Magnetic field calculation and measurement of permanent magnet and high temperature superconductor (M1Po2A-06 [30])

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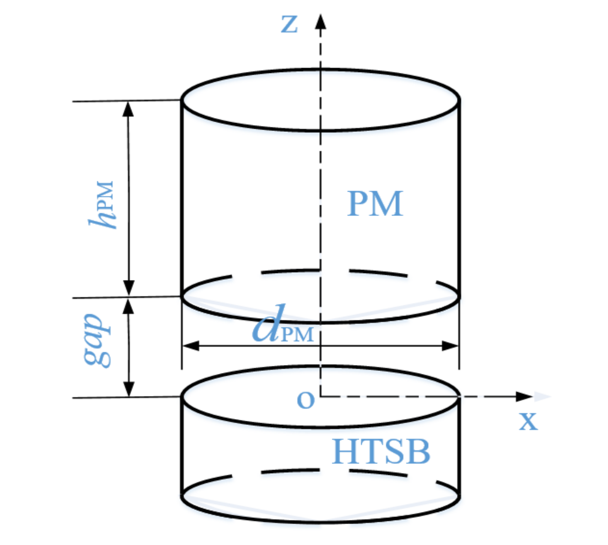
Introduction

The performance of high temperature superconducting (HTS) magnetic bearing is directly related to the excitation field density and distribution of the permanent magnets and the performance of the superconductors. The material uniformity and performance consistency of permanent magnets and superconductors greatly affect the rotational stability of HTS magnetic bearings. For small superconducting magnetic levitation systems, when the levitation force or the pinning force is small, the measurement error by measuring the force is large and the performance of the superconductor cannot be accurately reflected. The performance of the superconductor can be studied more deeply and accurately by measuring the trapped field density and distribution of superconductor. The difference between the superconductors can also be well distinguished. For the application of superconducting magnetic levitation system with permanent magnets and superconductors, the superconductors are magnetized by permanent magnets.

- The magnetic field of permanent magnets were calculated and measured, and a permanent magnet (PM) with suitable geometry structure for magnetizing a superconductor was designed.
- The magnetization of a HTS bulk was studied using a cylindrical permanent magnet, and the influence of permanent magnet excitation field on superconductor trapped field was measured.

Methodologies

High temperature superconducting magnetic system



- The finite element method was used to analyze the suspension characteristics of the superconducting-permanent magnet levitation system.
- The Bean critical state model was used to obtain the magnetization characteristic parameters of the superconductor.

Figure 1. Schematic diagram of HTS magnetic levitation system

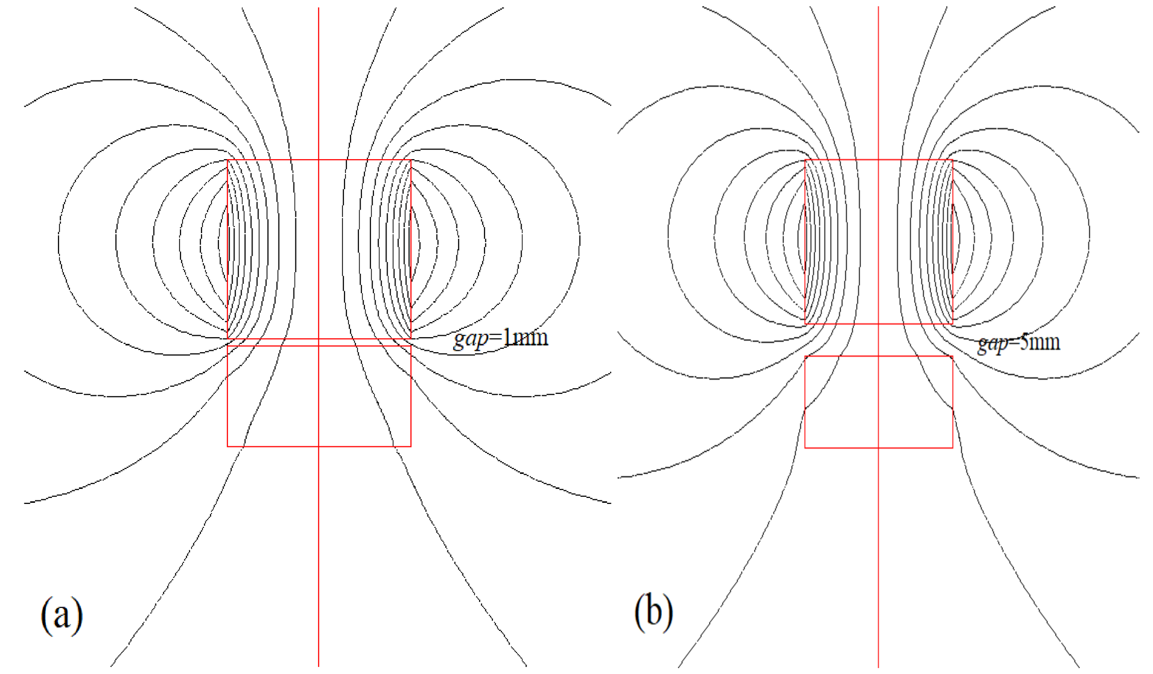


Figure 2. Magnetic field lines distribution at different gap locations

- The magnetic field lines at the two ends of the permanent magnet are not the same. The high temperature superconductor has the characteristics of repelling and trapping the magnetic field.
- The geometry of permanent magnet, as well as the gap, affects the distribution of the excitation field on the superconductor surface.
- In order to explore the influence of permanent magnet excitation field on superconductor trapped field, a suitable permanent magnet need to be designed and selected.

Magnet magnetic field finite element calculation

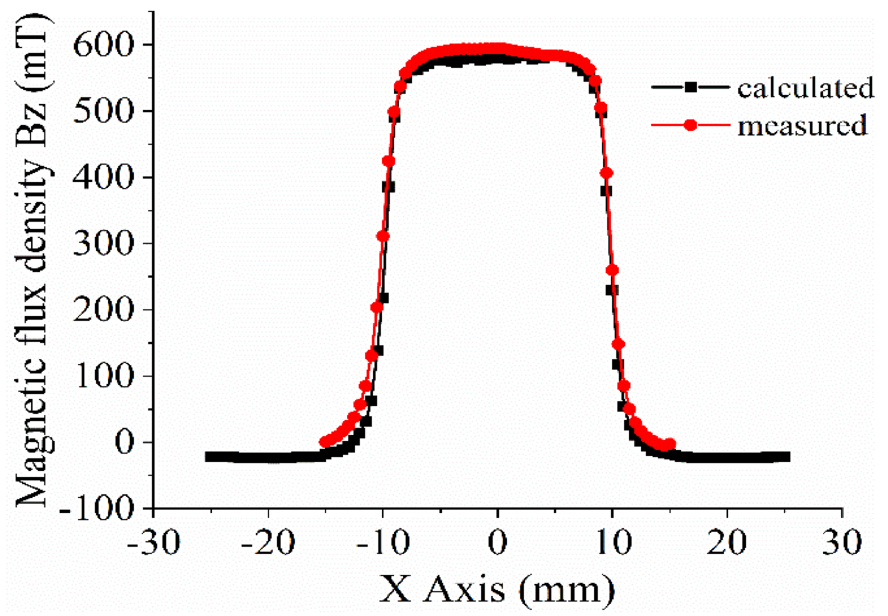


Figure 3. Comparison of calculated and measured values: the cylindrical permanent magnet (20 x 30 mm) is axially magnetized, and magnetic field *Bz* is parallel to the magnetization direction.

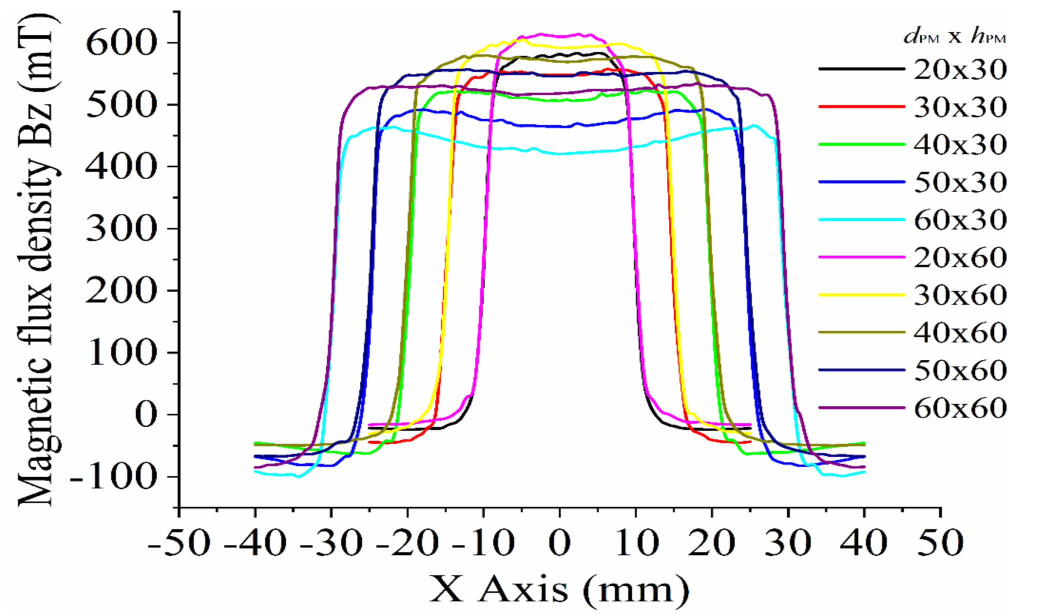


Figure 4. Magnetic field for different structures (d_{PM} x h_{PM}): The position of the calculation path is 0.5 mm from the end surface of the permanent magnet.

- The magnetic field of a cylindrical permanent magnet with diameter 20 mm and height 30 mm (20 x 30 mm) was calculated, and the calculated value agrees well with the measured value.
- The magnetic field distribution law of cylindrical permanent magnets with different structural dimensions is obtained.
- For the trapped flux measurement of 32 x 32 x 18 mm HTS bulk, a 40 x 60 mm cylindrical permanent magnet was selected as the excitation magnetic field of the HTS bulk.

Excitation magnetic field and trapped field measurement platform

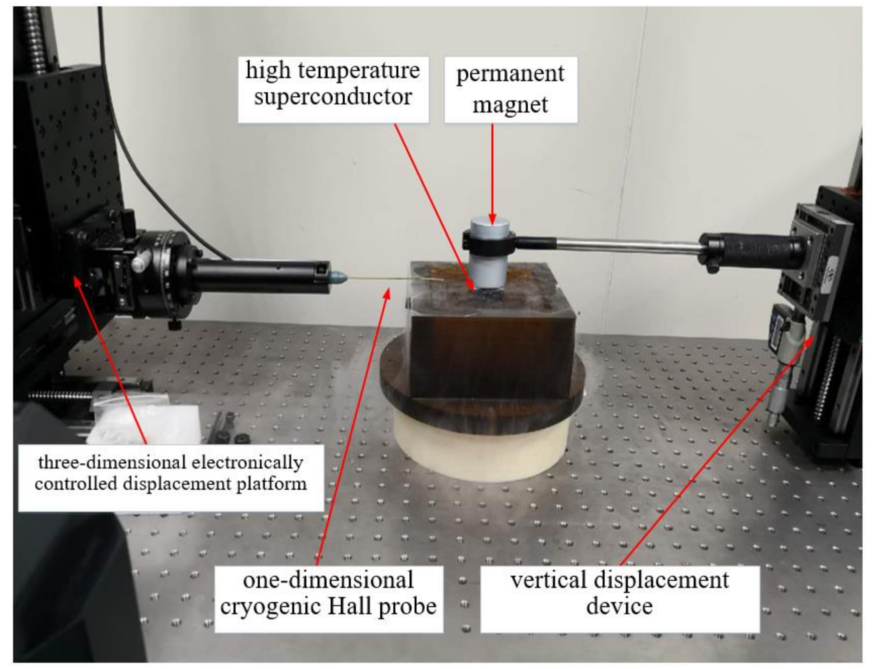


Figure 5. Photo of magnetic field and trapped-flux measurement platform

- In order to measure the spatial magnetic field of the permanent magnet and the trapped flux of the superconductor, a magnetic field measurement platform as shown in figure 5 was built.
- The one-dimensional cryogenic probe can be used in the range of liquid nitrogen temperature (77 K) and ambient temperature (295 K) with a measurement accuracy of ± 0.05% (0 - 2 T) of reading.
- The external magnetic field of the permanent magnet at the heights of 0.5 mm and 2 mm from the end surface and the trapped flux of the superconductor at the excitation gap of 0 mm and 2 mm are measured by the magnetic field measurement platform.

Results and discussion

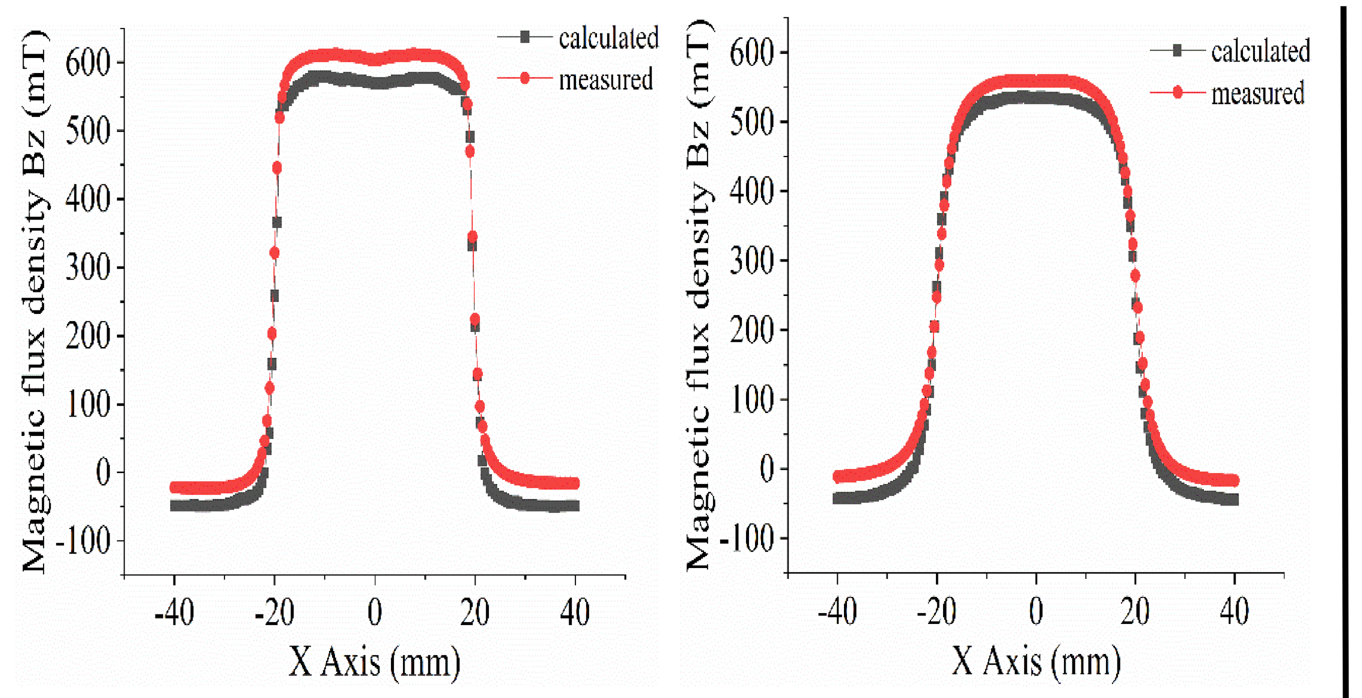


Figure 6. Magnetic field *Bz* of a 40 x 60 mm permanent magnet at 0.5 mm and 2 mm from the end surface of the permanent magnet: left is 0.5 mm, right is 2 mm.

- When the distance from the end surface of the permanent magnet is 0.5 mm, the average magnetic field value measured, in the range of -16 mm < x < 16 mm, is 607.75 mT, and the uniformity of the magnetic field distribution is 2.54%. The calculated and measured values have an error of approximately 5.71% in the range of -16 mm < x < 16 mm.
- When the distance from the end surface of the permanent magnet is 2 mm, the average magnetic field value measured, in the range of -16 mm < x < 16 mm, is 546.25 mT, and the uniformity of the magnetic field distribution is 13.04%. The average magnetic field value measured, in the range of -12 mm < x < 12 mm is 555.36 mT, and the uniformity of the magnetic field distribution is 3.31%. The calculated and measured values have an error of approximately 4.68% in the range of -16 mm < x < 16 mm.
- The magnetic field calculation of the permanent magnet can be used to provide reference for the structural design of external excitation field of superconductor. And the 40 x 60 mm permanent magnets can provide good excitation field uniformity in the range of -16 mm< x < 16 mm.

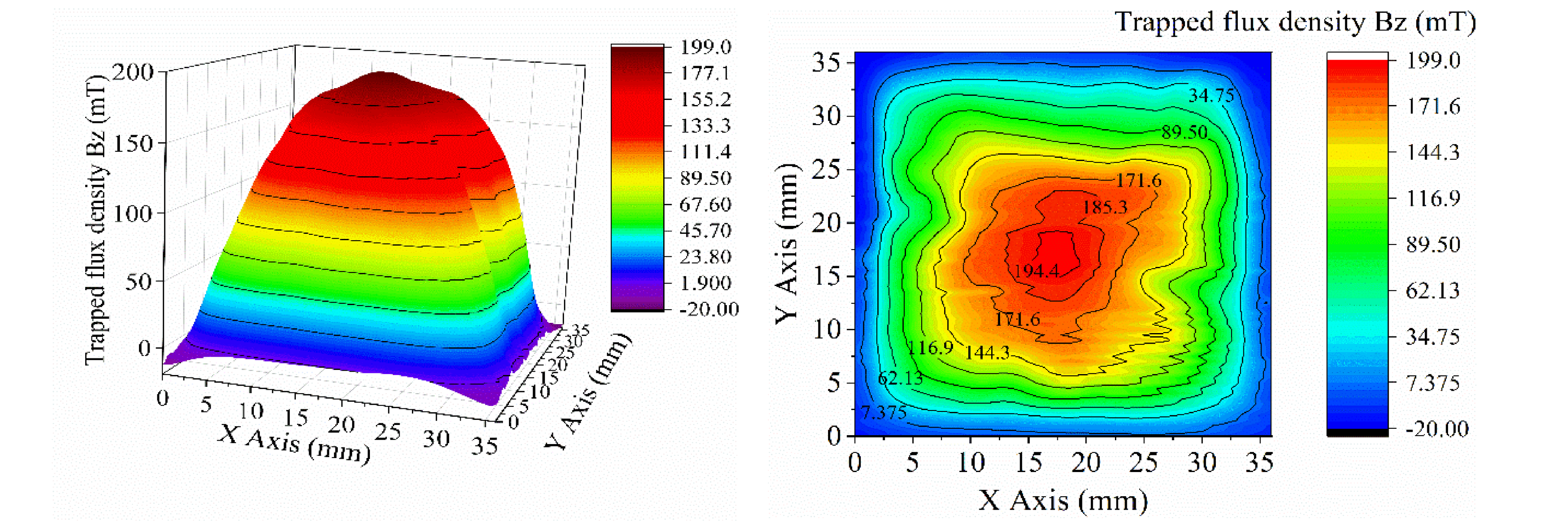


Figure 7. Trapped flux measurement results after 0 mm gap excitation: the measured surface is 0.5 mm from the surface of the superconductor, left is 3D trapped flux distribution, right is 2D trapped flux distribution.

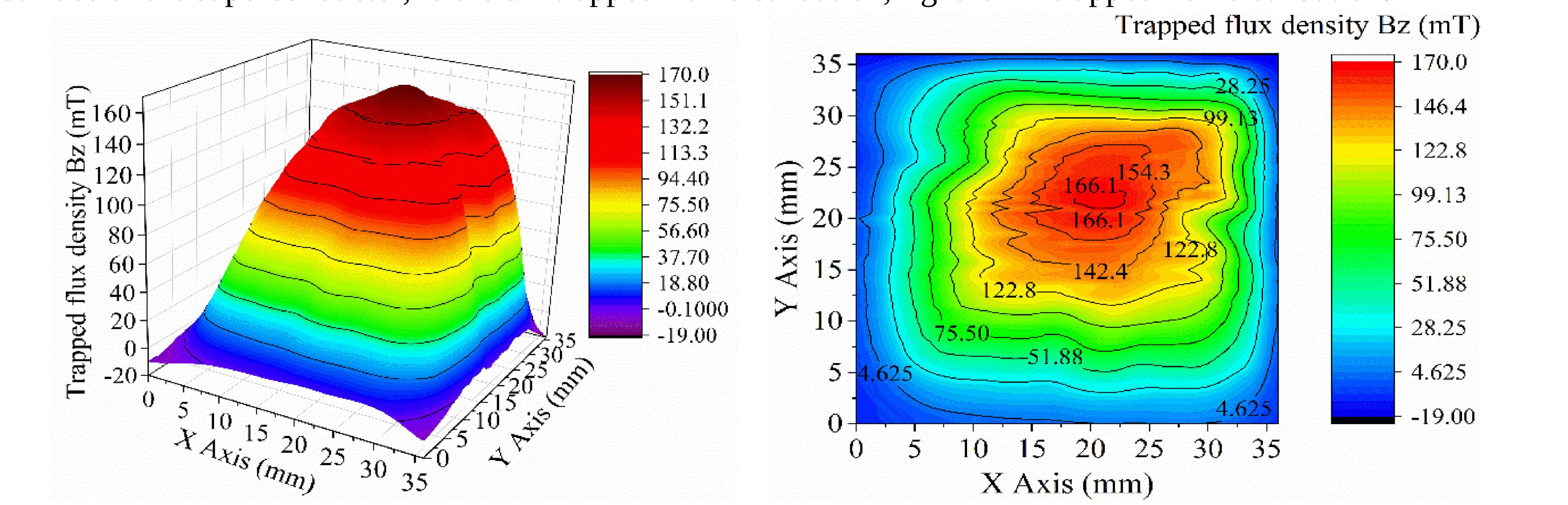


Figure 8. 2 mm excitation gap: the measured surface is 0.5 mm from the surface of the superconductor (Analysis: there are position errors for the fixing of the permanent magnet, and HTS bulk is inhomogeneous and irregular)

- When the excitation gap is 0 mm, the maximum trapped flux density is 199 mT, and when the excitation gap is 2 mm, it is 170 mT. The excitation field magnitude has a great influence on the superconductor trapped flux.
- The trapped flux density value is fully satisfies the measurement accuracy requirements of the Hall probe, and the trapped flux has obvious distribution characteristics, therefore, the study of the superconductor trapped flux by using the permanent magnet as the excitation field can realize the performance measurement of the high temperature superconductor.

Conclusion

- The magnetic field and distribution of cylindrical permanent magnets are calculated, and a measurement platform for measuring the magnetic field of permanent magnets and trapped flux of high temperature superconductors is built.
- The magnetic flux density on a plane 0.5 mm from the end surface of the 40 x 60 mm cylinder permanent magnet reaches to 607.75 mT in the direction of cylinder axis, and the magnetic field distribution uniformity in the range of 32 mm in diameter is 2.54%.
- When the excitation gap between the permanent magnet and the superconducting bulk is 0 mm, the maximum trapped flux density is 199 mT, and when the excitation gap is 2 mm, it is 170 mT.
- Based on the finite element calculation and magnetic field measurement of permanent magnet and superconductor, the performance measurement and screening of high temperature superconductors and permanent magnets can be performed.

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