The Effect of Cone Additional Permanent Magnet Thickness on Magnetic Field Distribution and the Levitation Force of Single Domain GdBCO Bulk Superconductor

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Abstract. It has been investigated that the interaction force between truncated cone permanent magnet (PM) and a GdBCO bulk (HTSC) superconducting permanent magnet (SCPM) magnetized by a truncated cone permanent magnet in their configurations at 77K. The influence of two configurations in different thickness of truncated cone permanent magnets of single domain GdBCO bulk capture field and superconducting magnetic levitation force results. The maximum superconducting magnetic levitation force first increases as H increase, and then decreases with H when it reaches a certain value, from 5.7N to 16.6N at first, and then it decreases to 3.8N. The vertical component of the magnetic field intensity on the top surface (h=2mm) of truncated cone permanent magnet first increases, and then decreases also, from 0.20T to 0.54T , and then decrease to 0.25T. These results indicate that the levitation force of high temperature superconductor bulk can be effectively improved by scientific choosing of shape and size of permanent magnet, and reasonable designing of the system configurations, which is very important during the practical design and applications of superconducting magnetic levitation system.

1. Introduction

High temperature superconducting materials can provide large magnetic levitation force and good self-stabilizing suspension in the application of external magnetic field due to their anti-magnetic properties. It has been widely used in magnetic suspension bearing systems,[1] superconducting energy storage flywheel,[2] high temperature superconducting transmission line, electromagnetic emission,[3] superconducting generator, seismic isolator,[4] high temperature superconducting magnetic suspension system and superconducting maglev train systems.[5] In practical, how to effectively improve the magnetic levitation force between permanent magnet and superconductor is particularly important. The magnetic levitation force are mainly related to the magnetic field strength that the permanent magnet used, [6] the magnetic field distribution, [7, 8] the thickness of the superconductor, [9] the radius, [10] the grain orientation, [11]and the degree of magnetization [12] in magnetization method. [13]

In the previous work,[14] the influence of the combination form of strip-shaped permanent magnets on the magnetic levitation force about superconducting blocks was studied. The result shows that the superconducting magnetic levitation force is closely relate to the configuration form and combination mode of the magnet and the spacing between the magnets. The magnetic levitation force between superconductor and permanent magnet was also studied by the introduction of the auxiliary permanent magnet. [15,16] These results show that the superconducting magnetic levitation force were closely related with the combination of permanent magnets, the introduction of permanent magnets, the
magnetic field distribution of the magnet, the magnetization of the superconducting block and the trapping magnetic field during field cooling. Cheng et al. [17] Put forward the effect of the magnetization of square-assisted permanent magnets on superconductors on the superconducting magnetic levitation force and the magnetic field of capture magnetic field. The result show that the superconducting magnetic levitation force and the trapping magnetic field related to the superconductor magnetization. However, these studies mainly focus on the effects of square permanent magnets, strip-shaped permanent magnets and combined magnets on the magnetic levitation force and the magnetic field distribution of superconductors. The influence of the thickness variation of the truncated cone permanent magnets on the characteristics of superconducting magnetic levitation forces has not been systematically studied.

In order to clarify the influence of the thickness variation about the truncated cone permanent magnet on the magnetic levitation force of the single-domain GdBCO superconductor, this paper studies the magnetic levitation force of the truncated cone permanent magnet and the single-domain GdBCO superconductor in the case of zero fields cold and axisymmetric. The influence of the thickness variation of the magnet on the magnetic levitation force of the superconductor. Some experimental conclusions with reference value are obtained.

2. Experimental

The single domain GdBCO superconductor used in the experiment was prepared by the top seed crystal melt texturing method (MTG). [18] The diameter of the sample is 20mm and the thickness is 12mm. The truncated cone permanent magnet used is magnetized along the axial direction. Figure 1 shows the macroscopic morphology of the experimental single-domain GdBCO superconductor. In order to systematically study the effect of the thickness variation of the truncated cone permanent magnet on the magnetic levitation force characteristics of the single-domain GdBCO superconductor, the experimental scheme shown in Figure 2 is designed. The three-dimensional magnetic field and magnetic force testing device is used to measure the influence of the thickness variation of the truncated cone permanent magnet on the magnetic levitation force of the single-domain GdBCO superconductor. The thicknesses are 5mm, 10mm, 15mm, 20mm, 25mm, 30mm, 35mm, 40mm, 45mm and 50mm respectively, and the corresponding upper surface diameter of the truncated-shaped permanent magnets are 32mm, 30mm, 26mm, 22mm, 18mm, 14mm, 12mm, 10mm, 8mm and 6mm, respectively. Before each experimental measurement, the truncated cone permanent magnet and the superconductor are in an axisymmetric state, and the vertical distance between the two is Z=35 mm. The liquid crystal nitrogen is used to start cooling the superconductor. After the superconductor is cooled to the liquid nitrogen temperature (77K), the truncated cone permanent magnet begins to vertically approach the superconductor along the axis. When the distance between the two is Z=2 mm, the truncated cone permanent magnet is returned along the original path and complete an experimental measurement.

Figure 1. The morphology of the sample.

Figure 2. The force measurement diagram between the permanent magnet and the superconductor.
3. Results and Discussion

Under the zero field cold experimental condition, when the vertical distance between the truncated cone permanent magnet and the superconductor is 2 mm, the relationship between the magnetic levitation force of the superconductor and the thickness of the truncated cone permanent magnet are shown in Figure 3. It shows that when the thickness H of the truncated cone permanent magnet increases from 5mm to 50mm, the magnetic levitation force of the superconductor is closely related to the thickness of the truncated cone permanent magnet. All superconductor magnetic levitation force curves are tilted as a whole to the lower left, and there is hysteresis. As H increases, the hysteresis of the superconducting magnetic levitation force first increases and then decreases. When H are 20mm and 25mm, corresponding to the diameter of the upper surface of the truncated cone permanent magnet are 22mm and 18mm, the superconducting magnetic levitation force has a large hysteresis. When H are 5mm and 50mm, corresponding to the diameter of the upper surface of the truncated cone permanent magnet are 32mm and 6mm, the superconducting magnetic levitation force is very small.

![Figure 3. The magnetic levitation force (Z=2mm) with the thickness H of the truncated cone permanent magnet.](image1)

![Figure 4. The maximum value of magnetic levitation force (Z=2mm) with the thickness H of the truncated cone permanent magnet.](image2)

Figure 4 is the relationship between the maximum value of superconducting magnetic levitation force (Minimum measuring gap distance Z=2mm) and the thickness H of truncated cone permanent magnet. It shows that with the increase of H, the maximum value of superconducting magnetic levitation force first increases and then decreases, from 5.7N to 16.6N, and then decreases to 3.8N. When H are 20mm and 25mm, corresponding to the diameter of the upper surface of the truncated
cone permanent magnet are 22mm and 18mm, the maximum value of superconducting magnetic levitation force is larger. When H are 5mm and 50mm, corresponding to the diameter of the upper surface of the truncated cone permanent magnet 32mm and 6mm, the maximum value of the superconducting magnetic levitation force is small.

In order to further clarify the influence of the variation of the thickness H of the truncated cone permanent magnet on the magnetic levitation force of the superconductor, the low-temperature Hall probe was used to measure the vertical component Bz of the magnetic field at Z=2mm on the upper surface of the truncated cone permanent magnet under the change of thickness H. Figure 5 is the relationship between the vertical component of the magnetic field strength along the diameter direction (BZ-X) from the upper surface of the magnet (h=2mm) and the thickness of the truncated cone permanent magnets of 5mm, 10mm, 15mm, 20mm, 25mm, 30mm, 35mm, 40mm, 45mm and 50mm, the corresponding upper surface diameter of the truncated permanent magnets are 32mm, 30mm, 26mm, 22mm, 18mm, 14mm, 12mm, 10mm, 8mm and 6mm respectively. In general, the vertical component of magnetic field strength is closely related to the thickness of the truncated cone permanent magnet. There are differences in the magnitude of the magnetic field and the distribution of the magnetic field at different thicknesses.

![Figure 5. The vertical component of the magnetic field of the permanent magnet upper surface (h = 2 mm) with transverse displacement (Bz-X) curve.](image)

![Figure 6. The maximum value of the vertical component of the magnetic field intensity on the upper surface of the permanent magnet (h=2mm) with the thickness variation (Bmax-H)](image)

Figure 6 shows the relation curve of the maximum value of the vertical component of the magnetic field intensity on the upper surface of the permanent magnet (h=2mm) with the thickness variation (Bmax-H). As the thickness of the magnet increases from 5mm to 50mm, the magnetic field strength
first increases and then decreases. The maximum magnetic field strength increases from 0.20T to 0.54T and then decreases to 0.25T. These maximum values is obtained at x=0mm. When H=25 mm and 30 mm, the peak values of the maximum magnetic field strength are substantially equal, corresponding to the upper surface diameter d=18 mm and 14 mm. This is inconsistent with the position where the maximum value of the superconducting magnetic levitation forces in Figure 4.

In the magnetic levitation system consisting of a truncated cone permanent magnet and a superconductor, the superconducting magnetic levitation force is not only related to the magnetic field strength of the applied external magnetic field, but also interact with the gradient of the magnetic field, the effective area of the interaction between the permanent magnet and the superconductor. When the thickness of the truncated cone permanent magnets are H=20mm and 25mm, corresponding to the diameter of the upper surface of the truncated permanent magnets are 22mm and 18mm, the diameter ratio of the superconductor is 20mm, and the magnetic field strength and effective area are optimized. Matching results in a maximum magnetic levitation force at H = 20 mm and 25 mm and similar.

4. Conclusions
The effect of the thickness of truncated cone permanent magnet on the magnetic levitation of GdBCO superconductor under axisymmetric condition is studied experimentally. The results show that the maximum magnetic levitation force changes with the thickness of the truncated cone permanent magnet, which are closely related to the magnetic field strength of the applied external magnetic field, magnetic gradient and the effective area of the interaction between permanent magnet and superconductor. When the diameter of the upper surface of the truncated permanent magnet and the diameter of the superconductor reach the optimum diameter ratio, and the magnetic field strength and effective area are optimally matched, the superconducting magnetic levitation force reaches a maximum value. These results show that in the practical application of magnetic levitation system, the scientific design and reasonable magnetized superconducting bulk material can adjust adjust the magnitude superconducting magnetic levitation force, thereby improving the magnetic levitation force characteristics.

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6. References
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