High Intensity Heavy-ion Accelerator Facility

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I. INTRODUCTION

The High Intensity Heavy-ion Accelerator Facility (HIAF) has been approved as one of the large-scale national science and technology infrastructural facilities in 12th Five-Year Plan. It has been constructing since the December of 2018 with a 7-year construction period. The total budget of 2.3 billion CNY was approved by the National Development and Reform Commission (NDRC), China. The HIAF project is organized by the Chinese Academy of Sciences (CAS) and implemented by the Institute of Modern Physics (IMP).

Figure 1.1 General Layout of the HIAF

HIAF is a new generation, world-leading high-intensity heavy-ion accelerator research facility. It is able to produce radioactive nuclides extremely far away from the line of beta stability. It can provide low energy heavy ion beams with the highest peak current in the world. It will be a state-of-the-art nuclear mass spectrometer which can provide pulsed heavy ion beams with a maximum energy of 4.25 GeV/u. The facility can provide a world-leading research platform to identify new nuclides, study weakly bound nuclear structures and reaction mechanisms, and especially measure the accurate masses of short-lived nuclei mass.

The HIAF project mainly consists of accelerators, experimental terminals, auxiliary devices and civil constructions. The accelerator complex is designed based on a combination of a superconducting linac and two synchrotrons. A series of new technologies are used in order to provide high-intensity, high-energy and high-quality heavy ion beams, and to produce radioactive nuclides far away from the stable line. The experimental terminals are constructed around the HIAF beam lines, to provide an excellent research conditions for nuclear physics, atomic physics, nuclear astrophysics and applications in materials and biology.

II. CONSTRUCTION PROGRESS

During the second year of the HIAF construction, development of key technologies has made a significant improvement. All prototypes have entered the final testing stage. The design and optimization of six major subjects have been finished completely. Prototypes related to these subjects are under construction or testing. Design of all conventional systems has been fixed and went into the assessment process. The HIAF BIM model, the construction drawing and the civil construction bidding process have been finished completely. The site construction work has been started this year.

1. Key technologies

In 2020, the key technologies and the prototypes have been made a significant breakthrough. A half-sized prototype of the first Nb_3Sn superconducting Electron Cyclotron Resonance (ECR) ion source magnet cold mass has been successfully developed and tested. High power 45 GHz microwave has been coupled to a high performance ECR ion source for the first time and intense highly charged ion beams have been produced. Efficient cooling of high-power microwave heating plasma chamber was realized with an innovative design of microchannel structure, which was one of the most challenging topics in the community. With an improved structure inductive heating oven, record beam intensities of highly charged uranium ions have been achieved.

Figure 2.1 Prototype of the first Nb_3Sn superconducting Electron Cyclotron Resonance (ECR) ion source magnet cold mass

Significant improvement was achieved on the prototype of the full-energy-storage fast-ramping power supply, especially on the topics of the space vector modulated rectification, the asymmetric H-bridge-based cascaded multi-level voltage switching control, the serial-parallel connection of high-power multi-converters and the high-performance digital control. The output current of 5100A was obtained in pulse operation mode. The current ramping rate is up to 52000A/s, which is much higher than its original design value. The voltage-switching full-energy-storage operation pattern of non-resonant power supply technology for synchrotrons has been verified firstly in the world. The power supply ensures a magnetic field ramping rate of 12T/s for heavy-ion accelerator to improve the operation efficiency.

Figure 2.2 Prototype of the full-energy-storage fast-cycling pulse-power

Figure 2.3 Output current of 5200A in pulse mode by the prototype

Based on the development of the prototype of the high-gradient broad-bandwidth fast-response RF system with nano-soft magnetic alloy (MA) loaded cavity, a platform for the MA core test and measurement was built at IMP. The production line of the MA core has been built by a cooperation with companies. A liquid-cooled MA core with a diameter of Φ750 mm was developed successfully, which is the best one in the world in the frequency range of 0.1~5.33 MHz.

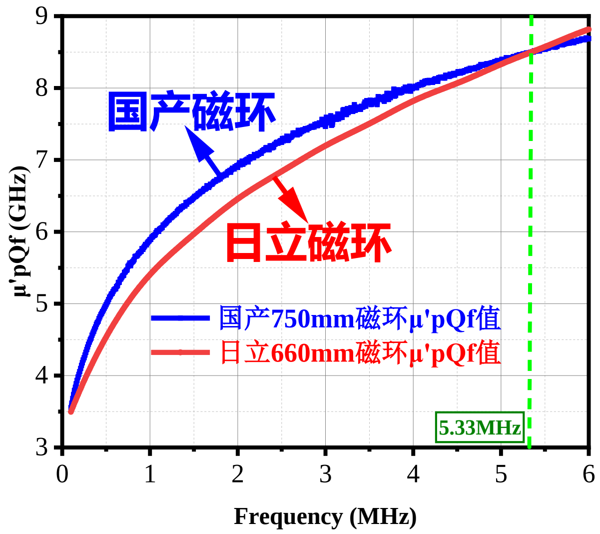

Figure 2.4 Key parameters measurement of HIAF core and Hitachi core


Figure 2.5 Equal tension horizontal winding system for core manufacture

The prototype of the ultra-thin-wall XHV chamber with ceramic lining, which was first proposed in the world, has been manufactured completely. The vacuum condition is better than 5×10^{-10}Pa. At the same time, the technology of Au/Ti/Cu/Ti multilayer coating on ceramic substrate has been developed based on long-term comparative experiments. The coating method significantly improves the adhesion of the film and could be used to solve the dynamic vacuum problems. The long-term baking stability data of cerium stabilized zirconia ceramics in XHV system have been obtained after twenty-two high temperature anti-aging tests of ceramics.

Figure2.6 Prototype of the ultra-thin-wall XHV chamber (left) and Au/Ti/Cu/Ti multilayer coating ceramic ring (right)

The full-size prototype of the fast ramping dipole magnet for BRing are completed. The technology of all-adhesive segmented laminated straight iron is adopted to ensure the high precision of the magnet. The strong fixed design is aimed at the cable support of the coil, which ensures the structure stability under the fast pulse operation. Coil test systems such as cylindrical coil, integral coil and coil array were built, and the static magnetic field test and dynamic test system calibration of the prototype were completed. By the magnetic field optimization, the static magnetic field achieved a high uniformity of $\pm 2.0\times 10^{-4}$ at full magnetic field in a wide good field region, which was better than the design requirement.

Figure 2.7 Full-size prototype of the fast ramping dipole magnet for BRing

The Canted Cosine Theta (CCT) coil technology is first adapted in the High energy FRagment Separator (HFRS). A prototype of the quadrupole and sextupole (Q&S) combination with half-aperture has been successfully developed and tested with the design current. The nested quadrupole and sextupole coils were energized to full current simultaneously after only one quench, which verifies the feasibility of the design and the reliability of the magnet structure.

Figure 2.8 Prototype of the quadrupole and sextupole (Q&S) combination with half-aperture

2. Major subjects

In 2020, six major subjects related to the HIAF project was organized and went smoothly. The design work and its optimization have been finished completely. The new generation particle accelerator physical control system (PACS) has been developed and applied on the HIRFL-CSR accelerator successfully. It is shown that the system is advanced, reliable and practical. An impedance-matching BPM (beam position monitor) related to the real-time closed orbit feedback subject is under design, in order to measure the beam position of ion beam bunches turn by turn in HIAF. In the machine protection subject, a protection scheme was proposed based on the beam optics. A redundant loop architecture for the interlock signal transmission and the post-mortem system for fault data processing were designed. In the timing system subject, a high precision time-delay digital circuit and its software debugging were finished. A commissioning together with other system will be arranged in the next year. In the

HFRS radiation protection subject, the unique protection scheme including shielding, pluggable unit, transport and maintenance was designed. A proof-of-principle experiment of this radiation protection scheme was demonstrated. The prototype of PF0 primary target chamber and the mechanical structure of beam dump were designed completely. The corner septum for two phase painting injection is designed to reduce the beam loss during injection period. In 2020, an optimization of high homogeneity electrostatic field in the septum was studied. A multi-parameter optimization model for the septum design was established. The structure with double auxiliary electrodes was fixed. The techinal design of prototype was complete.

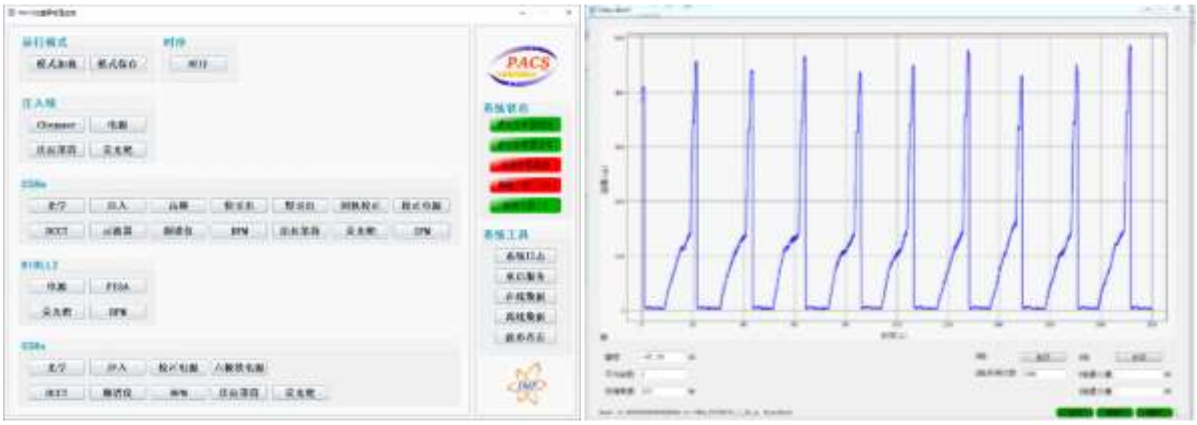

Figure 2.9 Control panel of PACS-CSR (left) and beam current in CSRm (right)

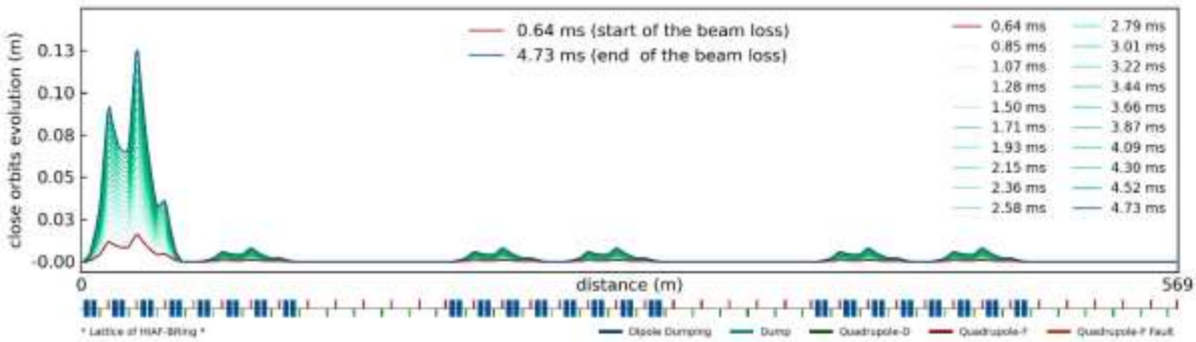

Figure 2.10 Machine protection scheme based on the beam optics

3. Conventional systems

Conventional systems, which have less technical challenges, are also the important parts of HIAF. In 2020, the main task of conventional systems is to improve the qualities, stabilities and reliabilities. There are nine conventional systems in HIAF, including magnets, power supplies, vacuum, computer control, beam diagnostics, electron cooler and so on. According to the HIAF CPM (Critical Path Method) plan, all conventional systems have finished the design optimization process. The design assessment and hardware manufacture were also started. It provides a thorough grounding in the HIAF construction in the future.

 

Figure 2.11 Electron cooler test bench (left) and magnetic field measurement platform for coils (right)

Figure 2.12 Pick-up for SRing stochastic cooling system

4. Civil construction

BIM (Building Information Modeling) technology was introduced and applied into the HIAF civil construction in 2020. Large mechanical assembly units, supporting system, buildings and Revit civil engineering 3-D drawing were combined in the BIM model. The HIAF BIM model is used to integrate the buildings, accelerator components, constructions and operations into a 3-D model information database. At present, a complete civil engineering equipment model has been built. The successful application of BIM technology in HIAF provides a strong data support for civil construction. It is a great significance to improve the quality and ensure the progress of the HIAF project.

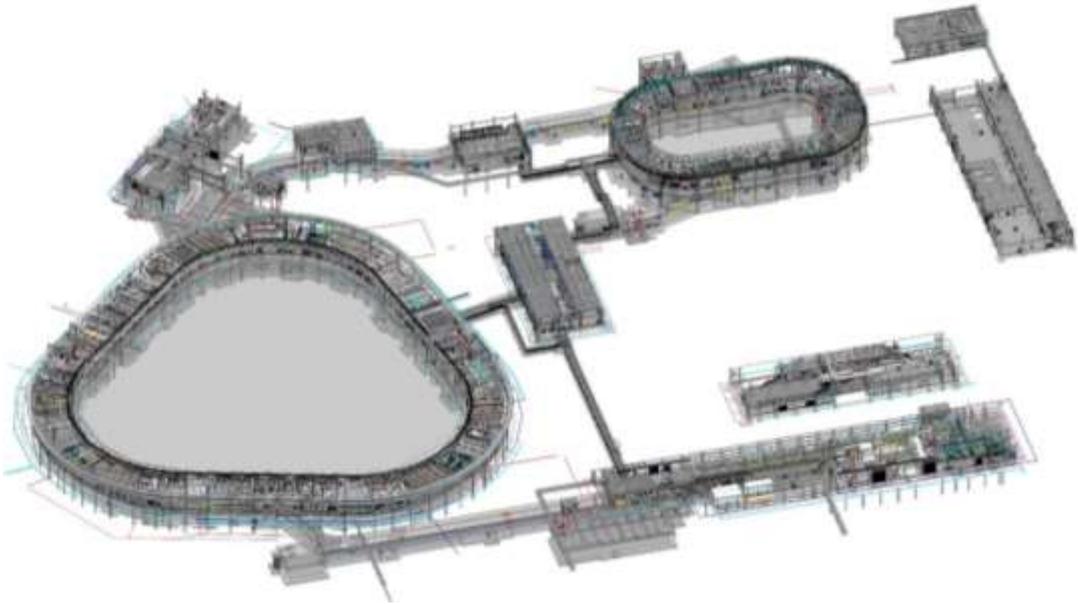

Figure 2.13 BIM model of the HIAF campus

After two years of intensive construction, all earthwork excavation, slope support, flood prevention and drainage, soil and water conservation and other on-site construction of HIAF were completed. At the same time, the project team and the design unit jointly optimize and refine the construction drawing design. The construction and installation of the accelerator tunnel and other units will be promoted as soon as possible according to the overall arrangement of the project.

Figure 2.14 Photo of the HIAF campus

Figure 2.15 HIAF operation build has been topped off

Preliminary design on the water cooling, air conditioning, power distribution, ground gird, electromagnetic compatibility and radiation protection has been completed, and all of them have been reviewed by experts. The construction drawing design work is being done.


Figure 2.16 On-line assessment meeting on air-conditioning system

5. Cooperation and communication

On 26th November, the Institute of Modern Physics and China Southern Power Grid signed a cooperation agreement in Lanzhou, to optimize the HIAF and CiADS energy system and improve the energy efficiency.

Figure 3.1 Signing ceremony on the cooperation agreements between IMP and CSPG

6. Milestones

On 16th Match, 2020, LUO Wen, Deputy Minister of National Development and Reform Commission (NDRC), visited the campus and investigated the construction of the HIAF and CiADS projects.

Figure 4.1 LUO Wen, Deputy Minister of NDRC visited the HIAF and CiADS campus

On 24th June, the review meeting on the Fire Protection Design of HIAF was organized by Department of Housing and Urban-Rural of Guangdong Province.

Figure 4.2 Review meeting on Fire Protection Design of HIAF

On 12th August, WANG Xi, Deputy Governor of Guangdong Province, visited the HIAF and CiADS campus and investigated the construction progress.

图 4.3 Academician ZHAN Wenlong gave an introduction of the HIAF status to Academician WANG Xi

On 5th September, LIU Ji Deputy Secretary of Municipal Party Committee, Mayor of Huizhou City, visited the campus and investigated the construction of the HIAF and CiADS projects.

On 8th December, ZHANG Tao, Vice President of the Chinese Academy of Sciences visited the campus and investigated the construction of the HIAF and CiADS projects.

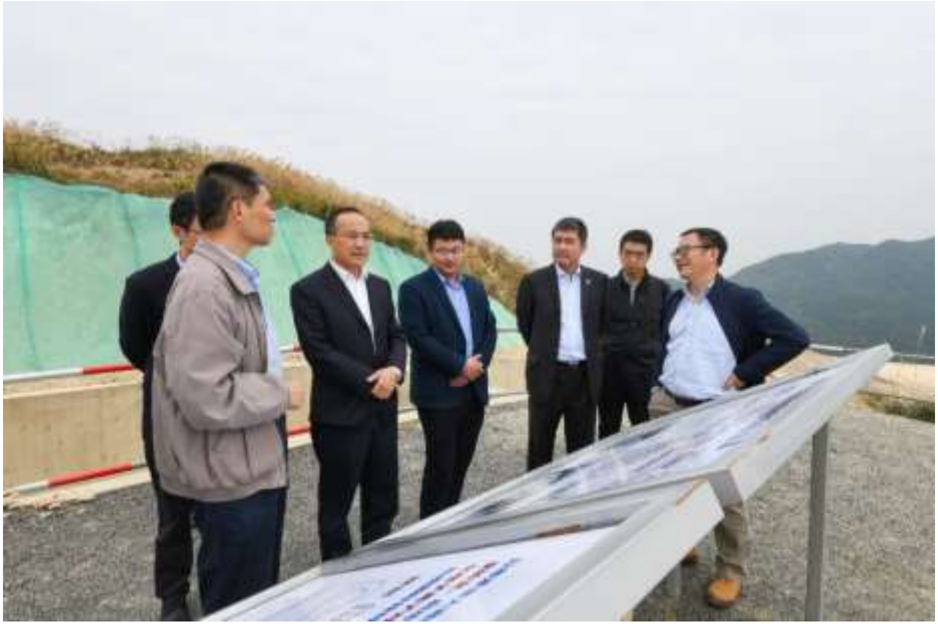

Figure 4.4 Academician ZHAN Wenlong gave an introduction of the HIAF and CiADS status to Academician ZHANG Tao