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Coasting characteristic of the flywheel system under anisotropy effect of bulk high temperature superconductors

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ABSTRACT

High-temperature superconductors (HTSCs) array with aligned growth section boundary (GSB) pattern (AGSBP) exhibits larger levitation force and suppression of levitation force decay above a permanent magnet guideway (PMG) compared with misaligned GSB pattern (MGSBP) has been studied in maglev train application (Zheng et al., 2013). This result maybe helpful and support a new way for the HTS bearing design for flywheel systems. So, in this paper, we further examine this growth anisotropy effect on the maglev performance of flywheel system. Levitation force and coasting time were investigated from the point-view of HTS flywheel applications. The GS/GSB alignment of AGSBP bulk HTSCs produces larger levitation force than that of MGSBP, but the coasting time is shorter than that of MGSBP, that is to say, the electric magnetic drag force with AGSBP is larger than that of MGSBP. This result may also exist in the maglev guideline when the maglev train stops freely.

1. Introduction

High-temperature superconducting bearing (HTSB) is used in the flywheel energy storage system (FESS) for energy storage with high efficiency due to the low friction loss [1–3], and HTSB with top-seeded melt-textured (TSMT) bulk high-Tc superconductors plays a crucial role of in this application. Lots of attention and effort from different point of view have been put into it [4–6]. Different size and arranged form have been studied, such as Large-scale HTS bulks for magnetic application and HTS magnetic bearings arranged in different form with PM bulk to achieve suitable levitation performance [7–9].

The TSMT bulks are typically around 20–60 mm in diameter with 5 growth sectors (GSs), which show different flux-trapping capabilities between growth section (GS) and their growth sector boundary (GSB) [10]. There were two angles of 0° or 45° between GSB and the Bz-max position, called as the aligned GSB pattern (AGSBP) and misaligned GSB pattern (MGSBP). Previous work has found that the bulk HTSC array with aligned GSB pattern (AGSBP), exhibits better capability for levitation and suppression of levitation force decay above a permanent magnet guideway (PMG) compared with misaligned GSB pattern (MGSBP) in both one layer HTSC and double-layer bulk HTSC in the HTS maglev train applications [9,11]. These series of results are helpful and support a new way for the HTSB design for flywheel systems, but pursuing larger levitation force is not the only aim in rotation application. The coasting time is another important factor. In this paper, we further examine this growth anisotropy effect on the maglev performance of a flywheel system. The levitation force and flywheel coasting time with different GS/GSB alignment are investigated from the point-view of HTS flywheel applications.

2. Experiments

Seven cylindrical YBaCuO bulks with 20 mm in diameter and 12 mm in thickness were used in field-cooling (FC) levitation force experiments. The applied magnetic field was generated by a PM ring and a PM cylindrical combination (PMRC). The PM ring's outer diameter is 55 mm, and inner diameter is 34 mm with 5 mm in thickness. The PM cylindrical is 12.5 mm in diameter with 5 mm in thickness. As shown in Fig. 1a, the flywheel with PMRC housing in a vacuum chamber driving by a PCB stator was located above the seven cylindrical YBaCuO bulks, whose seed surfaces were both towards the PMRC surface. The lower layer bulks was set in AGSBP or MGSBP to PMRC, that is, the angle between its GSB and the tangent of PM ring was 0° or 45°. The schematic illustration of the 0° alignment pattern was same as Fig. 1b, and the 45° alignment pattern was illustrated in Fig. 1c.

The measurements of levitation force in field cooling situations were carried out at liquid nitrogen temperature. The typical field cooling height (FCH) was set as 20 mm, which was the initialization

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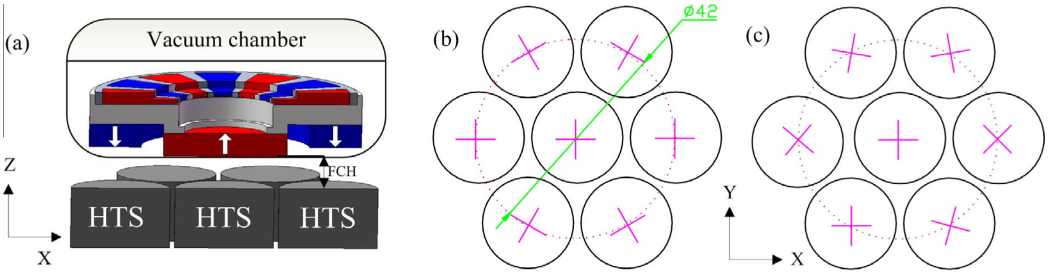

Fig. 1. Schematic illustrations of the bulk HTSC levitation flywheel system (a), the aligned GSB pattern of the lower-layer bulk HTSC to the PMRC (b), and the misaligned GSB pattern of the lower-layer bulk HTSC to the PMRC (c).

cooling height of the bulk combination below the PMRC. The cooling time was 15 min to ensure that all YBaCuO bulks can enter the superconductivity state. For flywheel coasting time measurements were continuously measured with 10 s interval at a constant working height of 7 mm above the HTSCs after the initialization cooling.

3. Results and discussion

The levitation force and flywheel coasting time were measured above the HTCB to study the GS/GSB aligned pattern effects of the bulk HTSCs on the maglev performance for the flywheel application.

3.1. Effect on levitation force

Field cooling levitation show better maglev performance in flywheel application, so only field cooling levitation force measurement was carried out. Fig. 2 shows the levitation force curves of the HTSCs with MGSBP and AGSBP in the cases of 20 mm FCH. The AGSBP bulk HTSC can obtain larger levitation force than that of MGSBP. The levitation force of the bulk HTSCs can be enhanced by 3.6% from 16.3 N to 16.9 N at the levitation gap of 7 mm in down direction when changing the bulk aligned pattern from MGSBP to AGSBP, and this ratio is 10.5% from 5.7 N to 6.3 N in up direction. The resulted is consistent with the paper [9] said.

3.2. Effect on flywheel coasting time

To compare and evaluate the coasting characteristic between AGSBP and MGSBP, flywheel coasting time experiments were further tested. Fig. 3 shows the coasting time curves of the flywheel of the bulk HTSCs with MGSBP and AGSBP in 7 mm FCH situations. The speed with time curve displays as an exponential decay when the flywheel stop freely, as shown in Fig. 3. The coasting time curve with AGSBP is above that of MGSBP, that is to say, the electric magnetic drag force with AGSBP is larger than that of MGSBP. At the 7 mm FCH condition, the coasting time of the flywheel of AGSBP is 890 s from 25,747 rpm to 4997 rpm, which is shorter than 910 s of MGSBP from 25,740 rpm to 5070 rpm. It indicates that the GS/GSB alignment of AGSBP dissipate more energy than that of MGSBP. Some energy is dissipated into magnetic field. The AC loss that occurs in the HTSB reduces the efficiency of the flywheel system, so the coasting time is shorter. Combined with the results of the levitation force, it indicates that the GS/GSB alignment of AGSBP bulk HTSCS produces larger levitation force than that of MGSBP. Maybe the overall Jc of GS and GSB of AGSBP were better excited, consequently, the levitation force will be larger, but the AC component also be enhanced, and the coasting time will be shorter.

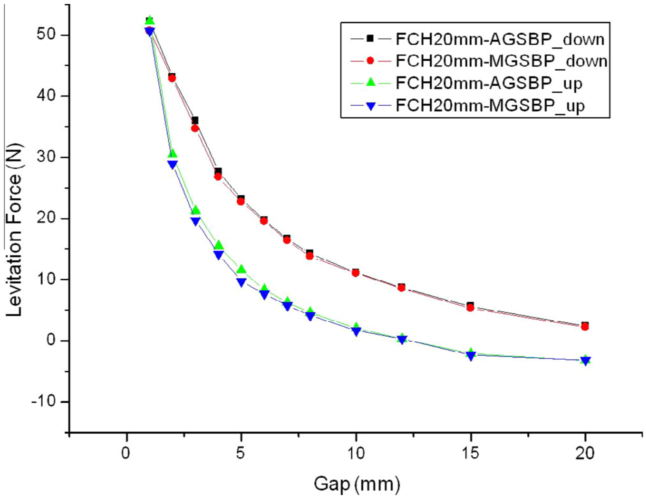

Fig. 2. Levitation force curves of the HTSCs with MGSBP and AGSBP in the cases of 20 mm FCH.

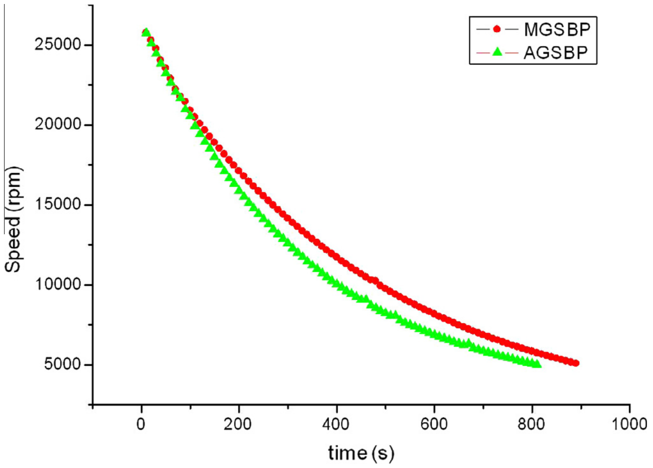

Fig. 3. Coasting curves of the flywheel with MGSBP and AGSBP.

4. Conclusion

We have investigated the coasting characteristic of the flywheel system with different GS/GSB alignment of bulk HTSCs. The levitation force and its coasting time for HTSB were compared. For the seven bulks HTSC with PMRC levitation unit, bulk arrays with AGSBP (the angle between the GSB and the tangent of PM ring is 0°) can obtain larger levitation force than that of MGSBP, but the coasting time is shorter than that of MGSBP. It indicate that the flywheel system dissipate more energy and lower efficiency. This result may also exist in the maglev guideline when the maglev train stops freely. So, the levitation force and coasting time or energy dissipation is a tradeoff. The GS/GSB alignment of bulk HTSCs should be considered according to the application.

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