High Intensity heavy-ion Accelerator Facility

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1. Overview

The High Intensity heavy-ion Accelerator Facility (HIAF) is a major national science infrastructure approved as one of the key national scientific infrastructure projects during the 12^{th} Five-Year Plan. The construction of the HIAF project started on December 23^{rd} 2018 in Huizhou City of Guangdong province. The construction period is 7 years and the total investment is 2.3 billion CNY. The Institute of Modern Physics of CAS is the legal entity of the HIAF project.

Figure 1.1 General Layout of the HIAF

The HIAF project will be one of the highest power heavy ion accelerators in the world. The scientific mission is to provide pulsed heavy ion beams with highest peak currents. The maximum energy is up to 4.25 GeV/u. It will be used to produce radioactive nuclides extremely far away from the beta stability line by fragmentation of those primary beams. The HIAF accelerator will be the most important and highest precision nuclear mass spectrometer in the world, which can provide a world-leading research platform on nuclides identification, weakly bound nuclear structures, reaction mechanisms and short-lived nuclei mass measurement.

The HIAF project construction contents comprise accelerators, experimental terminals, auxiliary systems and civil constructions. The accelerator complex mainly consists of a superconducting linac, a synchrotron booster and a storage ring. The combination of those accelerators is optimized to provide high-current, high-energy and high-quality heavy ions and rare radioactive isotopes. Six experimental terminals will be built around the HIAF beam lines for different research areas including nuclear physics, atomic physics, nuclear astrophysics, materials and biology.

2. Construction progress

In 2021, scientific equipment purchases and civil construction were in full swing. The key technologies developments including power supplies, RF cavities and vacuum chambers have been accomplished successfully. Tests of the prototypes showed that all parameters met or even exceeded the design specifications. The fabrications of these devices are still going on. Conventional equipment such as DC power supplies and common magnets began to be manufactured in batches. The auxiliary systems such as air-conditioning system and water-cooling system have been procured through open tender. The civil construction has been completed nearly 30%. Some buildings' main structures have been completed recently and now are offered for acceptance testing. The civil construction will be completely finished in 2022.

(1) Key technologies

The components of the 45 GHz Nb_3Sn ECR (Electron Cyclotron Resonance) ion source cold mass are now ready, with detailed tests and quality analysis being completed. Conventional parts of the ion source, such as injection setup, high power aluminum plasma chamber with micro-channel cooling, intense ion beam extraction system and so on, have been tested on the off-line test platform, and now are in place for final assembly.

Figure 2.1 Nb_3Sn ECR ion source cold mass

The MA-material (nanocrystalline soft magnetic alloy material) for RF system with high field-gradient, broad band and fast response time has broken through foreign blockade on material preparation and technical process. The domestic liquid-cooled magnetic alloy ring core with φ750 mm diameter has been successfully developed. Its key performance in the frequency range of 0.1~20 MHz surpasses the best product in the world and has reached the international advanced level. The first domestic production line for high performance and large size magnetic alloy ring has been established. The static and power state performances test platform for magnetic alloy ring has also been constructed. The system manufacturing of high-performance liquid-cooled magnetic alloy loading cavity, 500kW RF power source and low-level control system has been completed, and joint commissioning is underway.

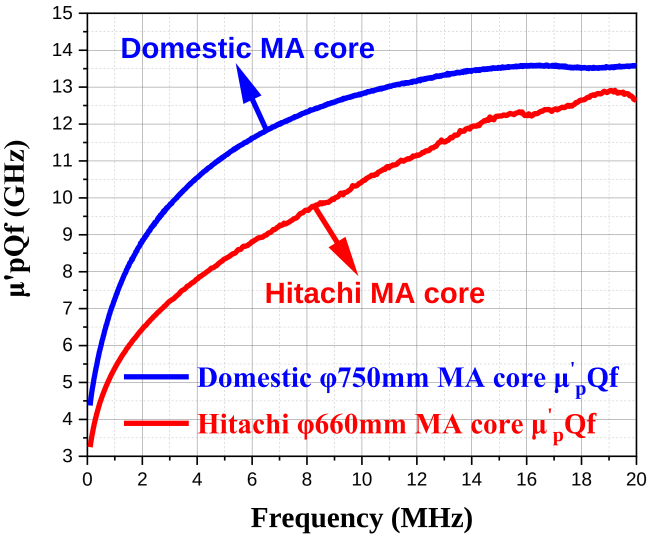

Figure 2.2 Domestic liquid-cooled MA ring cores (ø750mm) vs. Hitachi rings (ø

660mm)

Figure 2.3 MA loaded RF cavity prototype under test (vacuum: 5.5×10^{-12} mbar)

A breakthrough has been made in the development of the prototype of the full-energy-storage fast-cycling pulse power supply. Under the condition of full energy storage and vector rectification, all power units of a single prototype are debugged with real load in series and parallel mode. The experimental output is 3900A/3Hz with the rising rate 40000A/s and the tracking error $\pm9.6\times10^{-5}$, which reaches the international advanced level. The working principle of the whole machine, the second version of the SZF-3 controller and all indicators under a single magnet load have been verified. At present, high-frequency filtering experiments to suppress the power supply ripple have been carried out, and the bulk purchase of power supplies has been completed. The next step will be to carry out the long-term test of the reliability and stability of the power supply, discuss and optimize the power supply technological schemes, and start batch processing.

Figure 2.4 Prototype of the full-energy-storage fast-cycling pulse power supply

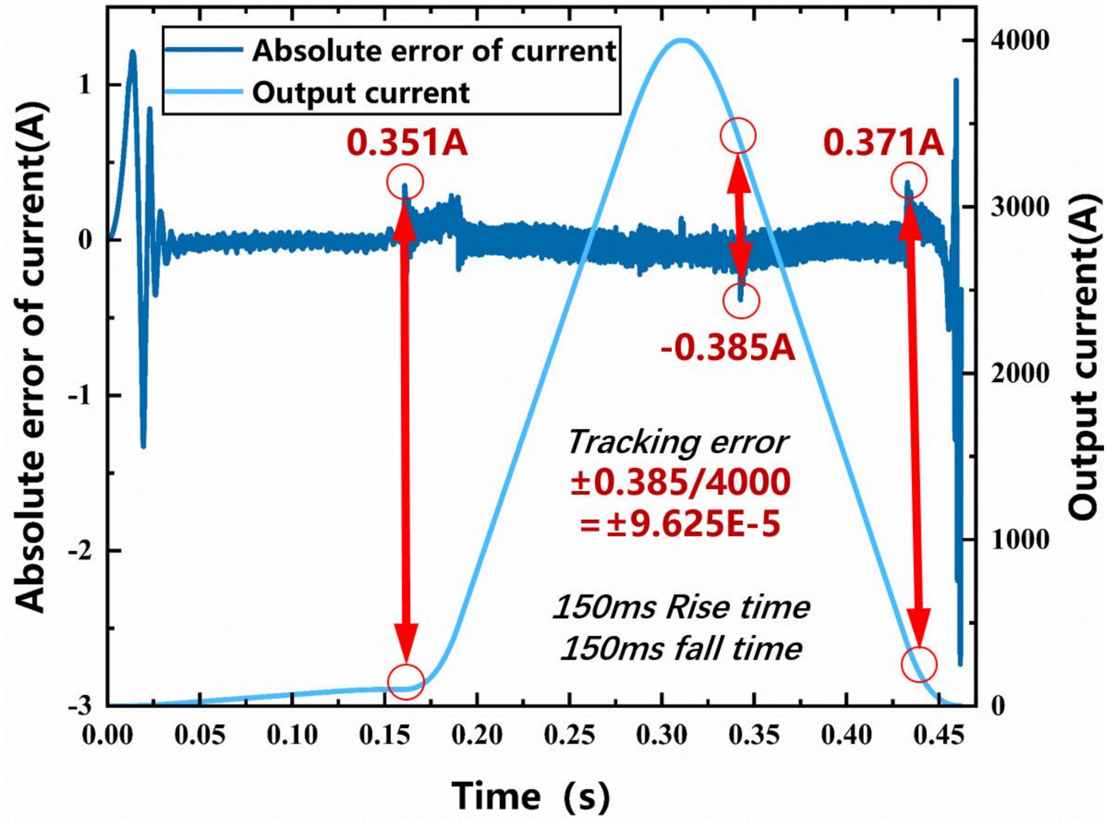

Figure 2.5 Output test of 3900A under real loads in the prototype of the full-energy-storage fast-cycling pulse power supply

The prototype of the fast ramping dipole magnets of BRing had been finished in 2020. After several rounds of optimization, the final process scheme has been finished in 2021, a lot of high-precision static and dynamic magnetic field measurements was already carried out. In order to test the combined performance of the key prototypes, a united test platform was developed based on the BRing layout diagram. The main purpose is to test the overall performance of the fast ramping dipole magnet, full-energy-storage fast-cycling pulse power supply, ceramic-lined thin-wall vacuum chamber, beam position monitor (BPM), electromagnetic compatibility, infrastructure, and so on. Up to now, 11 magnets have been manufactured, and all 48 magnets are expected to be finished by March 2023.

Figure 2.6 BRing fast ramping dipole magnet manufacturing site

Figure 2.7 United test platform for the dipole ramping

The first proposed full-scale prototype of the ceramic-lined thin-wall vacuum chamber in the world has been developed. The pressure of the large-section vacuum chamber is less than 4.3×10^{-12}mbar with the wall thickness of only 0.3mm. The batch production of the vacuum chamber has been implemented after repeated discussions and optimizations on the process scheme. The baking lifting support stand is designed and the combined test with the dipole magnet has been completed. The results show that the displacement of the ceramic-lined thin-wall vacuum chamber is less than 0.5mm, which solves the baking problem of the vacuum chamber. At the same time, the magnetron sputter coating machine for ceramic ring has been developed. Through the PLC automatic control system, the wide heating rangesing from room temperature to 300°C of the ceramic rings and the four thin layer surface deposition (Au/Ti/Cu/Ti) have been successfully realized.

Figure 2.8 Magnetron sputter coating machine for ceramic ring

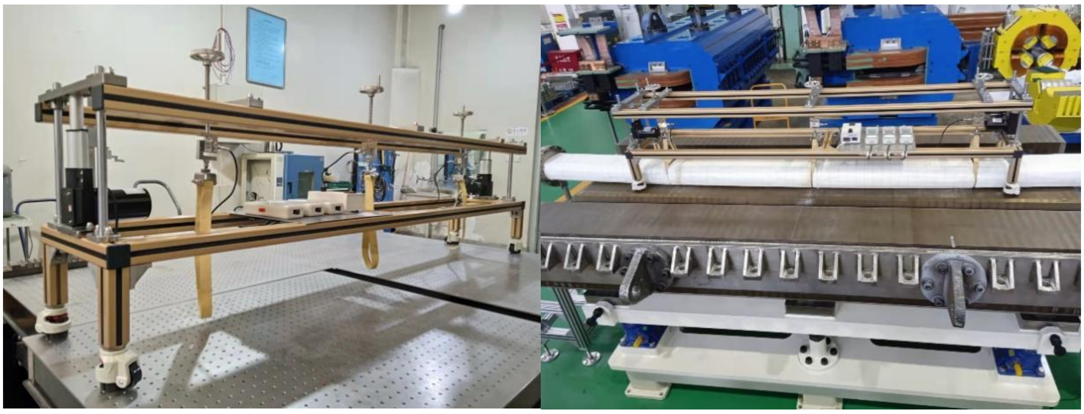

Figure 2.9 Combined test of the lifting support stand for ceramic-lined thin-wall vacuum chamber with the dipole magnet

In the HIAF FRagmentation Separator (HFRS), a novel Canted-Cosine-Theta (CCT) coil technology is used for the first time. Based on the experiences of the half-aperture CCT multipole prototype, the design group successfully developed a full-aperture superconducting multipole combined prototype magnet with full length of L800mm. The excitation current test of the octupole coil in low-temperature reaches to the design specifications, and the quadrupole coil reaches up to 92%. It is expected to finish the full current test and field quality verification in March 2022.

Figure 2.10 Full-aperture superconducting multipole combined prototype magnet and the low temperature test components

(2) Equipment processing and manufacturing

In 2021, most of the equipment's purchase and developments were on schedule. The HIAF quality control system has been implemented effectively to improve fabrication process and stabilization. Several rounds of iteration have been done to optimize the engineering design of the project. The qualities of the equipment during batch processing were strictly controlled by dedicated persons. Through the processing and testing of the first set of the equipment, the technology scheme and fabrication process were further optimized.

All subsystems of HIAF are progressing smoothly in accordance with the CPM plan. In the front-end system, fabrication and testing on various equipment have been finished, including the high-power stripping target, chopper, machine protection system and the fast chopper magnet, etc. In the superconducting ion Linac system (iLinac), most of the equipment, including RFQ, superconducting cavities, cryomodules and power sources, has been purchased and is about to arrive. In the magnet system, the sextuples of BRing and radiation resistant magnets of HFRS have already been purchased, and quadruples of BRing are on batch processing. All other magnets were designed and ready to be purchased. In the power supply system, the first set of three types of DC power supply have been manufactured and tested. The assembly and commissioning of the power supply for BRing kicker have also been completed. In the vacuum system, some standard equipment such as sputtering ion pumps have been purchased. Two specifications of ceramic-lined thin quadrupole vacuum chamber and the thin reinforced vacuum chamber have been manufactured and tested. In the beam diagnosis system, the self-designed beam position monitor (BPM) is completed. The first set of strip-line electrode, scintillator and ionization chamber have been manufactured and tested. In the machine protection system, algorithm design as well as hardware has been finished and tested. In the control system, high-precision distributed timing system has been designed and tested. In the electron cooling system, the high-precision solenoid coils and high-voltage isolation transformers have been manufactured and assembled.

Figure 2.11 Combined test of the front-end chopper, power supply, timing system and machine protection system

Figure 2.12 The 45 degree fast-chopper magnet (left) and its power supply (right) in front-end system

Figure 2.13 Rough processing of the RFQ in iLinac

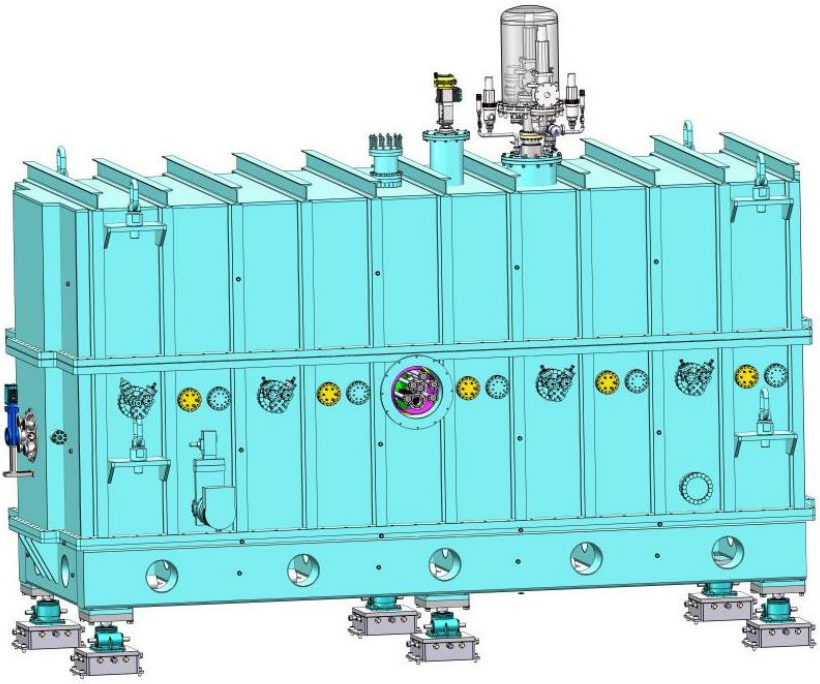

Figure 2.14 QWR007 cryomodule in iLinac

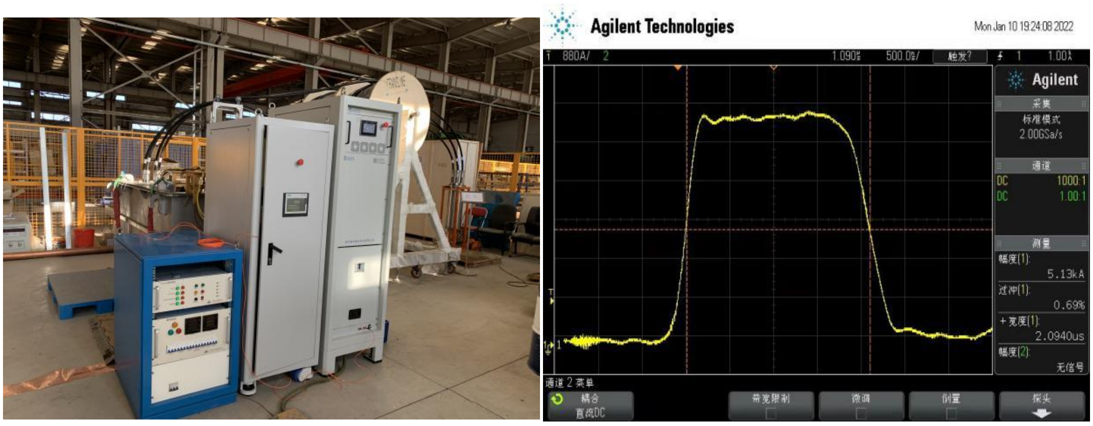

Figure 2.15 Overview of the BRing kicker power supply and its load current result

(rise time < 400ns, flatness ±2%)

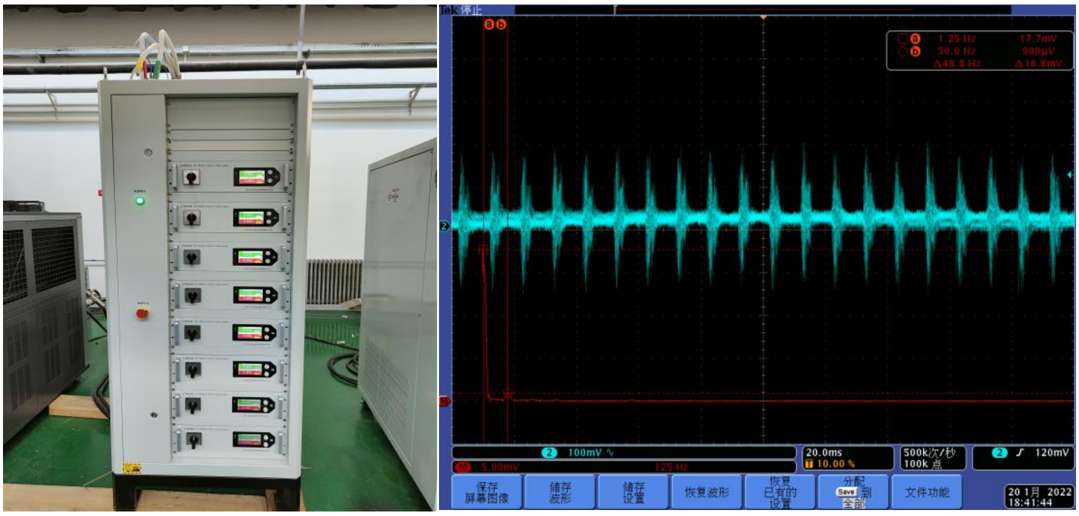

Figure 2.16 HFRS dipole power supply and its test result (1450A/145V)

Figure 2.17 The ceramic-lined thin vacuum chamber for the BRing quadrupole

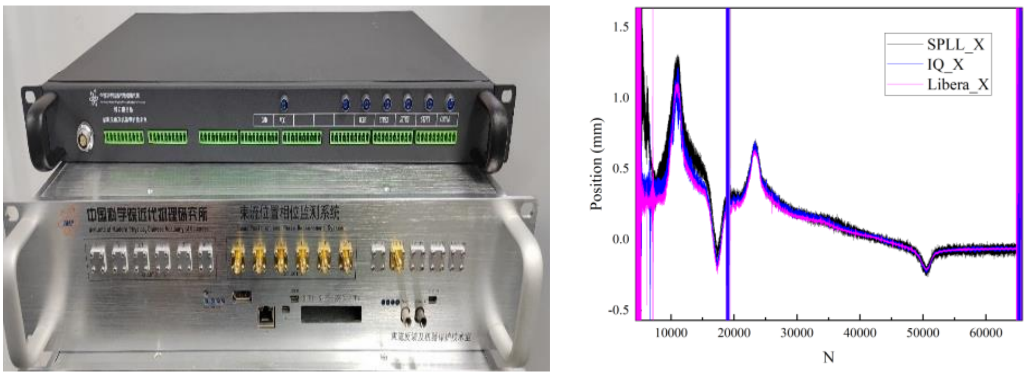

Figure 2.18 Comparison between the self-designed BPM electronics and the commercial Libera product (The online measurement results of the two products are in good agreement)

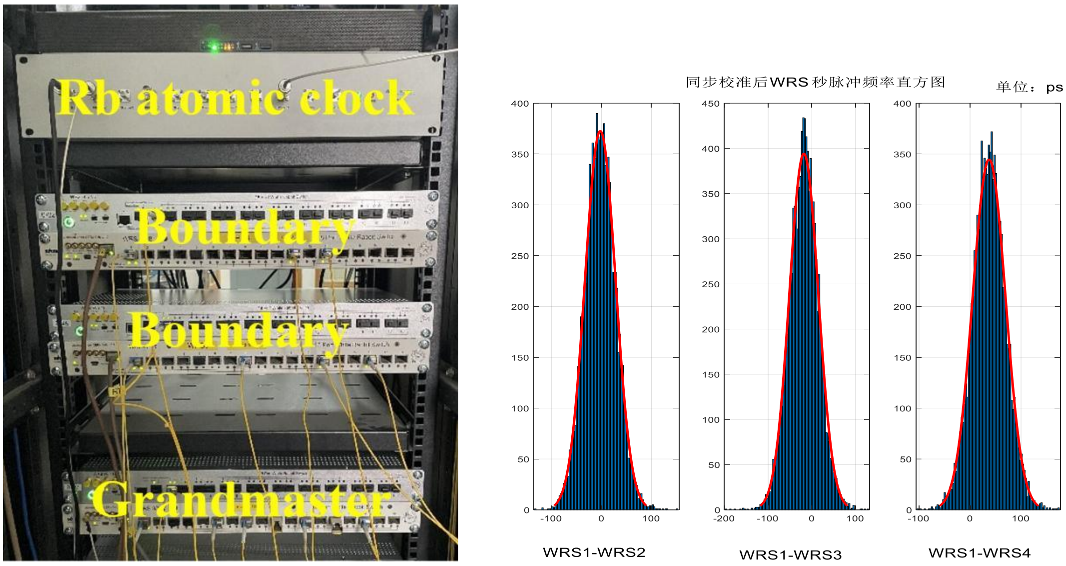

Figure 2.19 The timing system and its test result

Figure 2.20 The high-precision solenoid coil (left) and the isolation transformer (right) in the electron cooling system

(3) Experimental terminal detectors

In 2021, the experimental terminal has completed the joint BIM modeling of beam line and detectors' three-dimensional mechanical assembly combined with civil construction, and completed the optimized design of detectors and part of prototype processing. A diamond time-of-flight detector prototype has been developed. The prototype processing and the joint test between HFRS primary target chamber and pillow seal have been completed. The design and test of HFRS prototype about radiation-resistant fluorescent target have been completed. The prototype of the high-precision ring spectrometer SRing wall current detector and its in-beam test have been completed.

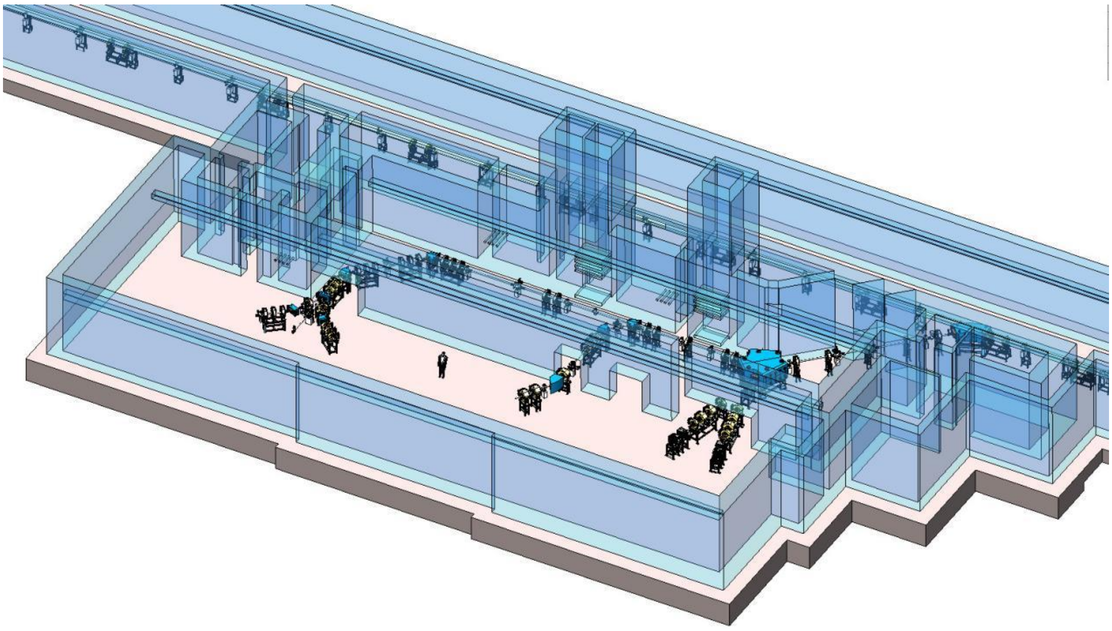

Figure 2.21 The 3D general layout of low-energy comprehensive terminal hall

Figure 2.22 The diamond time-of-flight detector prototype

Figure 2.23 The prototype processing and the joint test between HFRS primary target chamber and pillow seal

Figure 2.24 The prototype of HFRS radiation-resistant fluorescent target

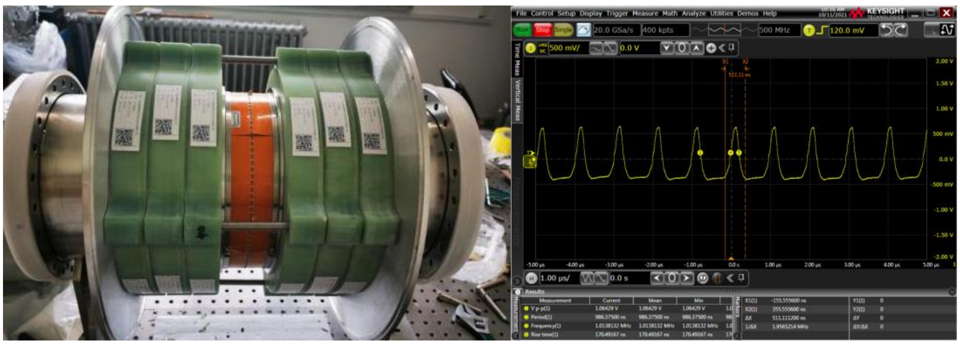

Figure 2.25 The prototype of the high-precision ring spectrometer SRing wall current detector and its in-beam test

(4) Construction progress

In 2021, subsystems including water-cooling, air-conditioning, power distribution, grounding grid, electromagnetic compatibility and radiation protection systems have been designed completely. All subsystem's design work has been reviewed by experts. Contracts for the water-cooling, air-conditioning and power distribution systems have already signed. Installation and commissioning will be started in June 2022.

Civil construction has been proceeded as planned. The construction of various parts and buildings of HIAF campus started in September. Up to now, nearly 30% of civil construction has already been completed. A total of 6500 square meters tunnel floor and 9000 cubic meters concrete had been completed this year. The buildings of test building, water supply building, dormitory, No. 1 refrigeration center, etc. have been completed.

Figure 2.26 Preliminary design review site of local supporting projects in Huizhou

Figure 2.27 Aerial photograph of HIAF campus (18th January, 2022)

Figure 2.28 Acceptance of HIAF accelerator tunnel collimating pile

Figure 2.29 Reinforcement binding of HIAF accelerator tunnel bottom plate

3. Miles Milestones

On 19th February, HU Hong, Secretary of municipal party committee, investigated the construction of HIAF and CiADS.

Figure 3.1 Hu Hong investigated HIAF and CiADS campus

On 27th March, DING Zhongli, Vice Chairman of the Standing Committee of National People's Congress and Chairman of the Chinese Democratic League, Academician of CAS, investigated the construction of HIAF and CiADS.

Figure 3.2 Academician DING Zhongli visited the HIAF and CiADS campus

On 13th April, WANG Rong, Chairman of Guangdong Political Consultative Conference, investigated the construction of HIAF and CiADS.

Figure 3.3 WANG Rong visited the HIAF and CiADS campus

On 2nd September, WU Shiwen, Deputy director of the Department of Science and Technology of Guangdong Province, investigated the construction of HIAF and CiADS.

Figure 3.4 WU Shiwen visited the campus of HIAF and CiADS