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Levitation force relaxation under reloading in a HTS Maglev system

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ABSTRACT

The loading capacity of the high-temperature superconducting (HTS) Maglev vehicle is an important parameter in the practical application. It is closely related to the levitation force of the HTS bulk. Many papers reported that the levitation force showed the relaxation characteristic. Because different loads cause different levitation gaps and different applied magnetic fields, the levitation force relaxations under the different loads are not the same. In terms of cylindrical YBCO bulk levitated over the permanent magnetic guideway, the relationship between the levitation force relaxation and the reloading is investigated experimentally in this paper. The decrement, the decrement rate and the relaxation rate of the levitation force are calculated, respectively. This work might be helpful for studying the loading capacity of the HTS Maglev vehicle.

1. Introduction

High-temperature superconducting (HTS) Maglev transport system is one of most promising applications of the magnetic levitation using the HTS bulks [1–3]. Since the first man-loading HTS Maglev test vehicle in the world was tested successfully on December 31, 2000 [4], more than 50,000 passengers have taken the HTS Maglev vehicle and it is operating very well. In the system, loading capacity of the vehicle is an important parameter in the practical application. It is closely related to the levitation force of the HTS bulk. Many papers reported that the levitation force showed the relaxation characteristic [5–13]. However, there is no report on the levitation force relaxation under different loads. In this paper, in terms of cylindrical melt-textured HTS YBCO bulk levitated over the permanent magnetic guideway, the relationship between the levitation force relaxation and the reloading is investigated experimentally. This work might be helpful for studying the loading capacity of the HTS Maglev vehicle.

2. Experimental

For simplicity, the HTS Maglev experimental system is composed of a single permanent magnetic guideway and a cylindrical melt-textured HTS YBCO bulk, as shown in Figs. 1 and 2 other than double guideways with multi-bulks. The permanent magnetic guideway is composed of NdFeB, pure iron, stainless steel and screws for clamping, as described in [14]. A diameter and a thickness of the YBCO bulk are 30 mm and 17 mm, respectively. The bulk is fixed on the bottom of a liquid nitrogen vessel which is mounted over the center of the permanent magnetic guideway. Generally, the bulk is cooled by liquid nitrogen in applied magnetic field above the guideway and field-cooling height is kept at 25 mm through all experiments.

A schematic drawing of the levitation force measurement system is shown in Fig. 1, which is a part of the superconducting magnetic levitation measurement system (SCML-2) [15]. As stated in Ref. [15], a unique function of the setup is that the liquid nitrogen vessel with YBCO bulk can be moved simultaneously in both vertical and horizontal directions. While the vessel is moved up and down along z-axis by the vertical drive platform, levitation force can be measured. While the vessel is held at a certain position, the time dependent change of levitation force can be measured, which is also the levitation force relaxation measurement.

3. Results and discussion

In Maglev system, levitation gap, a net distance between a guideway and the bottom of vehicle, is generally accepted to be 8–15 mm. Thus, we focus on that levitation gap range while the levitation force relaxation is measured for different reloading processes. When the levitation gap is 15 mm, the loading capacity is considered to be an elementary loading capacity of the HTS Maglev vehicle, and the corresponding load is L_e. When the levitation gap is

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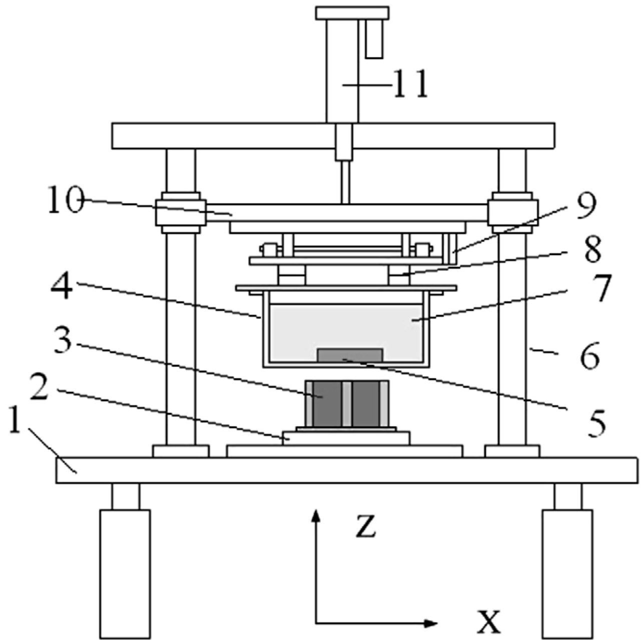

Fig. 1. Schematic drawing of the levitation force measurement system: (1) base; (2) lateral drive platform; (3) NdFeB guideway; (4) liquid nitrogen vessel; (5) YBCO bulk; (6) vertical guideway; (7) liquid nitrogen; (8) levitation force sensor; (9) guidance force sensor; (10) vertical drive platform; (11) servo motor.

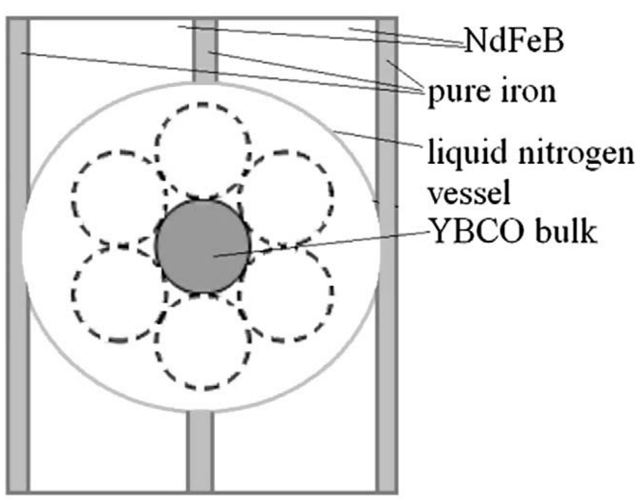

Fig. 2. The arrangement of the YBCO bulks.

lower than 15 mm, the loading capacity is more powerful than the elementary loading capacity, and the load is L_t. This part $(L_t - L_e)$ is called as the reloading in this paper. The reloading can increase as levitation gap becomes smaller. The relationship between the reloading and the levitation gap is shown in Fig. 3. Fig. 4 shows the measurement results of the levitation force relaxation where discrete points for experimental data. The relaxation time is 100 s. Because of disturbances and errors, the curves of the experimental data are not smooth. To smooth the curves, Gauss fitting method is employed and the fitting curves are shown with thick lines in Fig. 4. The Gauss fitting data is employed in the following analysis. Tseng et al. found that the levitation force nicely followed the linear log(t) decay [9]. Similarly, the curves of the levitation force with log(t) are also plotted, which are shown in Fig. 5. From both Figs. 4 and 5, it is found that the levitation force relaxation in-

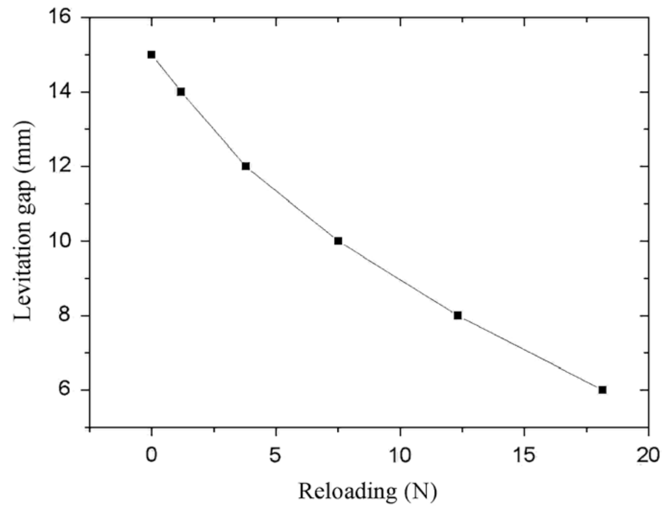

Fig. 3. The reloading dependence of the levitation gap.

creases with the increase of the reloading. It can be explained as follow.

When the levitation gap of the YBCO bulk is reduced due to the increase of the reloading, the distance between the permanent magnetic guideway and the YBCO bulk is decreased. Then the applied magnetic field increases and the Lorentz forces acting on the flux lines become stronger. According to the Bean model [16] and the flux creep theory [17], it can be concluded that this process cause more severe movements of the flux lines. Firstly, there are more flux lines which penetrate into the superconductor and the penetration depth increases. Secondly, the flux lines creep more severely in the superconductor. Then the more energy losses are produced and the levitation force relaxation becomes more obvious.

To further analyze the relationship between the levitation force relaxation and the reloading, the decrement, the decrement rate and the relaxation rate of the levitation force are defined and calculated in details.

3.1. The decrement of the levitation force

Here, the decrement of the levitation force is defined as:

$$\Delta F = F_{L1} - F_{L2} \tag{1}$$

F_{L1} denotes the levitation force before relaxation and F_{L2} denotes the levitation force after relaxation. ΔF is the decrement of the levitation force. The calculation results are shown in Fig. 6. When the reloading increases from 1.18 N to 18.14 N, ΔF increases from 0.09 N to 0.54 N. In the experiment, the decrement of the levitation force approximately follows the linear increase with the increase of the reloading. So the linear fitting is done. L denotes the reloading. The fitting expression is following:

$$\Delta F = 0.0275L + 0.0636 \tag{2}$$

3.2. The decrement rate of the levitation force

The decrement rate of the levitation force is defined as:

$$\beta = \frac{F_{L1} - F_{L2}}{F_{L1}} \times 100\% \tag{3}$$

β denotes the decrement rate of the levitation force and the calculation results are listed in Table 1. Fig. 7 shows that the decrement rate of the levitation force decreases approximately with the increase of the reloading. As shown in Fig. 7, the decrement rate of

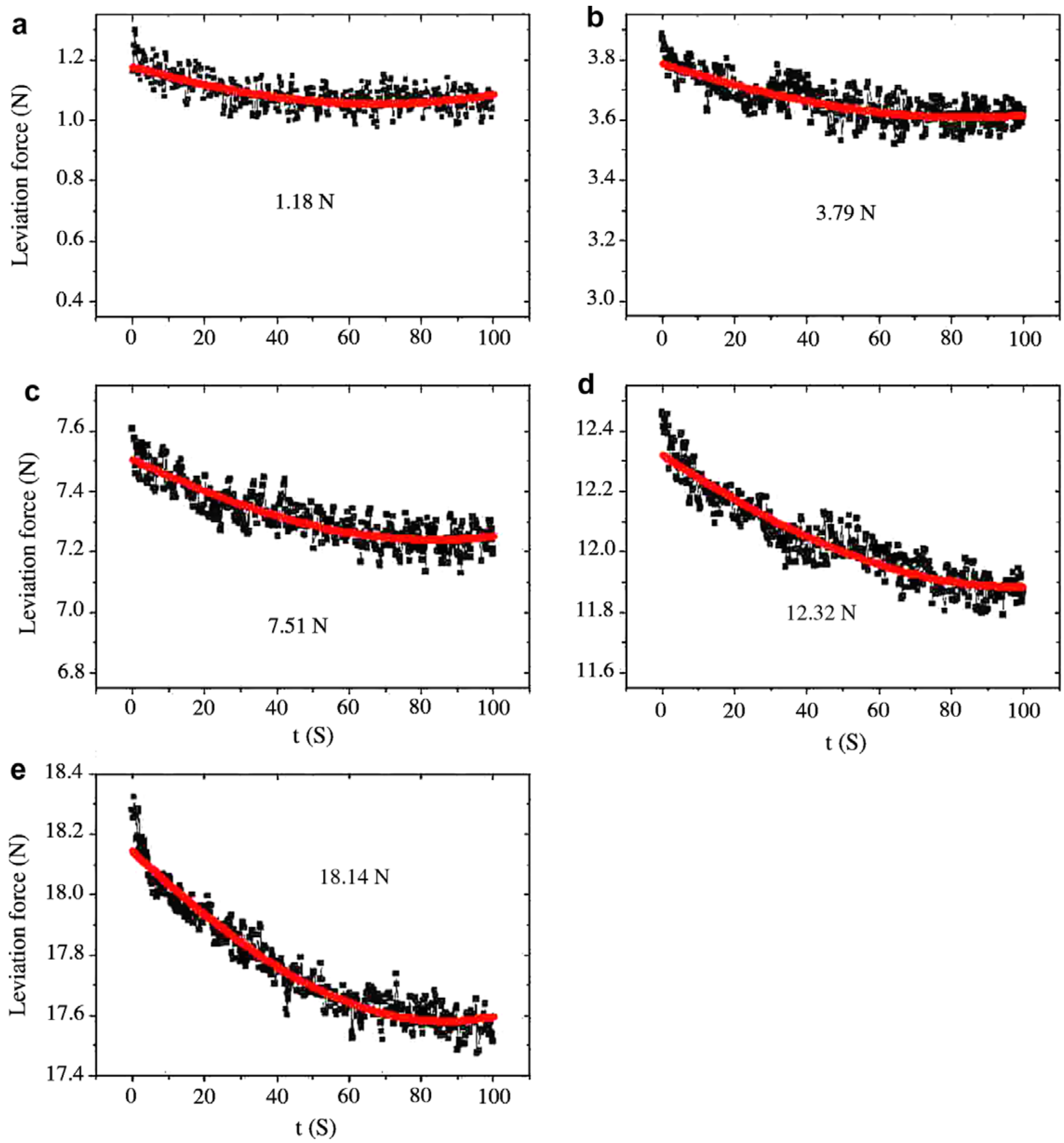

Fig. 4. The levitation force relaxation under the reloading.

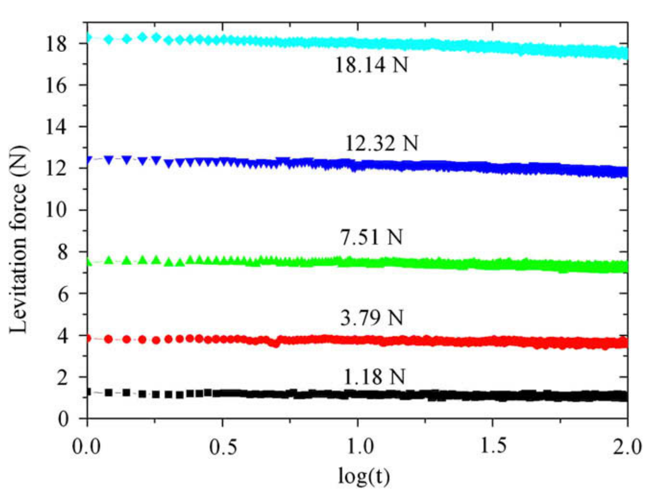

Fig. 5. The levitation force relaxation under the reloading ($\log(t)$).

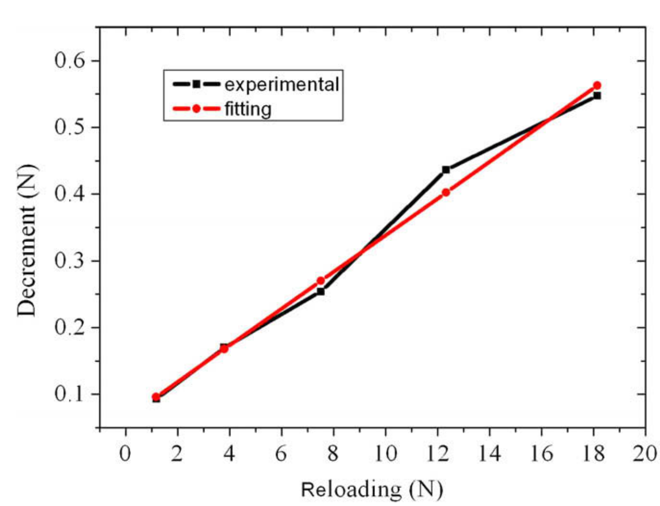

Fig. 6. The decrement of the levitation force with different reloading.

Table 1
Decrement rate of levitation force.

DG (mm)	F_{L1} (N)	F_{L2} (N)	β (%)
1	1.18	1.09	7.63
3	3.79	3.62	4.49
5	7.51	7.25	3.46
7	12.32	11.89	3.49
9	18.14	17.60	2.98

DG: Decrease of levitation gap.

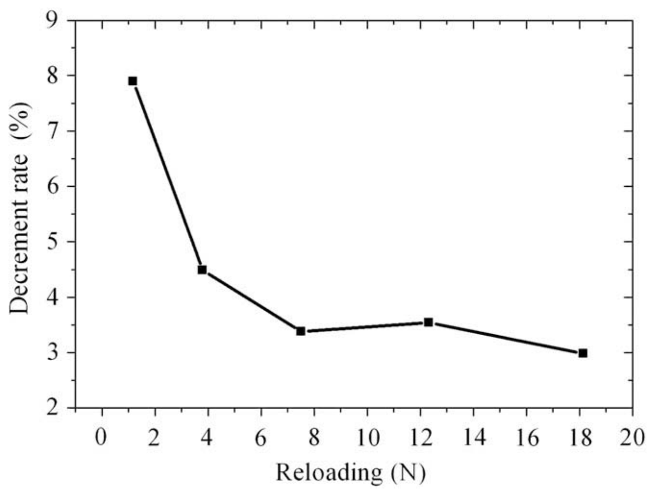

Fig. 7. The decrement rate of the levitation force with different reloading.

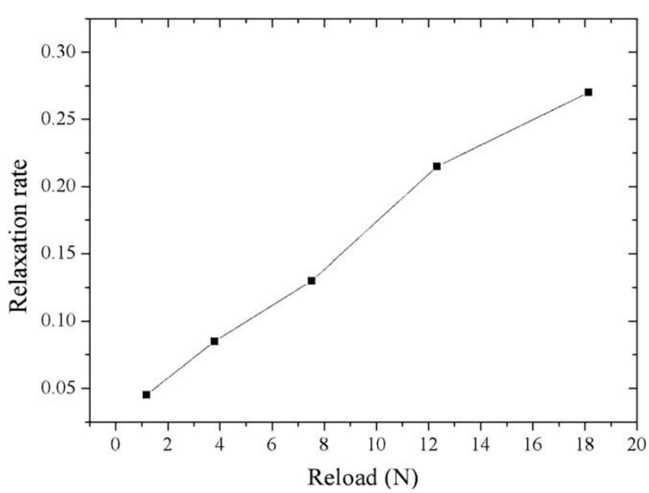

Fig. 8. The relaxation rate of the levitation force with different reloading.

the levitation force experiences a huge drop from 1.18 N to 3.79 N, and then, from 3.79 N to 18.14 N, the decrement rate of the levitation force slightly falls.

3.3. The relaxation rate of the levitation force

Smolyak and other authors found that the levitation force nicely followed the linear log(t) decay [7–9]. The relaxation rate is defined as:

$$\alpha = -dF/d(\log t) \tag{4}$$

F is the levitation force. t is the relaxation time. The calculation results are shown in Fig. 8. When the reloading is 1.18 N, the relaxation rate is 0.05. When the reloading is 18.14 N, the relaxation rate is 0.27. Fig. 8 shows that the relaxation rate approximately follows the linear increase with the increase of the reloading in the experiment.

4. Conclusion

The relationship between the levitation force relaxation and the reloading is investigated experimentally in this paper. The result shows that the levitation force relaxation increases with the increase of the reloading. The decrement, the decrement rate and the relaxation rate of the levitation force are calculated, respectively:

(a) The decrement of the levitation force increases with the increase of the reloading.
(b) The decrement rate of the levitation force decreases with the increase of the reloading.
(c) The relaxation rate of the levitation force increases with the increase of the reloading.

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