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Studies on the levitation height decay of the high temperature superconducting Maglev vehicle

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Abstract

The levitation height decay was found in the high temperature superconducting (HTS) Maglev test vehicle system during man-loading running. Experimental results show that the no-load levitating system would drift to a new equilibrium position by the external loaded history, but the new equilibrium position will almost not drift by the second-round same loaded history. A new method is proposed to improve the stability of the HTS Maglev vehicle, that is, a pre-load was applied to the HTS Maglev vehicle before running. The impulse responses are performed on the HTS Maglev vehicle before the pre-load and after the pre-load. The results show that the pre-load method is considerably effective to improve the stiffness and damping coefficient of the HTS Maglev vehicle. Moreover, it helps to suppress the levitation height decay and enhance the stability of the HTS Maglev vehicle in practical operation.

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Keywords: High temperature superconductor (HTSC); Maglev vehicle; Levitation height; Pre-load

1. Introduction

Due to the unique flux-pinning effect of high temperature superconductor (HTSC), the high temperature superconducting (HTS) Maglev system is self-stable without active control, which makes the superconducting magnetic bearing (SMB) [1] and HTS Maglev vehicle [2,3] be considered as two of the most potential applications. Much work has been done to improve the performances of the current HTS Maglev system, including the fabrication of the high performance HTSC material [4], the optimization of the permanent magnet guideway (PMG) [5], the extensive investigation on the static interaction force between bulk HTSC and permanent magnet [6], the enhancement of the stiffness, damping coefficient, load capability [7], and the dynamics stability [8].

Since the first man-loading HTS Maglev test vehicle was successfully developed in 2000, over 27,000 passengers have taken the vehicle [9]. During the man-loading running, the levitation height decay in the vehicle was found to be similar to the SMB under load. As well known, the levitation height decay results from the hysteretic characteristics of the HTSC [10]. As shown in Fig. 1, there is a typical large hysteresis loop in levitation force-gap curves of bulk HTSCs in No. 2 onboard liquid nitrogen vessel tested on July 22, 2004. As early as in 1988, Brandt has found the existence of a range of stable levitation positions at a single given force for the HTS Maglev system [11]. The levitation height decay will weaken the stability of the vehicle, which may cause the shake, even excursion to the vehicle, especially, as the passengers get on or off the vehicle. So it is significantly necessary to suppress the levitation height decay.

The super-cooling and the pre-loading methods have been successfully used to suppress the rotor gradual fall in SMB [12–14]. However, little work was done to suppress the levitation decay in the HTS Maglev vehicle

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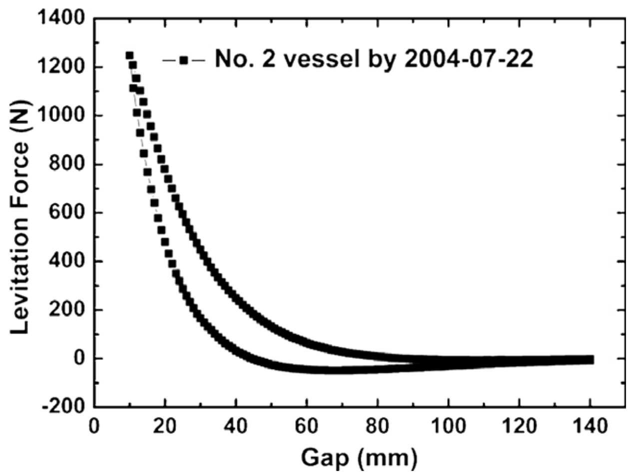

Fig. 1. The hysteretic levitation force–gap curve of bulk HTSCs in No. 2 onboard LN2 vessel tested on July 22, 2004.

system. A maximal pre-load is introduced to apply to the HTS Maglev vehicle before running. Experimental results show that the pre-load method is considerably effective to suppress the levitation height decay and enhance the stability of the HTS Maglev vehicle with higher stiffness and damping coefficient, which is helpful for the HTS Maglev vehicle in practical operation.

2. Experiments

All the experiments are performed on a simplified HTS Maglev vehicle model, as shown in Fig. 2. The vehicle model is 0.8 m in length, 1.2 m in width and 0.35 m in height. The total weight of the model (including the vessels with liquid nitrogen) is 45 kg. The two on-board liquid nitrogen vessels on each side of the model are the cryogenic equipments employed in the first man-loading HTS Maglev test vehicle [15], which is 0.576 m in length, 0.15 m in width and 0.168 m in height. There are 43 cylindrical melt-textured YBaCuO bulk HTSCs in each vessel, which is 30 mm in diameter and 17 mm in height.

Fig. 2. The photo of the simplified HTS Maglev vehicle model in levitating.

At the beginning of the experiment, the vehicle model with the on-board vessels was fixed above the center of the PMG symmetrically. Then, the bulk HTSCs in the vessels were cooled at field cooling height (FCH) 30 mm which is taken as the optimal FCH in dynamics concluded from the free vibration experiments of the vehicle model [16]. When the bulk HTSCs were cooled completely, the vehicle was set down, and then it was freely levitated over the PMG at an initial working height (WH).

2.1. Pre-load experiment

A pre-load was applied to the HTS Maglev vehicle before the running to improve the stability of the HTS Maglev vehicle, as shown in Fig. 3.

When FCH was 30 mm, the initial WH was 27.75 mm which is the average levitation height of the vehicle between the bottom of the vessel and the surface of the PMG. Then the pre-load was added to the vehicle step by step, 10 kg every time. The new WH was measured after each loading. For the HTS Maglev vehicle, the ideal levitation height is thought as the range from 10 mm to 15 mm, so the maximal pre-load is 130 kg, when the levitation height is 14.25 mm. Then the vehicle model was unloaded, and it returned to a new equilibrium position. The new levitation height was reduced to 19.75 mm. Subsequently, the same loading process was repeated. After the second-round load of 130 kg, the levitation height was reduced from 19.75 mm to 13.25 mm. Then the vehicle was unloaded again, the levitation height restored to 18.75 mm, as shown in Fig. 4 and Table 1.

2.2. Impulse response

The impulse responses were performed on the vehicle model both before and after the pre-load to validate the effect of the pre-load.

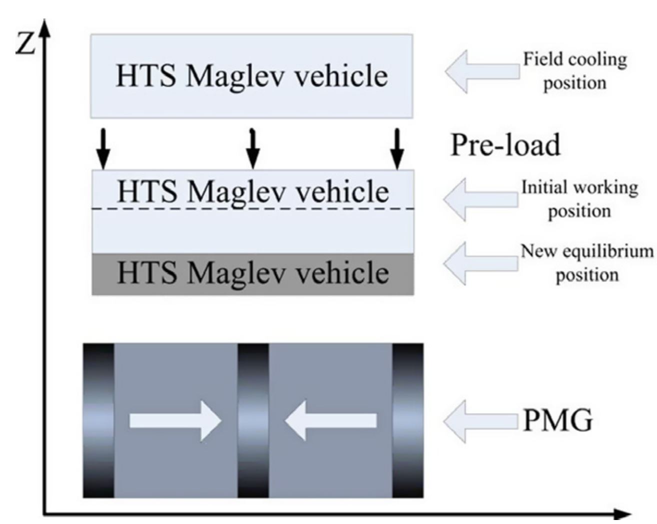

Fig. 3. The schematic diagram of the pre-load experiment.

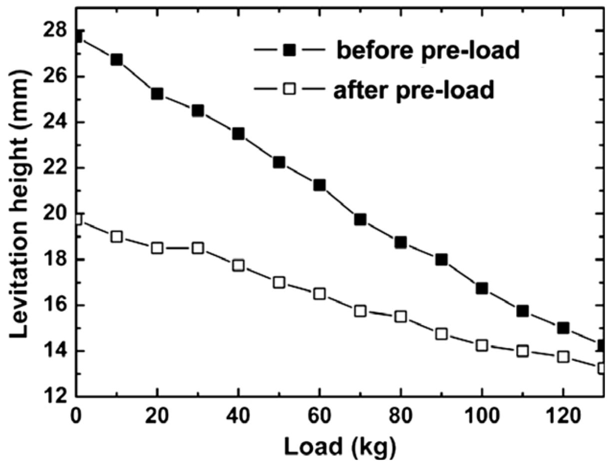

Fig. 4. The levitation height dependence on the load.

Table 1
The decrement of the levitation height after loaded history

Pre-load	L_0 (mm)	L_1 (mm)	L (mm)
No	27.75	19.75	8
Yes	19.75	18.75	1

L_0, the initial levitation height; L_1, the new levitation height after loaded history of 130 kg; L, the decrement of the levitation height.

Four accelerometers are installed at the four corners of the upper surface of the vehicle model. An impulse force in vertical direction was given to the vehicle model at a key-point by a small hammer. The free vibration curves in the vertical direction after the impulse force were gained by the pulse analyzer of B&K Company. The sampling time was set to 2 s, and the analysis frequency was set to 100 Hz by experience.

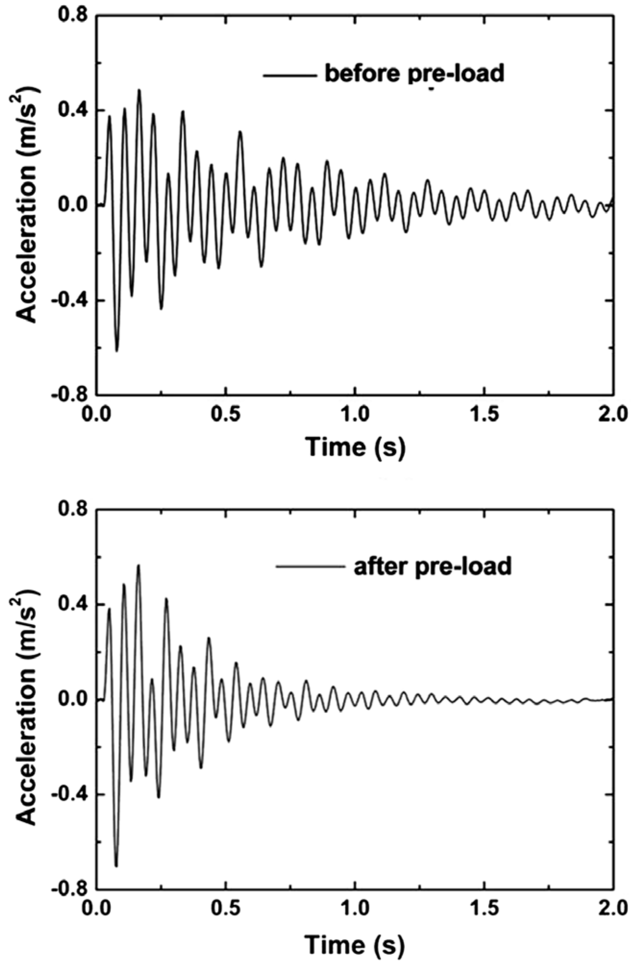

Fig. 5. The impulse response curves of the HTS Maglev vehicle model before and after the pre-load in the time domain.

3. Discussions

Fig. 4 shows that the levitation height linearly decreased with the increase of the load approximately. The slope of the curve after the pre-load is smaller than that before the pre-load. Table 1 shows the decrement of the levitation height after loaded history. These results indicate that the HTS Maglev vehicle is an elastic system, an elastic restore force will act when the vehicle is pulled down or up. But the restore force is limited, and the vehicle cannot return to the original position if the load is too big. The levitation height reduced by 8 mm without pre-load process. However, there is only 1 mm decrement when the pre-load is applied. So the pre-load can suppress the levitation height decay effectively. The next impulse response will further prove this conclusion.

Fig. 5 compares the impulse response curves of the HTS Maglev vehicle model before and after the pre-load in time domain. The vibration curves are some damped free vibration curves which seem to decrease exponentially. The vibration after the pre-load decreased more quickly than that before the pre-load, which indicates the damping coefficient of the HTS Maglev vehicle system after pre-load is bigger than that before the pre-load.

Fig. 6 compares the impulse response curves of the HTS Maglev vehicle model before and after the pre-load in frequency domain. After the pre-load, the resonant frequency drifted from 5.5 Hz to 7 Hz, which indicates that the increase of the stiffness of the system. At the same time, the width of the peak was broadened, indicating the increase of the damping coefficient.

To calculate the stiffness and damping coefficient, the dynamics model of the vehicle was applied to the results. The dynamics model of the vehicle in the vertical direction is written as

$$m\ddot{z} + c\dot{z} + kz = f, \tag{1}$$

where z is the vertical displacement of the HTS Maglev vehicle model, m is the mass of the vehicle model, k is the stiffness, c is the damping coefficient, f is the impulse force on the vehicle.

Eq. (1) is transformed into

$$\ddot{z} + 2\gamma\omega_n\dot{z} + \omega_n^2 z = \frac{f}{m}, \tag{2}$$

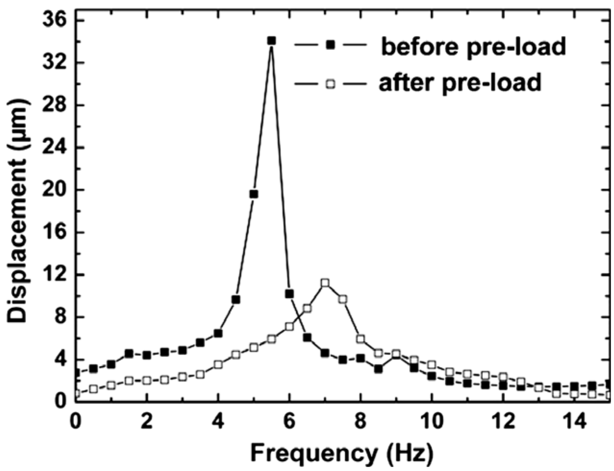

Fig. 6. The impulse response curves of the HTS Maglev vehicle model before and after the pre-load in the frequency domain.

Table 2
The stiffness k and damping coefficient c of the vehicle before and after pre-load

Pre-load	k (N/m)	c (N s/m)
No	53,740	144
Yes	87,050	214

where $\gamma = c/(2\sqrt{km})$ and $\omega_n = \sqrt{k/m}, \gamma$ is the damping ratio and ω_n is to resonant angle frequency.

Applying the dynamics model equations (1) and (2) to the impulse responses, the stiffness and damping coefficient were obtained. As shown in Table 2, after the pre-load, the stiffness and damping coefficient have improved very much. So after the pre-load, the HTS Maglev vehicle gets more stable with higher stiffness and damping coefficient, when the vehicle has better anti-vibration performances.

4. Conclusions

A pre-load was introduced to apply to the HTS Maglev vehicle before the running. The experimental results show that the decrement of the levitation height get much smaller, and the stiffness and damping coefficient get bigger after the pre-load. So the pre-load is very effective to suppress the levitation height decay and enhance the stability of the HTS Maglev vehicle, which is helpful for the HTS Maglev vehicle in practical man-loading operation.

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References

[1] J.R. Hull, Supercond. Sci. Technol. 13 (2000) R1.
[2] J.S. Wang, S.Y. Wang, Y.W. Zeng, H.Y. Huang, F. Luo, Z.P. Xu, Q.X. Tang, G.B. Lin, C.F. Zhang, Z.Y. Ren, G.M. Zhao, D.G. Zhu, S.H. Wang, H. Jiang, M. Zhu, C.Y. Deng, P.F. Hu, C.Y. Li, F. Liu, J.S. Lian, X.R. Wang, L.H. Wang, X.M. Shen, X.G. Dong, Physica C 378–381 (2002) 809.
[3] L. Schultz, O. De Haas, P. Verges, C. Beyer, S. Röhlig, H. Olsen, L. Kühn, D. Berger, U. Noteboom, U. Funk, IEEE Trans. Appl. Supercond. 15 (2005) 2031.
[4] M. Tomita, M. Murakami, Nature 421 (2003) 517.
[5] Z.G. Deng, J. Zheng, H.H. Song, S.Y. Wang, J.S. Wang, Mater. Sci. Forum 546–549 (2007) 1941.
[6] J.S. Wang, S.Y. Wang, in: A. Narlikar (Ed.), Frontiers in Superconducting Materials, Springer Verlag, Germany, 2005, p. 885.
[7] M. Okano, N. Tamada, S. Fuchino, I. Ishii, IEEE Trans. Appl. Supercond. 32 (1996) 2679.
[8] J. Zheng, Z.G. Deng, L.L. Wang, L. Liu, Y. Zhang, S.Y. Wang, J.S. Wang, in: presented at 2006 Appl. Supercond. Conf. No. 2LH08.
[9] J.S. Wang, S.Y. Wang, Y.W. Zeng, C.Y. Deng, Z.Y. Ren, X.R. Wang, H.H. Song, X.Z. Wang, J. Zheng, Y. Zhao, Supercond. Sci. Technol. 18 (2005) S215.
[10] F.C. Moon, M.M. Yanoviak, R. Ware, Appl. Phys. Lett. 52 (1988) 1534.
[11] E.H. Brandt, Appl. Phys. Lett. 53 (1988) 1554.
[12] H. Konishi, M. Isono, H. Nasu, M. Hirose, Physica C 392–396 (2003) 713.
[13] N. Koshizuka, F. Ishikawa, H. Nasu, M. Murakami, K. Matsunaga, S. Saito, O. Saito, Y. Nakamura, H. Yamamoto, R. Takahata, T. Oka, H. Ikezawa, M. Tomita, Physica C 378–381 (2002) 11.
[14] N. Koshizuka, F. Ishikawa, H. Nasu, M. Murakami, K. Matsunaga, S. Saito, O. Saito, Y. Nakamura, H. Yamamoto, R. Takahata, Y. Itoh, H. Ikezawa, M. Tomita, Physica C 386 (2003) 444.
[15] S.Y. Wang, J.S. Wang, Z.Y. Ren, M. Zhu, H. Jiang, X.R. Wang, X.M. Shen, H.H. Song, Physica C 386 (2003) 531.
[16] Z.G. Deng, J. Zheng, L. Liu, L.L. Wang, Y. Zhang, S.Y. Wang, J.S. Wang, in: presented at 2006 Appl. Supercond. Conf. No. 2LG08.