MAGNET MEASUREMENTS OF THE HALF MAGNETS

Y. Lu*, C. Zhang, Z. Ren, B. Liu, G. Feng
University of Science and Technology of China, Hefei, China

Abstract

The Hefei Advanced Light Facility (HALF), a fourth-generation light source based on a multi-bend achromat (MBA) lattice, is currently under construction. The storage ring consists of 20 cells and requires over 800 magnets. To assess the magnetic field quality and perform magnet fiducialization, several dedicated measurement systems have been developed. These include rotating-coil, stretched-wire, and Hall-probe systems. The field quality of multipole magnets is characterized using the rotating-coil system, while their magnetic centers are determined through single stretched-wire measurements. This paper presents the design of the measurement benches, outlines the corresponding measurement procedures, and reports the current measurement progress.

INTRODUCTION

The Hefei Advanced Light Facility (HALF) is a fourth-generation synchrotron radiation light source based on a diffraction limited storage ring in the low-energy region [1]. The overall layout of HALF is shown in Fig. 1. Electron beam is generated from a thermionic high voltage DC gun and the beam energy can be accelerated to 2.2 GeV at the exit of the linac. The HALF storage ring uses a hybrid six-bend-achromat (H6BA) lattice, which replaces the three combined-function bend unit cells of the original H7BA lattice with two longitudinal gradient bend (LGB) and reverse bend (RB) unit cells and a mid-straight section. The storage ring consists of 20 cells and requires over 800 magnets. All multipole magnets and LGB magnet are fiducialized and measured before the installation to confirm that alignment and field quality satisfy the requirement.

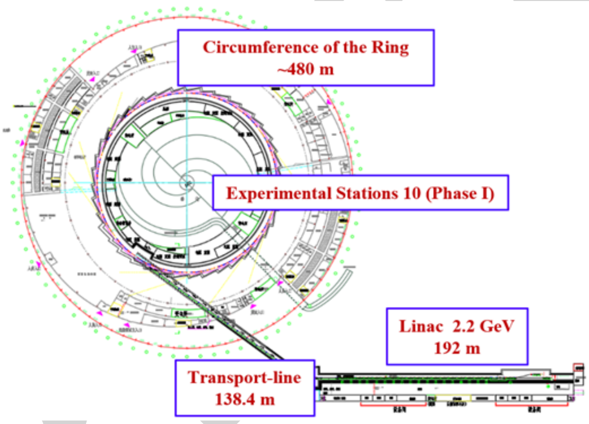


Figure 1: Layout of the HALF accelerator system.

Three types of measurement systems—the rotating coil measurement system, the single stretched wire measurement system, and the Hall probe measurement system—have been designed and established in the testing hall. To enable the measurement of all magnets prior to installation, each system has two measurement platforms. The rotating coil is used for measuring magnetic field harmonic components and integrated field gradient, and the single stretched wire system measures the magnetic center for magnet fiducialization. The measurement benches are installed in an air-conditioned room with constant temperature and humidity. The detail of the measurement systems are explained in the following sections.

* yaolu131@ustc.edu.cn

ROTATING COIL MEASUREMENT SYSTEM

The rotating coil measurement system mainly consists of two Newport XY stages, a fast digital integrator (FDI), a rotatory encoder, a stepper motor and a marble platform support. The photo of the rotating coil measurement system is shown in Fig. 2. The coil is embedded within a ceramic structure, offering enhanced mechanical strength and extended service life. There are two different rotating coils for quadrupole and sextupole bucking. Before the measurement of magnetic flux, the magnets must be precisely aligned to ensure that the central axis of the ceramic coil coincides with the mechanical center axis of the magnet.

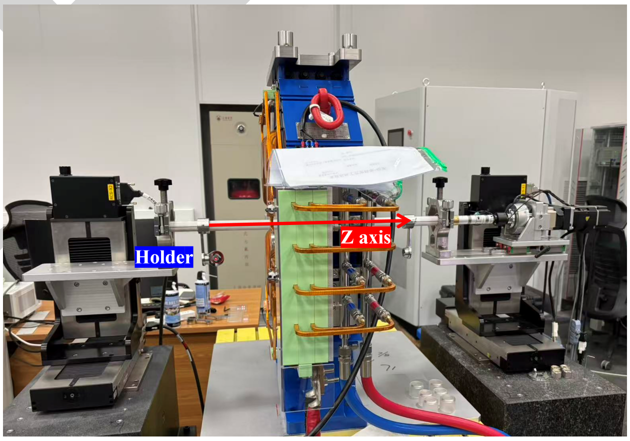


Figure 2: Photo of the rotating coil measurement system.

To accomplish the fiducialization of the magnets, the positions of the fiducial targets in the magnet mechanical coordinate system are first determined at the fabrication facility using a Coordinate Measuring Machine (CMM). In the testing hall, two target holders are mounted at both ends of the ceramic coil. By rotating the coil and recording the positions of the target spheres with a laser tracker, circles are fitted to the measured trajectories at both ends. The Newport stage is used to adjust the height difference between the upstream and downstream ends to less than 5 µm. The

Y-axis is defined based on the global coordinate system of the laser tracker. The coordinate system of the rotating coil is thereby established. It should be noted that the Z-axis and Y-axis are nearly orthogonal; however, they do not form a true Cartesian coordinate system. The support platform is then adjusted until the transverse deviation between the target coordinates in the rotating coil coordinate system and those provided by the factory is within 10 µm. Then the magnet is considered to be properly aligned, and the measurement can be started.

The rotation is driven by a stepper motor with high-resolution positioning capability, while the encoder provides trigger signals to the FDI. The total number of trigger signals is determined based on the encoder parameters to ensure that the FDI can record the flux signal within a single rotation. Two types of coils are used for measuring quadrupole and sextupole magnets. They are equipped with dipole and quadrupole bucking, and dipole, quadrupole, and sextupole bucking, respectively. For the octupole magnet, the harmonic components are extracted using a single coil without bucking. For the integrated field, the results obtained from the coil are calibrated using the results from the Hall probe measurement system. Although the rotating coil can measure the magnetic center and determine the deviation between the mechanical rotation axis and the magnetic axis [2], the final result is obtained using the single stretched wire method due to fabrication errors in the coil [3, 4]. This method is described in the next section.

SINGLE STRETCHED WIRE MEASUREMENT SYSTEM

The single stretched wire measurement system mainly consists of a marble bench, two Newport XY stages, a FDI, a marble platform support, a granite triangular square and a digital multimeter. As shown in Fig. 3, the system is used to measure the magnetic center and perform a coordinate transformations used for fiducialization. To achieve a non-magnetic, high tensile strength and low density, the material of the wire is made of TiAlV. At first, the magnet is aligned by a laser tracker under a coordinate of the test bench. To link the coordinate information between the mechanical center and magnetic center of magnet, a coordinate transformation is performed by the marble platform support, the granite triangular square and digital multimeter. The marble platform support and the granite triangular square are of Grade 00, with a flatness better than 2 µm.

After measuring the magnetic center, the magnetic center is recorded by the Newport device. Then the wire is removed and a 304 stainless steel sphere is placed sequentially on the target holders (T1, T2, T3, and T4). An electrical circuit is established using the stretched wire and a multimeter, enabling the coordinates of each holder to be determined. The contact position is identified based on variations in electrical resistance, and the center of the sphere on each target holder is subsequently determined by fitting the measured points.

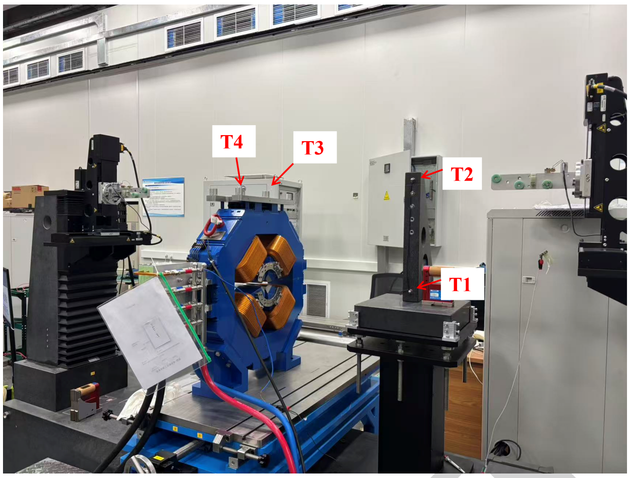


Figure 3: Single stretched wire measurement system.

The coordinates of the magnetic center and the target holders in the coordinate system of the stretched wire platform are thus obtained. By combining these with the coordinates of T3 and T4 in the coordinate system established by, the offset between the magnetic center and the mechanical center can be determined. Experimental validation shows that the measurement accuracy is within 10 µm.

HALL PROBE MEASUREMENT SYSTEM

The Hall probe measurement system is used to measure all LGB magnets and a subset of multipole magnets to calibrate the integral field data obtained from the rotating coil system. An overview of the Hall probe measurement system for measuring an LGB magnet is shown in Fig. 4. The system mainly consists of a movable granite bench, a teslameter, and magnetic landmark.

Figure 4: Hall probe measurement system for measuring LGB magnet.

A bench coordinate system can be defined on fiducials on the bench. A target holder is mounted on the movable bench. The longitudinal axis is defined by translating the bench and acquiring the target coordinates at the start and end positions. Based on the coordinates of the targets located on the top of the magnet, the magnet is aligned on the support bench using a laser tracker.

Before measurement, a permanent-magnet-based dipole magnet is used to align the orientation of the Hall probe. The probe holder assembly allows rotation of the probe. A magnetic fiducial target is used to determine the position of the sensitive area of the Hall probe in the bench coordinate system. A fiducial is mounted on its yoke, through which the magnetic center of the target is determined.

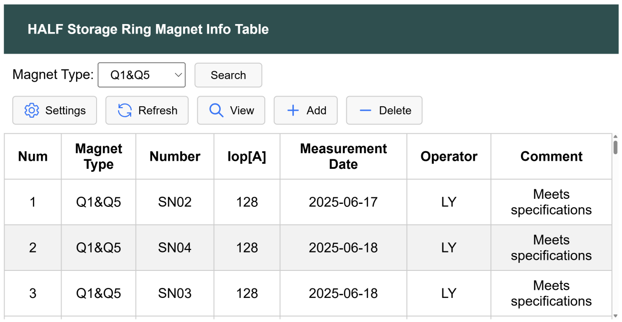
After alignment and Hall probe calibration, magnetic field measurements are performed as a series of line scans along the magnet Z-axis at fixed X and Y positions. To reduce measurement time, the magnetic field data are acquired on-the-fly at 2 mm intervals with a velocity of 8 mm/s, taking advantage of the high sampling rate of the SENIS teslameter (up to 7.5 kS/s). The longitudinal field distribution is obtained by fitting the teslameter data together with the position data from the motion controller. Compared with the static measurement method, the difference in the integrated field of the LGB magnet is less than 0.05 %.

MAGNET DATABASE

Owing to the large number of magnets, a dedicated database has been developed to manage and maintain the magnet measurement data. There is much magnet-related data mentioned in previous sections, such as excitation curve data, magnetic center data, and target information. Various applications need to access a combination of these data. Therefore, a magnet database has been developed using MySQL and PHP to enable efficient data management and convenient querying. MySQL offers strong capabilities in structured data storage, query optimization, and data integrity, making it suitable for handling large volumes of measurement results. PHP enables flexible development of a web-based interface, allowing users to perform data entry, modification, and retrieval conveniently through a browser.

The interface of the HALF storage ring magnet information table is shown in Fig. 5. The magnet data are organized by magnet type. Apart from the measurement date and operator, the main information of one measured magnet is coordinates of six targets, fiducialization result of six target, magnetic center and excitation curve result. For the multipole magnets of HALF storage ring, there are four types of quadrupole magnets, two types of sextupole magnets and two types of reverse-bend magnets. Users can view the detail information for each magnet and edit the excitation curve data and update the comment.

In the HALF storage ring, both quadrupole magnets and reverse-bend magnets include non-standard designs with slots to accommodate vacuum chambers for synchrotron radiation extraction. The standard quadrupole magnets are of laminated type, whereas the non-standard quadrupole magnets are of solid (massive) type. As a result, the excitation curves of these non-standard magnets differ from one another. Therefore, the magnet database and its web-based management platform not only provide a comprehensive



Num	Magnet Type	Number	Iop[A]	Measurement Date	Operator	Comment
1	Q1&Q5	SN02	128	2025-06-17	LY	Meets specifications
2	Q1&Q5	SN04	128	2025-06-18	LY	Meets specifications
3	Q1&Q5	SN03	128	2025-06-18	LY	Meets specifications

Figure 5: Interface of the HALF storage ring magnet info table.

summary of the measurement data for all magnets, but also support commissioning by enabling precise adjustment of magnet strengths.

SUMMARY AND OUTLOOK

For the construction of HALF, three kinds of magnetic field measurement systems have been established from March 2025. The first storage ring magnets arrived from June 2025. All multipole magnets and LGB magnets need to be pre-examined and fiducialized before installation in the ring. The measurement will be finished in June 2026.

To save the magnet data and satisfy the convenience of commissioning, a web-based database has been developed. In the future, the database will be connected to online server to record the magnet information and process variables in EPICS (Experimental Physics and Industrial Control System).

REFERENCES

[1] Z. Sun, G. Feng, and X. Liu, "Construction of Hefei Advanced Light Facility Begins", *Innovation*, vol. 4, no. 6, 100514 doi:10.1016/j.xinn.2023.100514

[2] L. Zhang *et al.*, "A single-turn rotating coil magnetic center calibration system designed for high energy photon source", *Meas. Sci. Technol.*, vol. 34, no. 8, p. 085017. doi:10.1088/1361-6501/accebc

[3] H. Liu *et al.*, "Magnetic Center Measurement and Fiducialization Method for Half", presented at the 17th International Particle Accelerator Conf. (IPAC'26), Deauville, France, May 2026, paper TUP7717, this conference.

[4] H. Liu *et al.*, "Magnetic center measurement and fiducialization with single stretched wire and precision surface plate", *Nucl. Instrum. Methods Phys. Res. A*, vol. 1082, p. 171051, 2026. doi:10.1016/j.nima.2025.171051