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Comprehensive comparison of the levitation performance of bulk YBaCuO arrays above two different types of magnetic guideways

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ABSTRACT

The permanent magnet guideway (PMG) is an important part of high temperature superconducting (HTS) maglev systems. So far, two types of PMG, the normal PMG and Halbach-type PMG, are widely applied in present maglev transportation systems. In this paper, the levitation performance of high temperature superconductor bulks above the two PMGs was synthetically compared. Both static levitation performance and dynamic response characteristics were investigated. Benefiting from the reasonable magnetic field distribution, the Halbach-type PMG is able to gain larger levitation force, greater levitation force decay during the same relaxation time, bigger resonance frequency and dynamic stiffness for the bulk superconductor levitation unit compared with the normal PMG. Another finding is that the Halbach-type PMG is not sensitive to the levitation performance of the bulk levitation unit with different arrays. These results are helpful for the practical application of HTS maglev systems.

1. Introduction

The property of high temperature superconductors (HTSCs) freely levitating above the permanent magnets appears in many applications such as contactless bearings, flywheel energy storage system and transportation [1]. The high temperature superconducting (HTS) maglev transportation system with the characteristics of non-friction, self-stable, low maintenance, no emission and high speed, has attracted attentions around the world [2–4]. Following the first man-loading HTS maglev vehicle developed successfully by ASCLab, SWJTU in 2000, a new prototype with a 45 m-long HTS maglev loop was built subsequently [5]. Also, a 200 m-long test line by which the vehicle can carry 24 passengers was also built in Brazil [6]. These efforts from many researchers keep promoting the practical engineering application of the HTS maglev system.

In general, permanent magnets are assembled as permanent magnet guideway (PMG) into various configurations to acquire high magnetic field in the HTS maglev system. Due to the interaction between the permanent magnets and HTSCs, the magnetic flux density and distribution of PMG affect the performances of the maglev vehicle significantly. There are two different types of PMGs configurations which include the normal PMG and the Halbach-type PMG, widely applied in present HTS maglev transportation systems [7]. Much work has been done to optimize the external applied field for the maglev vehicle to achieve better levitation performance [8–10].

In present work, the levitation performance of YBaCuO bulks above the two types of PMG was experimentally investigated. The static parameters including levitation force and its relaxation were discussed. The levitation force of the bulks with different arrays was investigated, too. Besides, the dynamic parameters including acceleration, natural frequency (NF) and stiffness of the levitating unit consisting of a cryostat and the HTSCs have also been explored.

2. Experiments

In experiments, a normal PMG and a Halbach-type PMG were applied. The schematic diagrams of the two PMGs are shown in Fig. 1. The cross-section of the PMGs is respectively 116×32 mm^2 and 120×25 mm^2. The magnetic material of the two PMGs is Nd-Fe-B with magnetic energy product of 45 MGOe. In the center of the normal PMG, iron is used as flux connectors to strengthen its magnetic flux density. For convenience, the normal PMG was denoted as PMG1, and the Halbach-type PMG as PMG2. Fig. 2 presents the PMGs' vertical component of the magnetic flux density (B_z). It can be figured out that the B_z of PMG1 has one largest peak in the center and two secondary peaks. In contrast, PMG2 has two peaks and they are symmetric about its center-line. Furthermore, the peak value of PMG1 is a little larger than PMG2.

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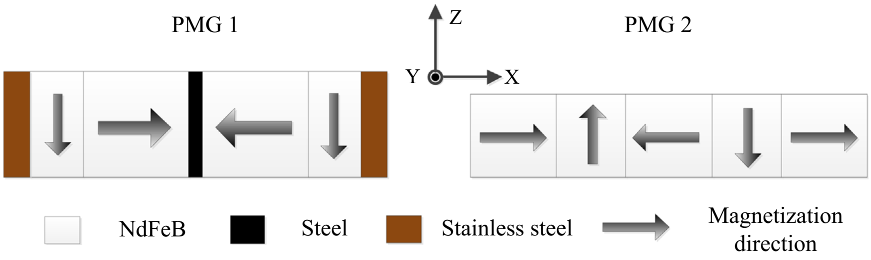

Fig. 1. Schematic diagrams of the PMGs. PMG1 represents the normal PMG and PMG2 for the Halbach-type PMG.

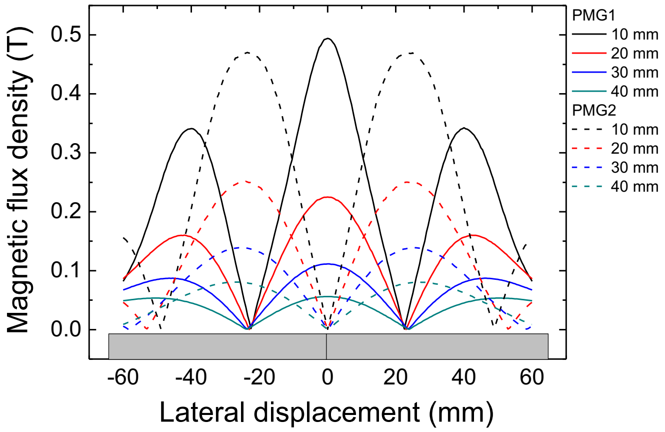

Fig. 2. Absolute values of the vertical component of the magnetic flux density (B_z) of the PMGs at different heights. The gray region represents HTS bulks in the horizontal direction.

2.1. Static experiments

In the static experiments, a levitation unit composed of four rectangular three-seed melt-textured YBaCuO bulks with dimension of $64 \times 32 \times 13$ mm^3 for each was extracted to explore the different performances of the two types of PMG. The critical current density of the material is at least 10^4 A/cm^2 at 77 K, and the transition temperature is 92 K. The maximum trapped flux density of the bulks' surface can be reached to 1.5 T. SCML-2, a self-developed HTS maglev measurement system [11], was employed to investigate the electromagnetic force of the levitation unit above the PMGs. Both field-cooling (FC) and zero-field-cooling (ZFC) conditions were considered. The heights for FC and ZFC condition are 30 mm and 60 mm, respectively. The height is regarded as the distance between the bottom of the levitation unit and the surface of the PMGs. The levitation force and levitation force relaxation were measured in the experiments.

First of all, the levitation unit was immersed in liquid nitrogen and cooled for 20 minutes to ensure that the HTSCs entered the superconducting state. During the measurements of levitation force, the unit was descended from the cooling positon to the lowest position of 10 mm and then ascended to the initial positon with a speed of 1 mm/s. For the levitation force relaxation, the levitation unit was moved from the cooling position to the height of 15 mm and measured the levitation force for 300 s.

In addition, since the arrays of the bulks may affect the levitation force of the maglev system, the levitation force of various bulk arrays above the two PMGs was also investigated. Using the same process, the levitation force of three arrays in ZFC and FC conditions were measured.

2.2. Dynamic experiments

In addition to static performance, the dynamic characteristics of HTS maglev system were also investigated. In this part, the dynamic response characteristics of a cryostat provided by ATZ GmbH (Germany), with 24 YBCO bulks inside [12] levitated above the two PMGs were studied as shown in Fig. 3. The total weight of the cryostat including full liquid nitrogen is 18 kg. The applied test instruments are a B&K vibration analyzer and several tri-axis accelerometers. The dynamic signals with different cooling heights and load weights were measured and analyzed through a pulse force by a hammer vertically applied on the top center of the cryostat. The performances of loading and unloading weight to the cryostat were studied. The maximum loading weight was 20 kg and the Field cooling heights (FCHs) were chosen as 15, 20, 25, 30, 35 and 40 mm.

3. Results and discussion

3.1. Static performances

Levitation force is an important parameter to evaluate the loading capacity of the HTS maglev system. Fig. 4 shows the levitation force of the levitation unit in ZFC and FC conditions. Comparing the figures, the levitation force in ZFC condition is larger than that in FC condition. The levitation force is closely related to the induced current in HTSCs and the applied external magnetic felid [13]. When the HTSCs descend from the cooling position to the measuring position, the variation of magnetic flux in ZFC condition is larger than FC condition. The induced current is larger thus contributes to a larger levitation force in ZFC condition.

From the two figures, it can be seen that the levitation force of

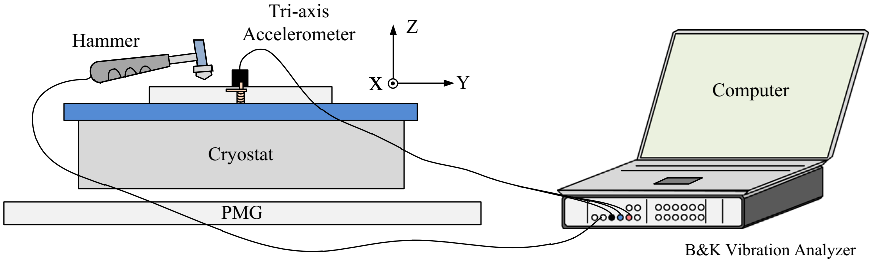

Fig. 3. Schematic diagram of the dynamic experimental scene.