7 - 5 Status of the Superconducting Magnet System for HFRS

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The High Energy Fragment Separator (HFRS) within the Heavy-ion Accelerator Facility (HIAF) features a beamline comprised of 11 sets of superconducting dipoles and 39 sets of combined multipoles, spanning a length of approximately 180 m. The dipoles are constructed using warm iron superferric technology. Meanwhile, the combined multipoles feature a coil dominated DCT (Discrete Cosine-Theta) coil structure, offering a large aperture, high polar field, compact design, and robust operation. Overall, these superconducting magnets provide critical functionality for precise ion beam transport and separation in the HFRS.

The superferric superconducting dipoles boast a 15.7 m deflection radius, up to 1.6 T field, 320 mm wide good field region, and 2.74 m effective length. Comprising two superconducting coils, a coil box, a cryostat, and warm laminated iron, their prototype achieved the design current of 210 A without quench, yielding a magnetic field of 1.64 T in the good field area. Figure 1 (left panel) confirms excellent agreement between calculated and measured magnetic fields, while the right panel displays integral field homogeneities within in the good field region at different magnetic fields, fulfilling HFRS requirements. Currently, ten superferric dipoles are in batch production in Xian.

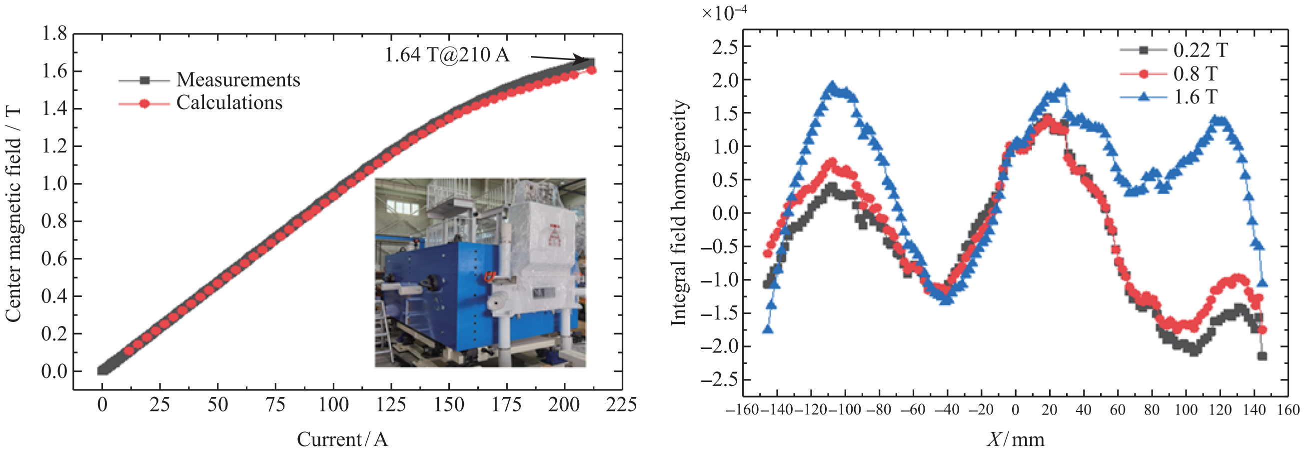

Fig. 1 (color online) The left panel is measured and calculated center magnetic field intensity versus the operating current of the super ferric superconducting dipole. The right panel shows the integral field homogeneities in the good field area at different center magnetic fields.

The DCT-type superconducting combined multipole has a large aperture of ϕ 320 mm and serves multiple field functions, including quadrupole, sextupole, octupole, and bidirectional correctors. Each unification coil requires specific field strengths of 13 T/m, 20 T/m^2, 200 T/m^3, and 0.1 Tm. The first prototype, L800-II, was successfully developed in late 2021, followed by L800-I and L1200, completed and delivered to Lanzhou in early 2022 (Fig. 2, left panel). During low-temperature excitation training, all single coils achieved their design current excitation, with correctors reaching 0.09 T@300 A, quadrupoles achieving 11.43 T/m@466 A, and sextupoles reaching 20 T/m@2230 A. The training process for L800-I and L1200 quadrupoles is depicted in Fig. 2, right panel. Next, the development of Triplet thermostats for the three prototypes will be completed, and batch processing and testing of HFRS series superconducting combined multipoles will be carried out.

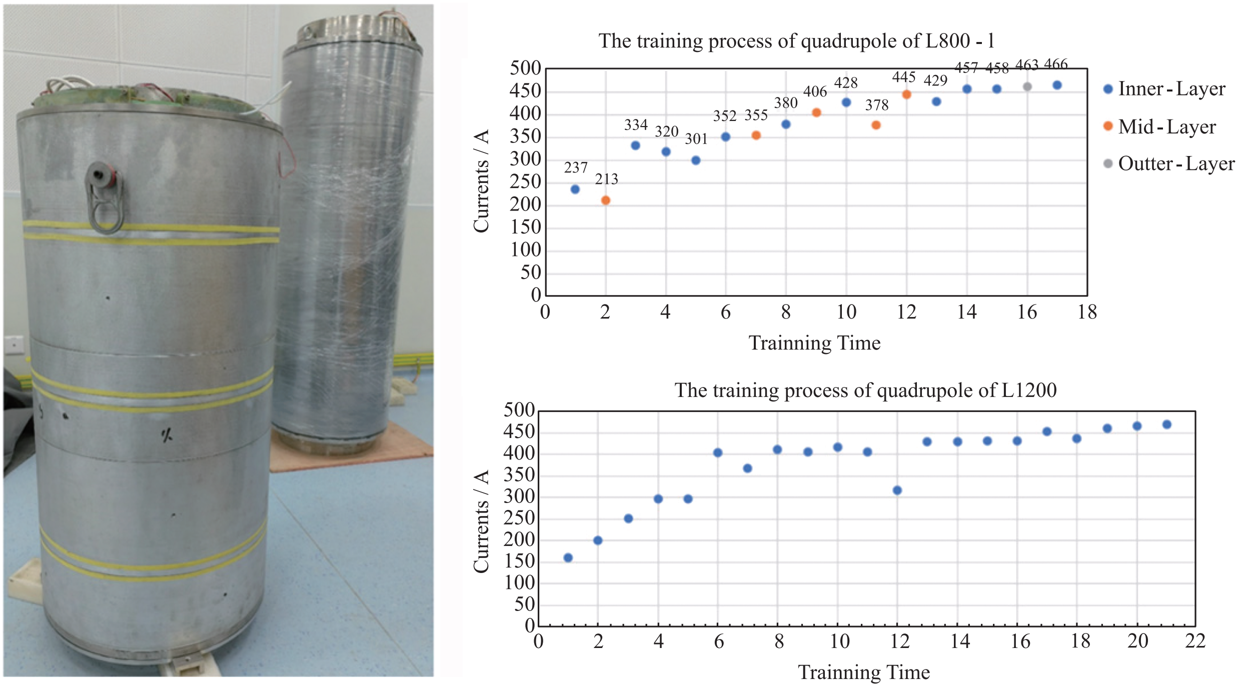

Fig. 2 (color online) The left panel shows the new two prototype multipole of L800-I and L1200, and the right panel shows the training process of quadrupoles in L800-I and L1200.

7 - 6 Design of Leakage Field Shielding Structure of the Septum Magnet for HIAF

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Septum magnet is one of the key components of synchrotron injection and extraction system. Because the excitation current flows through the septum plate coil, the excitation current is subjected to a large electromagnetic force. At the same time, under the limitation of the septum plate size, the leakage field has an effect on the circulating beam near the septum plate[1]. There are several septum magnets in the HIAF accelerator complex, so the shielding structure needs to be optimized and analyzed to further reduce the losses caused by magnetic leakage.

Based on the diversion plate type septum magnet at present, the leakage field is shielded by magnetic materials[2]. End shielding plate is installed at both ends of the septum magnet to shield end leakage field, and septum shielding plate is installed at the septum plate position to reduce the influence of edge field on the circulating beam pipeline area. By optimizing and analyzing the shielding structure with different parameters, the shielding structure is proposed to effectively suppress the leakage field, as shown in Fig. 1. At the same time, the problem of large leakage field at the corresponding position of the iron core end was solved by optimizing the coil model.

According to the final assembly, the height of the septum shielding plate is the same as that of the iron core, the length exceeds the core by 100 mm, and the thickness of the end shielding plate is 5 mm. It is compared with the leakage field distribution in the center of the circulating beam pipe without shielding, as shown in the Fig. 2. As can be seen from the Fig. 2, the shielding structure can effectively suppress the leakage field, especially in the part where the circulating beam is closest to the septum magnet. At present, the shielding structure has met the beam physics requirements, and the leakage field value is reduced from 0.549 to 0.036 T·mm, which is an order of magnitude smaller than that without shielding.