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ScienceDirect
Physica C 467 (2007) 125–129
PHYSICA C
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Three-dimensional measurements of forces between magnet and superconductor in a levitation system

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Received 7 August 2007; received in revised form 12 September 2007; accepted 14 September 2007
Available online 25 September 2007

Abstract

An updated high temperature superconductor maglev measurement system was used to investigate the three-dimensional levitation force and lateral force in the levitation system consisting of a rectangular magnet and a cylindrical superconductor. The optimization levitation region was found at the same levitation height with various displacements in the X- and Y-direction. It was also found that the forces between the magnet and the superconductor show anisotropically in the X–Y plane.

Keywords: Three-dimensional measurement; Optimization levitation region

1. Introduction

Since the original work of Moon, Yanoviak and Ware [1] and their measurements of the vertical levitation force and lateral force of bulk high temperature superconducting ceramic in a permanent magnet and superconductor levitation system, the studies focused on a permanent magnet (PM) and a high temperature superconductor (HTS) levitation system have been carried out for almost 20 years. Up to now, the vertical levitation force between the PM and superconductor occupied the center of interest; it is in one-dimension, such as that reported in Refs. [2–6]. The lateral force of a levitated permanent magnet over a superconductor has also been investigated experimentally and theoretically, these results were in one-dimension [7,8] and in two-dimension [9,10]. Furthermore, the magnetic field distributions of PM are in three-dimensional [11] in space, while there are few reports about the influences of three-dimensional magnetic field distributions on the levitation force and lateral force. Del Valle et al. [12] optimized the levitation of an infinitely long superconductor and infinitely long permanent magnets with different arrangements from a theoretical analysis, but the optimization experimental results of levitation system have not previously been made. In this paper, an updated HTS maglev measuring system, which can be used to investigate the three-dimensional interaction forces between a magnet and a superconductor at one time is used to study the levitation system consisted of a rectangular-shaped magnet and a cylindrical superconductor. In the end, we optimize the levitation system with various displacements in the X- and Y-direction at the same levitation height and obtain the best region for levitation.

2. Experimental details

All the experiments were carried out using an updated HTS maglev measurement system [13] developed by the Applied Superconductivity Laboratory at the Southwest Jiaotong University in China. This system as shown in Fig. 1 is fully controlled by a computer. Two orthometric installation electromotion seats realize the movements in the X- and Y-direction simultaneously or solely. The

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doi:10.1016/j.physc.2007.09.010

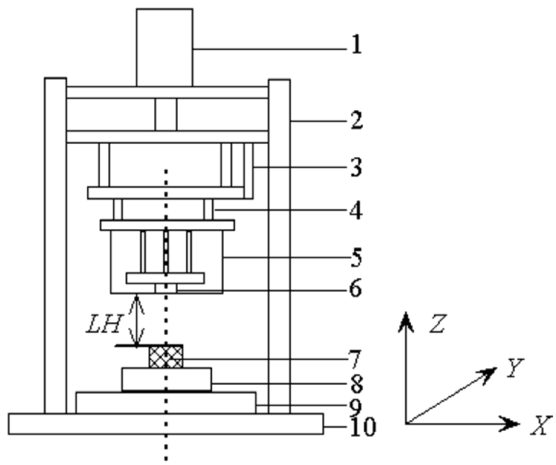

Fig. 1. Scheme of the HTS measurement system: 1, servomotor; 2, frame; 3, lateral sensor; 4, vertical sensor; 5, liquid nitrogen vessel; 6, superconductor; 7, permanent magnet; 8, *Y* electromotion seat; 9, *X* electromotion seat; 10, Base. LH is an abbreviation for the distance between the bottom of the liquid nitrogen vessel and the surface of the permanent magnet.

position precisions in the *X*- and *Y*-directions are 0.01 mm. A vertical servomotor is used to position the nonmagnetic columnar liquid nitrogen vessel with a thickness of 5 mm, which is used to fix a HTS above the PM with 150 mm vertical maximum displacement and with 0.01 mm precision. Because there is no force sensor in the *Y*-direction, the superconductor is kept in a similar fixed direction before the performance of a force measurement each time and as a result three-dimensional forces are obtained.

The HTS bulk was composed of yttrium–barium–copper-oxide (YBaCuO) cylinder with a diameter of 30 mm and a thickness of 18 mm, which was fabricated by the General Research Institute for Nonferrous Metals (Beijing), the details of which were described elsewhere [14]. The rectangular-shaped sintered permanent magnet (40 mm long, 40 mm wide and 10 mm thick) made up of NdFeB, which was used in the experiments is polarized axially; and the concentrating surface magnetic flux density is up to 0.35 T.

The experiments were performed by first placing the superconductor into the liquid nitrogen vessel and then it was cooled in a zero magnetic field. After the sample turned into the superconducting state, the PM was placed below the vessel and moved to the expected positions in the *X*- and *Y*-direction such as 0, 4, 8, 12, 16 and 20 mm, respectively. The vessel, positioned over the magnet, was then lowered vertically toward the surface of the magnet. The levitation force and lateral force were collected as a function of distance between the PM and the bottom of the vessel with various displacements in the *X*- and *Y*-direction at the same time. Throughout the experiments the velocity of the vessel was set at 0.05 mm/s with the maximum vertical displacement of 30 mm. In addition, the experiments were carried out to realize the optimization of the levitation system at a levitation height of 2 mm. The detailed processes are described as follows. After the sample turned into the superconducting state, the electromotions in the three directions were moved to the expected positions such as at a vertical distance of the vessel of 30 mm, at a displacement of the PM in the *X*-direction of −25 mm, and at displacements in the *Y*-direction of 0, 4, 8, 12, 16 and 20 mm, respectively. The vessel was then moved vertically toward the surface of the magnet, until the bottom of the vessel reached a distance of 2 mm away from the PM. Subsequently, the PM at a speed of 0.5 mm/s started to move along the *X*-direction in the interval from $X = -25$ mm to $X = 25$ mm, the levitation force and lateral force were recorded as a function of the lateral displacements in the *X*-direction at displacements of 0, 4, 8, 12, 16 and 20 mm in the *Y*-direction. These results can realize the optimization of the levitation system.

3. Results and discussion

Fig. 2a shows the three-dimensional levitation forces between the magnet and superconductor with the same vertical displacement and various displacements in the *X*- and *Y*-direction. One can see that the maximum levitation force is not in the axis of the rectangular magnet, it is determined by the distributions characteristics of the magnetic field in space. Both in the *X*- and *Y*-direction, the levitation forces increase to the peak values and then decrease with the displacements increasing. The maximum levitation force is 4.14 N in the *X*-direction and the minimum is 2.67 N, while the maximum levitation force in the *Y*-direction is 4.37 N and the minimum value is 2.83 N. Fig. 2b is the projected map of Fig. 2a in the *X*–*Y* plane. One can see that the distributions of levitation forces in the *X*- and *Y*-direction are not consistent; it means the levitation force is anisotropic.

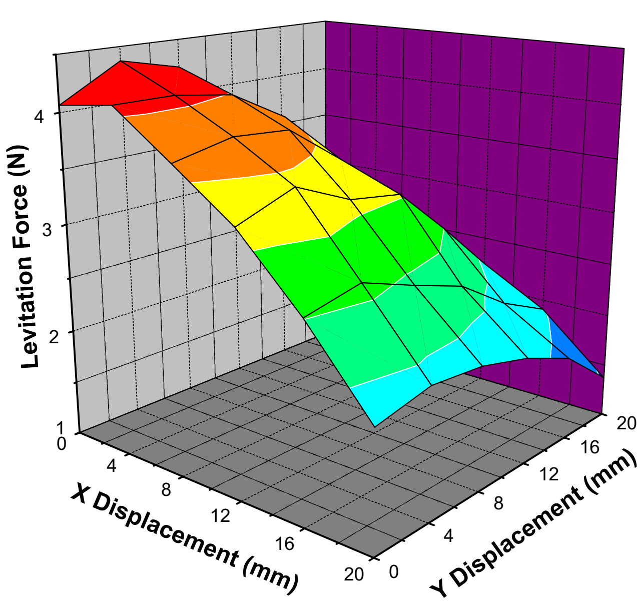

Fig. 2a. The three-dimensional levitation forces results between the magnet and superconductor with the same vertical distance and various displacements in the *X*- and *Y*-direction.