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Dynamical tests in a linear superconducting magnetic bearing

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Abstract

The unique properties of high critical temperature superconductors (HTS) make possible the development of an effective and self-stable magnetic levitation (MagLev) transportation system. In this context, a full scale MagLev vehicle, named MagLev-Cobra, has been developed at the Laboratory for Applied Superconductivity (LASUP/UFRJ). The vehicle is borne by a linear superconducting magnetic bearing (LSMB). The most important design constraint of the levitation system is the force that appears due to the interaction between the HTS and the permanent magnetic (PM) rail, which composes the LSMB. Static and dynamic characteristics of this force must be studied. The static behavior was already reported in previous work. The dynamic operation of this kind of vehicle, which considers the entry and exit of passengers and vibration movements, may result in the decrease of the gap between the superconductor and the PM rail in LSMB. In order to emulate the vehicle operation and to study the gap variation with time, the superconductors are submitted to a series of vertical displacements performed with the help of an experimental test rig. These movements are controlled by a time-variant reference force that reproduces the vehicle dynamic. In the present work, the results obtained for the dynamic gap behavior are presented. These measurements are essential to the commissioning process of a superconducting MagLev full scale vehicle.

1. Introduction

Since the discovery of High Temperature Superconductors (HTS) the interest in the in the application of these materials has increased. Among the various applications there are the superconducting magnetic
levitation (MagLev) systems. Due the unique properties of HTS is possible to develop an effective and self-stable superconducting MagLev transportation system [1]-[3]. In this context, the Laboratory for Applied Superconductivity (LASUP) of Federal University of Rio de Janeiro (UFRJ) is developing a full scale MagLev vehicle named Maglev-Cobra [4].

The proposed Superconducting MagLev vehicle is borne by a linear superconducting magnetic bearing (LSMB). The LSMB is composed essentially by HTS bulks, which are accommodated inside a cryostat, and a permanent magnetic (PM) rail. One of the most important parameter of the levitation system is the force that appears due to the interaction between the HTS and the PM rail. Thus, for proper development of such a vehicle it is necessary to study the static and dynamic behavior of the levitation force. The static behavior of this force in a LSMB has already been extensively studied in previous work [5]-[7]. The oscillations of a permanent magnet above HTS samples have been studied by different authors [8], [9]. However, none of this shows the influence of this oscillation in the levitation gap. The dynamic operation of this kind of vehicle, which considers the entry and exit of passengers and vibration movements, which can also be caused by inhomogeneous magnetic field along the rail, may result in the decrease of the gap between the superconductor and the PM rail in LSMB. The vibration movements can also be produced by the inhomogeneous magnetic field along the PM rail [10].

In this work the dynamic gap behavior during a real operation of a Superconducting MagLev vehicle is investigated. The measurements are performed by way of an experimental rig, which is able to reproduce the operational conditions of this system. A series of vertical oscillations are imposed and the gap variation between the cryostat and the PM rail is monitored through an ultra-sonic position sensor. These movements are controlled by a time-variant reference force that reproduces the vehicle dynamic. The results presented here are essential to the commissioning process of a superconducting MagLev full scale vehicle.

2. Experiment Setup

As it was described in the previous section, during the real operation of a superconducting MagLev vehicle, the onboard HTS bulks confront a variation on the load. In order to emulate this situation, an experimental rig showed in Fig. 1 was used. This equipment is able to perform vertical (z direction) movements and also to measure the magnetic levitation force between the HTS and the PM rail, through a six-axis force transducer [11]. The gap is monitored by an ultra-sonic position sensor with a measurement range of 30–300 mm, and with a precision of 0.02 mm.

![Fig. 1. Measurement system. The six-axis force transducer, cryostat, PM rail and the position sensor are indicated.](image-url)
The LSMB used in this experiment is composed by a cryostat (Fig. 2(a)), which has 24 three seeded YBCO bulks with a final size of 32 mm x 64 mm x 12 mm inside, and a magnetic rail. The magnetic rail is mounted using Nd-Fe-B PM blocks with a perpendicular section of 50 mm x 50mm and 50 mm x 25mm, arranged in a mixed Halbach and flux shaper configuration. The magnetic rail cross section is showed in Fig. 2(b).

Fig. 2. Details of the (a) cryostat and (b) the cross section of the PM rail. The units are in millimeters.

2.1. Measurement procedure

The control system is performed in order to make the measured force following a time-varying reference. This force reference is adjusted to well reproduce the vehicle dynamic. The measurements were done with the superconducting transition in the presence of magnetic field (field cooling - FC). This cooling process is performed with the superconductor near to the PM rail in a certain cooling high (CH). The ultra-sonic position sensor was fixed on the PM rail to collect the displacement data.

The dynamic tests were conducted using two different procedures. For the first one, the cryostat is positioned in a CH of 35 mm and it is filled with Liquid Nitrogen (LN2). After that, the system starts its movement and conduct the cryostat closer to the PM rail until the measured force reaches a reference value of 1900 N. From this stage, the cryostat starts to oscillate with amplitude of 100 N. This first pattern can be seen in figure 3(a). The second dynamic test was conducted almost the same way. The big difference between them is that the reference force is replaced by two distinct values and the cryostat, after the approach movement, oscillates around two reference values, as shown in Figure 3 (b). This test is more complex than the first one and reproduces not only the vehicle vibrations as well the entry and exit of passengers.

To compare the dynamic behavior with the static one another type of measurement was performed. As in the previous tests, the cryostat was firstly filled with LN2 in a CH of 35 mm. Then, the system start to move the cryostat until the measured force reaches a value of 1900 N and it stops. Due to the flux-creep effect, the levitation force starts to decrease [12]. The system compensates this decay approaching the cryostat to the PM rail keeping the measured force always equal to the reference force. This procedure reproduces the static force behavior resulting in a reduction of the levitation gap.
3. Results and Discussions

Figures 4 and 5 show the comparison between the levitation gap decay, obtained from the first dynamic test (blue curve), and the results obtained due the flux-creep effect (red curve). As one can observe, the levitation gap decay are similar in both situation. With the exception of oscillating movements, the final gap after a period of approximately 2 hours is the same. According the graphic, for this first dynamic test, the decrease obtained for the gap was 7%.
Figure 6 shows the results obtained for the second dynamic test. This test is more complex than the first one. It considers the entry and exit of passengers in the vehicle by varying the value of reference force as shown in figure 3(b). The sudden change of load makes the trapped magnetic flux in the superconductor vary considerably altering the behavior of the levitation gap decay. For this reason, the comparison with the results obtained due the flux-creep effect, as showed for the first test, is not appropriate in this case. However, it can be seen from the graph that the levitation gap decreases was 9%. This represents a difference of only two percentage points over the first test. This proves that the system has the ability to maintain the levitation gap due its strong stiffness.
4. Conclusions

This work focused in the real operation of a superconducting MagLev vehicle. The dynamic operation of such a vehicle, which considers the entry and exit of passengers and vibration movements, may result in the decrease of the levitation gap. In order to analyze this decrease were performed two different dynamic tests and a static one. For the dynamic tests, the cryostat is submitted to oscillations around a reference force, which can assume different values. For the static test, the system keeps the measured force always in the same value of the reference force. The levitation gap for all the measurements are storage and analyzed.

The results showed that the levitation gap, for the first dynamic test, decreases at the same rate when compared with the static one. The second dynamic test showed a more complex levitation gap behavior. However, it is possible to say that the gap decrease is no more drastic than the previous one. Thus, one can conclude that the vertical movements produced by the dynamic operation of a MagLev vehicle do not represent a serious complication in terms of the levitation gap decay.

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