ISBN: 978-3-95450-260-8 ISSN: 2673-5547 doi: 10.18429/JACoW-HIAT2025-MOY01

STATUS OF THE HIAF ACCELERATOR FACILITY IN CHINA*

J. C. Yang† and HIAF project team
Institute of Modern Physics of the Chinese Academy of Sciences, Lanzhou, China

Abstract

The High Intensity Heavy-Ion Accelerator Facility (HIAF) is one of the major scientific infrastructures in China. The project is managed by Institute of Modern Physics, Chinese Academy of Sciences, and the construction is started on December, 2018 in Huizhou City of Guangdong Province. The main feature of this facility is to provide high intensity heavy ion beam pulse for various experiments. At present, most of the accelerator equipment has been installed and tested. The beam commissioning is scheduled for the second half of 2025. In this paper, an overview of the status and perspective of the HIAF project is reported.

INTRODUCTION

The High Intensity heavy-ion Accelerator Facility is a new accelerator facility under construction at the Institute of Modern Physics (IMP) in China [1]. It is designed to provide intense primary heavy ion beams for nuclear and atomic physics, as well as other application fields. The accelerator consists mainly of a superconducting electron-cyclotron-resonance (SECR) ion source, a continuous wave (CW) superconducting ion linac (iLinac), a booster synchrotron (BRing) and a high precision spectrometer ring (SRing). A fragment separator (HFRS) is also applied as the beam line to connect BRing and SRing. Six experimental terminals will be built in phase-I at HIAF. The layout of the HIAF accelerator was shown in Fig. 1, and the main parameters are listed in Table 1.

The construction of the HIAF project was started officially in December 23rd, 2018. Up to now, all the construction of the accelerator tunnel and on-ground buildings has been completed. Auxiliary facilities such as cooling water, ventilation and air conditioning, high and low-voltage power distribution, power distribution, and cryogenic systems have been installed and debugged, and are now in operation. Almost all the accelerator components have been installed and online testing has been completed. An updated time schedule of HIAF construction is shown in Fig. 2. The first beam is expected to be launched at BRing in the middle of 2025. The Day-one experiment is proposed around the end of 2025.

Figure 1: Layout of the HIAF project and the on-site landscape.

Table 1: Main Parameters of the HIAF Accelerators

	SECR	iLinac	BRing	HFRS	SRing
Length / circumference (m)	---	114	569	192	277
Final energy of U (MeV/u)	0.014 (U^{35+})	17 (U^{35+})	835 (U^{35+})	800 (U^{92+})	800 (U^{92+})
Max. magnetic rigidity (Tm)	---	---	34	25	15
Max. beam intensity of U	50 pμA (U^{35+})	28 pμA (U^{35+})	10^{11}ppp (U^{35+})		10^{10}ppp (U^{92+})
Operation mode	DC or pulse	CW or pulse	fast ramping (12T/s, 3Hz)	Momentum-resolution 1100	DC or deceleration
Emittance or Acceptance (H/V, π·mm·mrad, dp/p)		5 / 5	200/100, 0.5%	±30mrad(H)/±15 mrad(V), ±2%	40/40, 1.5%, normal mode

---

* Work supported by the National Development and Reform Commission, China

† email address: yangjch@impcas.ac.cn.

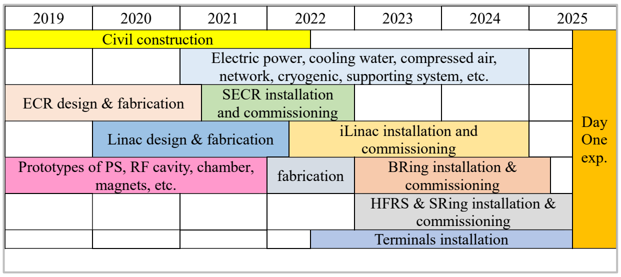

Figure 2: Time schedule of the HIAF construction.

FRONT END

Pulsed 50 pμA (~1 ms) U^{35+} ion beam from SECR is required in the HIAF project, which is 5 times higher than the present records of the 3rd generation ECR ion source. It can only be met by sources operating at higher magnetic field and higher microwave frequency. SECR incorporates with a Nb_3Sn high field superconducting magnet and a quasi-optical 45 GHz gyrotron microwave system, as shown in Fig. 3. The biggest challenge lies in the design and fabrication of the Nb_3Sn magnet [2]. A promising cold mass design has been completed by a collaboration with LBNL, as shown in Fig. 3. Up to now, the full-sized cold-mass have been completed and tested, and the whole system is ready to be installed in this year.

Figure 3: The world's first 45 GHz ECR ion source has been successfully developed and commissioned.

Working at the frequency of 81.25 MHz, the HIAF RFQ aims at accelerating particles with a charge-to-mass ratio of up to 1/7, increasing the energy of particles from 0.014 MeV/u to 0.8 MeV/u in a length of 8.55 m. Depending on the particle type, the RFQ was designed to work in CW or pulse mode, and the KP factor was controlled below 1.6 and 2.0 for the two modes to reduce the RF breakdown rate. The RFQ has been installed in the HIAF accelerator tunnel as shown in Fig. 4, and the first 1emA $^{16}O^{6+}$ beam have been successfully commissioned.

Figure 4: HIAF RFQ have been installed and commissioned.

LINAC INJECTOR

The iLinac is used as the injector of BRing and the main accelerator for the low energy nuclear structure terminal. That's why a CW superconducting linac is proposed in HIAF. Two types of accelerating structures in 17 cryomodules are used to achieve the energy of 17 MeV/u for U^{35+} ion beam. The first 6 cryomodules with QWR007 cavities is used to accelerate U^{35+} ions to 5.4 MeV/u. The rest cryomodules are installed with HWR015 cavities. These cavities will be made based on the experience of the CiADS project. A layout of iLinac is shown in Fig. 5, the installation and commissioning of the system will be completed soon this year.

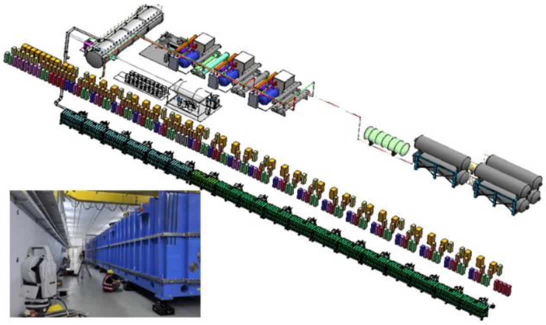

Figure 5: 3-D view of iLinac. SECR locates on left side.

BOOSTER SYNCHROTRON

The Booster Ring (BRing) is the key component of the HIAF project. It is designed with a maximum magnetic rigidity of 34 Tm, which is intended for the storage of U^{35+} ions to an intensity of 2×10^{11} particles with the energy of 835 MeV/u. It has a three-folding symmetry lattice with DBA (double bend achromat) structure. The ionization processes with residual gas particles is the main issue with respect to potential beam loss. Therefore, the lattice design is to localize the beam loss at certain positions to install collimators [3]. BRing offers a transverse H/V acceptance of 200/100 π·mm·mrad to overcome space charge limits of high intensity beams. It is operated below the transition energy to avoid beam loss by transition-energy crossing.

To obtain a high average beam intensity and avoid space charge limits, transverse phase space painting (4-D) is implemented for beam accumulation and a rapid ramping cycle [4] is used to reduce the integral ionization cross section. Related components such as tilted electrostatic septum, ceramic-lined thin-wall vacuum chamber, fast-cycling power supply and magnetic alloy (MA) acceleration cavities are developed for BRing. As shown in Fig. 6, the installation the BRing has been finished and all the supporting systems are undergoing beamless testing. The beam commissioning is scheduled to begin by the end of 2025.

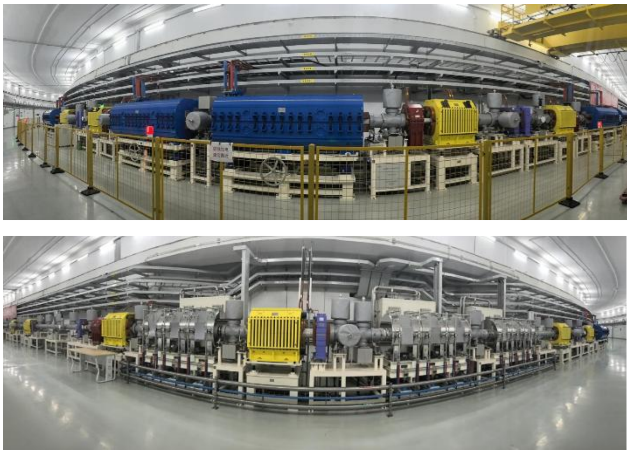

Figure 6: BRing layout in the tunnel.

FRAGMENT SEPARATOR

The High energy Fragment Separator (HFRS) is an in-flight separator at relativistic energy. The schematic layout is shown in Fig. 7. A primary beam from BRing hits the target at PF0. The rare isotopes produced by projectile fragmentation or fission will be collected and purified by the HFRS with the Bρ-ΔE-Bρ method. The magnetic rigidity up to 25 Tm can be operated in HFRS. The large acceptance including the angular acceptances ±30 mrad (H) / ±15 mrad (V) and the momentum acceptance ±2% provides a high collecting efficiency. A two-stage structure is used in HFRS design. The pre-separator is used to dump the primary beams and undesired fragments. The main separator is used to identify the rare isotopes. Details of the HFRS design can be found in Ref. [5]. Currently, the target station and the beam transportation line have been installed, and beamless testing is underway.

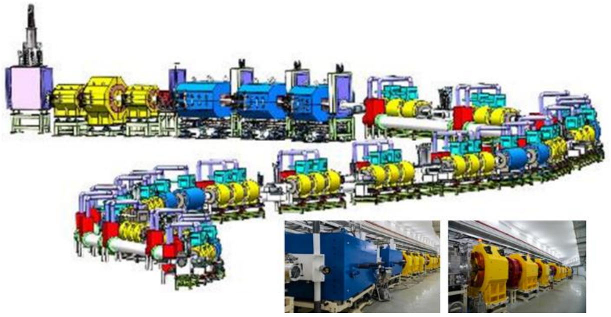

Figure 7: 3-D view of HFRS and on-site photos (partial).

SPECTROMETER RING

SRing is designed as a multi-function experimental storage ring, which can be operated in three modes. Firstly, it will be used as an isochronous mass spectrometer (IMS mode) with two TOF detectors for short-lived neutron-rich nuclei. Secondly, it is used to collect and cool long-lived rare isotopes for nuclear experiments, or accumulate and extract highly-charged stable ions for high energy density physics (normal mode). Thirdly, it can be used to store H-like, He-like or other special charge state ions for internal target experiments (target mode). Ions can be decelerated to tens MeV in this mode. Details are available in Ref. [6].

A 450 keV magnetized DC electron cooler is used to boost the luminosity of internal target experiments, and proposed to accumulate isotopes combined with stochastic cooling and barrier bucket system [7]. In addition, an electron target system is equipped in SRing for atomic physics, which is similar to the e-cooler and can provide electron beam up to 80 keV.

At present, all components of the SRing accelerator have been installed and tested (Fig. 8). Next, the experimental components are being installed. The Day-one experiment is expected to be carried out at the end the 2025 or early 2026.

Figure 8: SRing layout in the tunnel.

SUBSYSTEMS

The HIAF project has successfully implemented several key technologies through rigorous testing and long-term operation, meeting the design specifications. Notable achievements include the fully-stored fast-cycling power supply system, which has been fully installed and operational, achieving a maximum current of 3,900 A (Fig. 9), a maximum voltage of 4,300 V, and a maximum current rise rate of 38,000 A/s, with a stable operating frequency of 3 Hz. These performance parameters meet the design specifications, and the system has undergone long-term operational testing and precise dynamic calibration of the magnetic field at high frequencies, ensuring a magnetic field error of less than 1 Gauss.

The project has also successfully implemented five high-gradient magnetic alloy high-frequency systems, completing system-wide joint testing. In the most challenging frequency range of 0.29 to 2.1 MHz, the system has achieved an international record of 35 kV/m voltage gradient, with voltage precision better than ±1% (Fig. 10) and phase precision better than ±1°, marking a leading international standard.

The HIAF project has pioneered the use of titanium alloy skeleton ultra-thin wall vacuum chambers, successfully installed to form the world's largest high-vacuum system for an accelerator, achieving a vacuum level of better than 7×10^{-12} mbar (Fig. 11).

In addition, the project has developed a series of high-end beam diagnostic electronic equipment, achieving full domestic production. Over 1,500 sets of 20 different types of self-developed electronic devices have been installed, addressing the high-precision, large-dynamic-range, multi-parameter measurement requirements for the HIAF beam, as well as microsecond-level interlock protection.

The HIAF project has also developed a new generation of high-security high-speed communication protocol, CVLink, and a large-scale high-performance accelerator cluster control platform, LACCS. These systems enable precise, intelligent beam control, overcoming key technologies such as the autonomous security of accelerator control software and efficient processing of large datasets. Currently, the LACCS control system has been successfully applied to the HIAF facility.

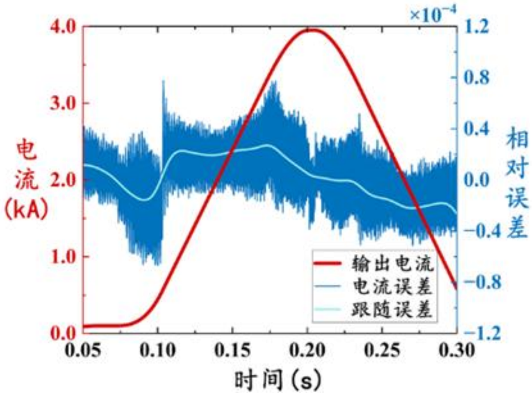

Figure 9: The power system testing result shows that the maximum current can reach 3900A with an accuracy better than ±5e-5.

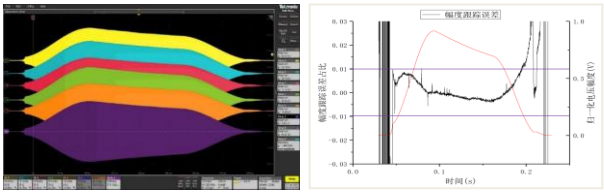

Figure 10: measured voltage (up to 350kV) and accuracy (voltage ±1% and phase ±1°) for five sets RF.

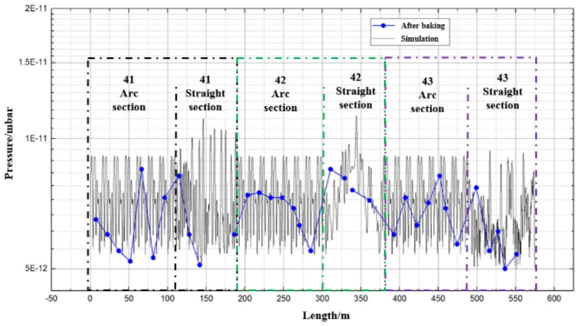

Figure 11: simulation and measurement results of the vacuum pressure in BRing.

CONCLUSION

The HIAF project is the biggest heavy ion accelerator project under-construction in China. There are several challenges related to the ion source, the linac, the RF cavities, the power supplies and so on. In past few years, the HIAF project team have developed several prototypes and obtained test results. The HIAF construction will be benefit on these works. At present, most of the accelerator equipment has been installed and tested. The beam commissioning of the accelerator complex is planned in 2025.

ACKNOWLEDGEMENTS

We thank all the colleagues working on the HIAF project for their valuable contributions on this article.

REFERENCES

[1] J. C. Yang *et al.*, “High Intensity heavy ion Accelerator Facility (HIAF) in China,” *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 317, pp. 263-265, Dec. 2013. `doi:10.1016/j.nimb.2013.08.046`

[2] L. Sun *et al.*, “Superconducting magnets for high performance ECR ion sources,” *IEEE Trans. Appl. Supercond.*, vol. 28, no. 3, pp. 1–6, Apr. 2018. `doi:10.1109/tasc.2018.2791943`

[3] P. Li *et al.*, “The collimation system design for the Booster Ring in the HIAF project,” *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 920, pp. 14–21, Mar. 2019. `doi:10.1016/j.nima.2018.12.064`

[4] C. R. Prior and G. H. Rees, “Multiturn injection and lattice design for HIDIF,” *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 415, no. 1–2, pp. 357–362, Sep. 1998. `doi:10.1016/s0168-9002(98)00406-9`

[5] L. N. Sheng *et al.*, “Ion-optical design of High energy FRagment Separator (HFRS) at HIAF,” *Nucl. Instrum. Methods Phys. Res., Sect. B*, vol. 469, pp. 1–9, Apr. 2020. `doi:10.1016/j.nimb.2020.02.026`

[6] B. Wu *et al.*, “The design of the Spectrometer Ring at the HIAF,” *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 881, pp. 27–35, Feb. 2018. `doi:10.1016/j.nima.2017.08.017`

[7] L. J. Mao *et al.*, “The Electron Cooling System for the HIAF Project in China”, in *Proc. COOL'19*, Novosibirsk, Russia, Sep. 2019, pp. 14-17. `doi:10.18429/JACoW-COOL2019-MOZ01`