 4.

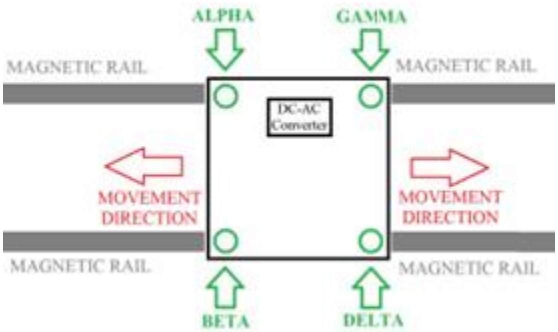

Figure 4 The four levitation height position sensors (alpha, beta, gamma, delta).

The height sensors installed on the wagon are ultrasonic sensors developed by the manufacturer Balluff with a range between 30 and 400 mm. They have the facility of restricting the acquisition range for more precise measurements. In this case, the range has been reduced to 30 up to 80 mm. As an example, Figure 5 shows the behavior of the beta and gamma sensors, which are located at opposite vertices of the wagon's diagonal.

The test trips were carried out in free fall along the test line. This is possible because one end of the test track is higher than the other. Since there is no friction due to levitation, only the force of gravity moves the wagon. In this way, the two trips present the same travelling time, except for the moment when the inverter is activated to brake the vehicle. The figures show the variation in levitation height over two trips. As can be seen, the profile is similar throughout the entire time (for the same sensor) except when the inverter is activated, which causes noise in the signal and alters the final travel time. In addition, the beta sensor had average height variations between 44 and 53 mm, while the gamma ranged between 47 and 56 mm.

Figure 6 presents a velocity test run. The data were obtained with a retro-reflective photoelectric sensor that allows the velocity measurement without contact. Based on this information, by integration, it will be possible to determine the vehicle position. This will be an input for the automation system.

4. Conclusion

This paper was prepared during the first semester of 2023, in the middle of the efforts that will allow the MagLev Cobra Vehicle to start daily operation, in October, connecting two stations (200 meters apart) in the Campus of the Federal University of Rio de Janeiro (UFRJ). If we succeed, it will be the first SML-MagLev System in the world to reach TRL08. The next step, the TRL09 level, will require a line, at least 1 km long, to test operation in ramps, curves and at speeds of 50 to 70 km/h. For that, a technical and economic feasibility study is on the verge to be concluded. This proposal will still be in UFRJ Campus, but, this time, connecting the University Technological Center, mainly devoted to the education of engineers, to the Technological Park, where companies like Siemens, Ambev, FMC, GE, Vallourec, Halliburton, Schlumberger, Tenaris, Suez, have installed research centers. With this second step, we will contribute to turn the UFRJ Campus in an example of a city of the future.

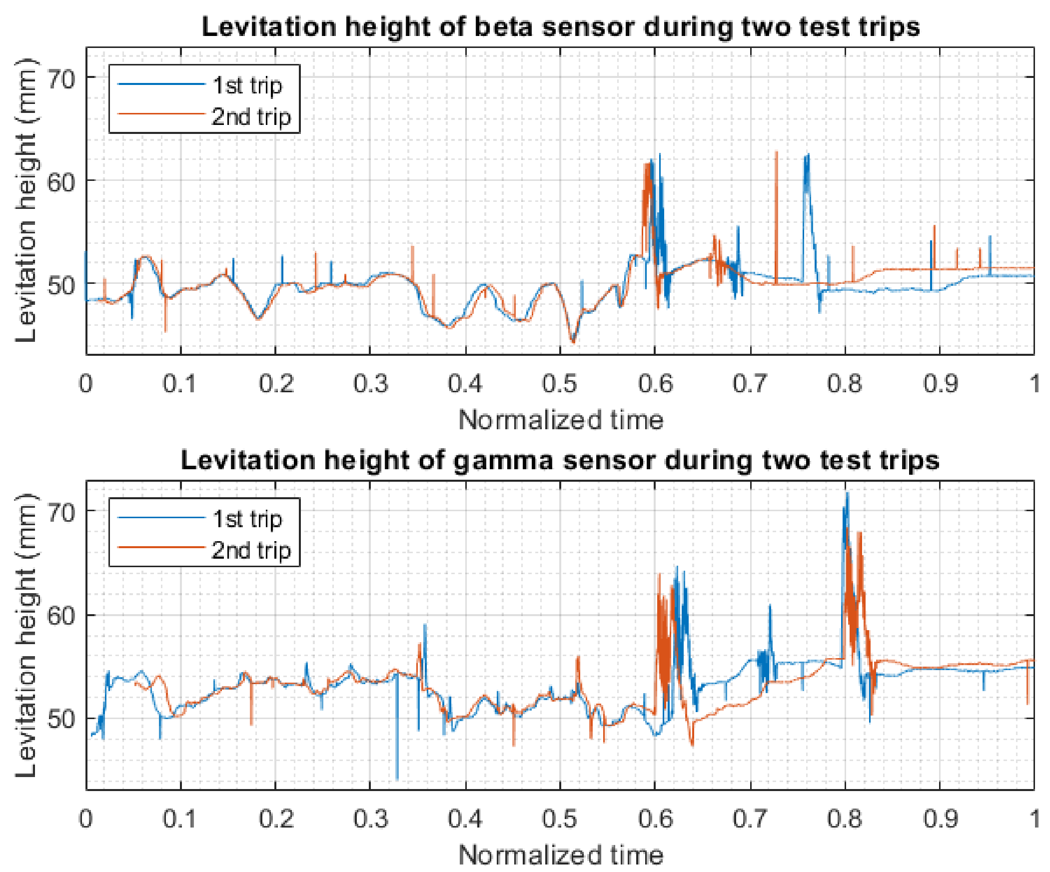

Figure 5 Levitation height measurements during two test ride.

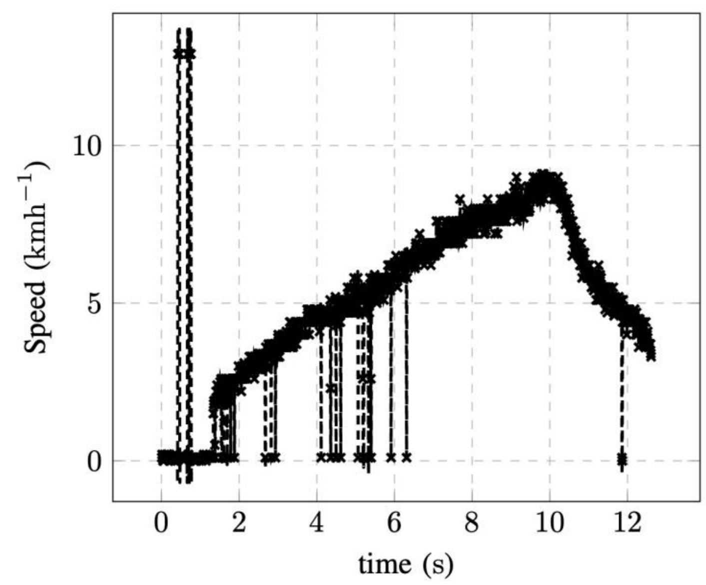

Figure 6 A velocity test run.

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