Journal of Alloys and Compounds 662 (2016) 546–556

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Design of magnetic levitation force measurement system at any low temperatures from 20K to room temperature

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A R T I C L E I N F O

Article history:
Received 31 August 2015
Received in revised form
25 November 2015
Accepted 30 November 2015
Available online 8 December 2015

Keywords:
Magnetic levitation force
Lateral force
Magnetic stiffness
YBCO
Maglev

A B S T R A C T

Most of the magnetic levitation force measurements in previous studies were performed at liquid nitrogen temperatures. Magnetic levitation force measurement system is needed for the levitation force of MgB2 and iron based superconducting samples. Magnetic levitation force measurement system was designed in this study. In this system, beside vertical force versus vertical motion, lateral and vertical force versus lateral motion measurements, the vertical force versus temperature at the fixed distance between permanent magnet PM and superconducting sample SC, and the vertical force versus time measurements were performed at any temperatures from 20 K to 300 K. Thanks to these measurements, the temperature dependence, time dependence, and the distance (magnetic field) and temperature dependences of SC can be investigated. On the other hand, the magnetic stiffness (MS) measurements can be performed in this system. MS dependence on temperature can be investigated by using the measurement of MS at different temperature in the range. These measurements at any temperatures in the range help the superconductivity properties of the superconductors, whose transition temperature is below the liquid nitrogen temperature, be characterized.

1. Introduction

The common property of technological applications such as fly-wheel [1] and bearing in energy storage [2–4], magnetically levitated trains (MagLev trains) in transportations [5] rely on the magnetic levitation forces between the permanent magnets (PM) and the superconductors. Magnetic levitation force of the superconductors is directly related to the critical current density *Jc*. In the calculation of the magnetic levitation force, there are lots of parameters such as the shape and size of the PM and the superconducting sample, the positions of them, the magnetic profile of PM, and the temperature dependency of the superconducting sample which should be exactly known. On the other hand, measurement of the magnetic levitation force has been performed. Most of the studies on the levitation force measurements have been done in liquid nitrogen [6,7], argon, oxygen [8,9] and helium temperatures [10]. Most of the measurements at these temperatures are on the variation of magnetic levitation force with vertical motion of PM toward to the sample in axial direction. Beside lateral and levitation forces in the lateral motion of PM or sample perpendicular to axial direction of the cylindrical shaped sample, the time and temperature dependency of levitation force and the magnetic stiffness are very important in MagLev, bearing and Fly-wheel systems, as well. Magnetic stiffness of the superconductor, which is strength against to the magnetic field, is the major property among these dependencies for the applications.

In this study, we aimed to design the magnetic levitation force measurement system (MLFMS) at any low temperatures. Our goal in this system is to measure magnetic levitation, lateral, magnetic stiffness temperature and the time dependency of the force not only at the liquid nitrogen but also at the other temperatures from around 20 K to the transition temperature of the superconductors up to the room temperature. This system can also measure the magnetic levitation force of MgB_2, Fe based superconductors as well.

The following part of this paper focuses on the design of MLFMS. The requirements and the steps of the system design were explained. The results of the experiments and the tests carried out using the system were presented.

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http://dx.doi.org/10.1016/j.jallcom.2015.11.230

2. Experimental setup

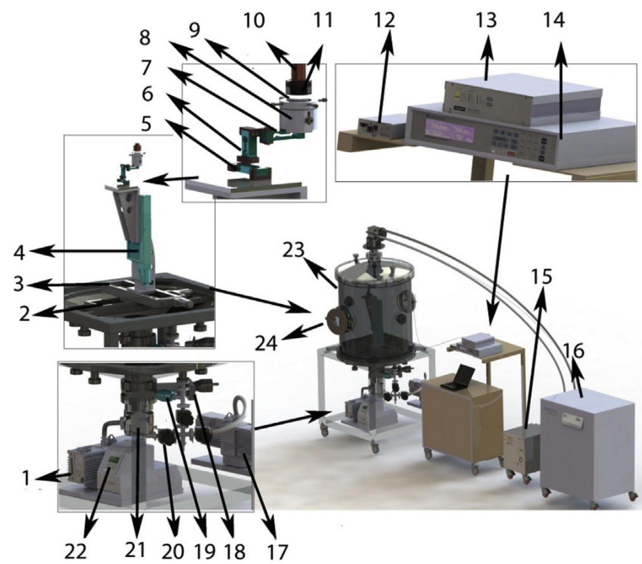
2.1. Design of magnetic levitation force measurement system (MLFMS)

Magnetic levitation force between the superconducting samples (SC) whose transition temperature is higher than the liquid nitrogen temperature and the permanent magnet (PM) have been studied in air atmosphere by many researchers [11–14]. However, the magnetic levitation force measurements of MgB2 samples in the superconducting state [15–17], and that of YBCO [6] were performed. All the measurements of levitations at low temperatures are on the vertical magnetic levitation force in the vertical motion and the minimum vertical distance between PM and SC in their studies is bigger than 4 mm because the sample is in vacuum and the motion system included PM is in air. On the other hand, the distance between PM and SC is achieved shorter value than 4 mm in the magnetic bearing for flywheel energy storage system [1]. The system, designed in this study, can measure magnetic levitation force in vertical direction, lateral and levitation force in horizontal direction, levitation force with the variation of temperature, levitation force with increasing time at constant temperature, and the magnetic stiffness at any constant temperatures between 18 K and Tc. In this system the minimum distance between PM and SC is 1.5 mm.

This system includes some parts such as XYZ motion system and loadcell configuration, Sample cooling and temperature control, Vacuum chamber and software which can fully control MLFMS. The real and the schematic view of the system with details is shown in Fig. 1a and Fig. 1b, respectively.

2.1.1. Vacuum chamber

SC and PM have to be inside of the vacuum chamber to be close as 1.5 mm between the bottom face of SC and the top face of PM. Because PM is moved in 3D to the specific position by the xyz positioner, the positioner has to be inside of vacuum chamber. For this reason, the sizes of the vacuum chamber, shown in Fig. 1, are in diameter of 800 mm, height of 900 mm and the wall thickness of 15 mm to reach the vacuum level up to 10^{-7} Torr. One rotary pump (Varian DS-302) for roughing, and turbo molecular pump station (Edwards TMP station) are used in this system for high vacuum level. Manual gate valve between the chamber and the turbo molecular pump at the bottom side of the chamber is used to keep the chamber in vacuum. Electrical feedthrough connection for XYZ positioner, three loadcells, heater cartridge and two temperature sensors are attached to the back side of the chamber in Fig. 1. Vacuum feedthrough with three manual valves attached to the bottom side of the chamber is used for the roughing pump and opening to air atmosphere. Vacuum gauge (Edwards WRG) is used to measure the vacuum level of the chamber. Rotary pump and turbo molecular pump station are taken place without physical contact to the chamber to keep from noisy originated by vibration to loadcells at low level. Fast entry door is used to change the superconducting sample. The cold head of the cryostat is taken part to the top of the vacuum chamber. SC is pasted to the sample holder of cold head of the cryostat by thermally high conductive high vacuum grease (Apiezon N). On the other hand, SC is cooled down to low temperature or heated up from not only its top but also its bottom face because SC is fixed by the sample fixer (hardened copper nut). The bottom thickness of the nut is 1 mm and the gap of 0.5 mm between the bottom surface of the nut and the top surface of PM. PM is thought not to be influenced by temperature of SC thanks to the vacuum level (10^{-7} Torr) of the vacuum chamber. The limit for the minimum distance between bottom face center of SC and top face center of PM is 1.5 mm which is adjusted in the



a)

b)

Fig. 1. a) Whole view of the magnetic levitation force measurement system at low temperatures: temperatures: 1. (Edwards RV12) rotary pump of turbo molecular pump (TMPS) station, 2. linear stage of x axis, 3. linear stage of y axis, 4. linear stage of z axis direction, 5. loadcell of Fx, 6. loadcell of Fy, 7. loadcell of Fz, 8. Permanent magnet holder, 9. Permanent magnet (PM) in cylindrical shape, 10. Superconducting sample (SC) holder of cryostat, 11. Superconducting sample in cylindrical shape, 12. Loadcell reader NI-ENET-9237, 13. MiCos XYZ linear stage controller, 14. LakeShore 336 temperature controller, 15. CKW-21 Sumitomo Close Cycle Refrigerator Compressor, 16. Durachill Chiller, 17. Varian DS-302 rotary pump for rough vacuum, 18. Manual gate valve, 19. Edwards WRG gauge, 20. Manual valves, 21. Turbo molecular pump of TMPS, 22. TIC controller of TMPS, 23. Vacuum chamber (VC), 24. Fast entry door of VC. b) View of vacuum chamber and some instruments of magnetic levitation force measurement system.

vacuum chamber by using the permanent magnet holder, shown in Fig. 2. In the measurement system, the most important points are the parallelization of PM and SC and the same axial direction. For the horizontally and the vertically parallelization four fixing screws for PM (Number 6 in Fig. 2) are used. After setting the minimum distance between PM and SC, the vertical fixing screw is used to fix