Levitation performance of YBCO bulks below the liquid nitrogen temperature zone

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Abstract

High-temperature superconducting magnetic levitation system has the intrinsic advantage of self-stabilizing levitation without external control. The levitation force and the guidance force are important parameters of HTS Maglev system. Many experiments and studies have been done to study the levitation force during liquid nitrogen (LN$_2$) temperature zone and suggest that the levitation performance of YBCO bulks is better at lower temperature. However, the relationship between levitation force of multiple YBCO bulks and the temperature below the LN$_2$ temperature zone is seldom studied. Therefore, it is necessary to investigate the levitation performance of multiple bulks at temperatures below 77 K. A low temperature experimental platform was set up based on SCML-01. By this system, measurements of levitation force versus temperature and levitation force versus field cooling heights (FCHs) can be performed at temperatures from 50 K to 90 K. The experimental results showing that the decreasing temperature is beneficial to improve the levitation performance of HTS bulks, and as the temperature decreases the rate of the levitation force increase becomes gently. And the effect of the temperature on the levitation force is considerably minute in low FCH. Moreover, the low temperature could also reduce the hysteresis loop area. According to the experimental data, the most suitable FCH at different temperatures and the lowest cost can be found between the consumption of the bulks and the cryogenic system when designing the HTS Maglev cryogenic system. The results are important for the engineering application of the HTS Maglev train.

Key words—multiple YBCO bulks, low temperature, levitation force, refrigerator.

The low temperature platform

In the experiments, eight rectangular three-seeded YBCO bulks (64*32*13) were used. The permanent magnet guideway (PMG) consists of rectangular NdFeB permanent magnets arranged in a Halbach array.

![Schematic of the PMG cross section and bulk array under the PMG](image)

The levitation force of YBCO bulks is measured using the HTS maglev measurement system SCML-01

![Schematic of the updated SCML-01 together with a low temperature platform](image)
Resutls and Discussion

The levitation force curves versus vertical distance between YBCO bulks and Halbach PMG when the FCHs are 20 mm, 30 mm and 40 mm.

Fig. 3. Levitation force curves of HTS bulks under different temperatures of 50 K, 60 K, 70 K, 80 K and 90 K in the case of FCH 20 mm, 30 mm, 40 mm

<table>
<thead>
<tr>
<th>Levitation force (N)</th>
<th>T=50 K</th>
<th>T=60 K</th>
<th>T=70 K</th>
<th>T=80 K</th>
<th>T=90 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCH=40 mm</td>
<td>1121.5</td>
<td>1060.6</td>
<td>1001.0</td>
<td>812.9</td>
<td>315.1</td>
</tr>
<tr>
<td>FCH=30 mm</td>
<td>995.2</td>
<td>941.8</td>
<td>888.9</td>
<td>726.5</td>
<td>314.4</td>
</tr>
<tr>
<td>FCH=20 mm</td>
<td>704.1</td>
<td>677.9</td>
<td>636.0</td>
<td>533.4</td>
<td>288.7</td>
</tr>
</tbody>
</table>

This phenomenon can be described as the change of current density of HTS bulks under different temperature conditions. According to the calculation formula of levitation force:

\[ F \propto J_c \frac{dB}{dz} \]  

where \( F \) indicates the levitation force, \( J_c \) is the critical current density of YBCO and \( dB/dz \) is the gradient of magnetic induction at the direction of \( z \). The relationship between \( J_c \) and YBCO temperature \( (T) \) of YBCO bulk is shown in the formula :

\[ J_c \propto J_{c1} \frac{1}{1} \frac{T_c - T}{T_c - T_0} \]

where \( T_c \) is the critical temperature of YBCO bulk, \( T_0 \) is ambient temperature or LN\(_2\) temperature, \( J_{c1} \) is the critical current density of 77 K YBCO. As shown in Eq. 2, the temperature decrease of YBCO can directly lead to the enhancement of critical current density \( (J_c) \) inside the bulks. As Fig. 3. shown, under the interaction between the higher \( J_c \) and the magnetic field supplied by the PMG, the levitation force becomes more superior.

According to the data comparison from 50 K to 90 K in 20 mm, 30 mm, 40 mm FCH, it is found that the original FCH and the temperature is the key element for the enhancement of the levitation force. Especially, we can obtain better levitation performance (1121.5 N) at lower temperature (50 K) in higher FCH (40 mm).

Conclusion

1. The levitation force is larger obviously at lower temperature than at higher temperature near the critical temperature of the YBCO.
2. The rate of the levitation force increase becomes gently between 80 and 50 K. Moreover, with the FCH falling, the growth rate of levitation force measured under different temperature conditions are gradually reduce.
3. The low temperature condition is not only able to take a larger levitation force but also to reduce the hysteresis loop area of levitation curves.
4. In this experiment, we can obtain the greater levitation force from 50 K in 40 mm FCH.