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DEVELOPMENT OF ELECTRON COOLER COMPONENTS FOR HIAF ACCELERATOR*

L. J. Mao†, J. Li, M. R. Li, H. J. Lu, F. Ma, X. M. Ma, X. P. Sha, M. T. Tang, K. M. Yan, X. D. Yang, H. Zhao, L. X. Zhao, Y. B. Zhou, IMP CAS, Lanzhou, China

Abstract

The High Intensity heavy-ion Accelerator Facility (HIAF) is under constructed at IMP in China, which is used to provide high intensity heavy ion beam pulse. A 450 keV electron cooler was proposed to boost the luminosity of high-density internal targets experiment in the spectrometer ring (SRing) at HIAF. The cooler is designed based on changes of the 300 keV cooler at IMP, which was made by BINP in 2004. In this paper, experimental testing results of the prototypes of the coils, the electron gun and the collector are reported. The technical challenges and solutions on the 450 keV high voltage system are discussed.

INTRODUCTION

The High Intensity heavy-ion Accelerator Facility (HIAF) is a new accelerator 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. The facility 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 used as a 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. The main parameters are listed in Table 1.

The construction of the HIAF project was started officially in December 23rd, 2018. Up to now, roughly 50% of civil construction is finished. The first component of SECR is planned to equip in the tunnel in the middle of 2022. The first beam will be accelerated at BRing in the middle of 2025. A Day-one experiment is proposed before the end of 2025.

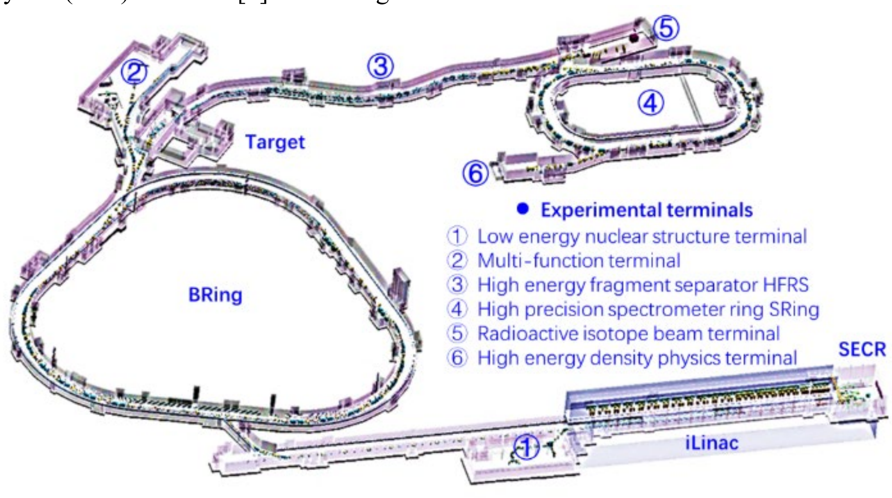

Figure 1: Layout of the HIAF project.

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	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

SRing is a versatile storage ring employed in nuclear and atomic experiments with stored stable or radioactive ion beams. Especially, the highly-charged stable ions can be used either at the injection energies or at lower energies

* Work supported by the National Development and Reform Commission, China
†maolijun@impcas.ac.cn.

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after deceleration. A powerful electron cooling system is needed for the stable ion beams in the energy range of 800 to 30 MeV/u [2]. It also allows few intermediate energies cooling in the deceleration operation mode, to obtain a high efficiency and low losses during the deceleration of ion beams. The electron beam should be turned off during the ramping of the high voltage deceleration. In addition, the electron cooling involves isotopes beam cooling together with the stochastic cooling system. The electron cooler will be installed in the 16 meter-straight section of SRing. The total length of the cooler in ion beam direction is 11.2 m. the height is limited by the tunnel up to 6 m. The high voltage tank is equipped on the side of the cooler. Figure 2 shows a general model of SRing electron cooler.

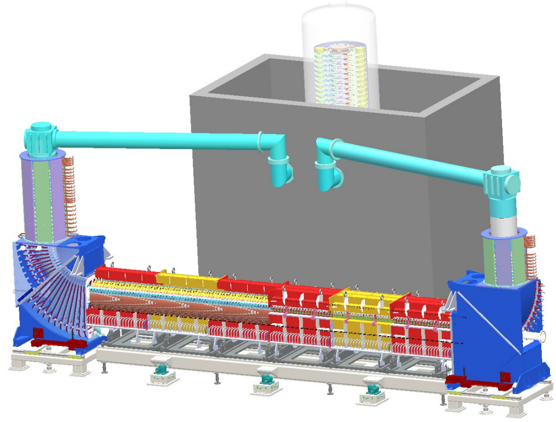

Figure 2: 3-D structure of SRing electron cooler.

DESIGN PARAMETERS

The ion beam $^{238}U^{92+}$ is taken as a reference for the design work of SRing electron cooler. The ion energy ranges from 800 MeV/u to 30 MeV/u (deceleration) that corresponds to the electron energy range of 450 keV and 15 keV. The cooling time around 10 sec is needed at the top energy. Therefore, a DC magnetized electron cooler with the electron beam current up to 2.0 A is required. According the cooling process simulation performed by a multi particle tracking code, the main parameters of the cooler was fixed as shown in Table 2.

Table 2: Technical Parameters of SRing Cooler.

Parameters	Value
Maximum acceleration voltage	450 kV
Voltage ripple	$<5.0\times10^{-5}$
Cathode radius	1.5 cm
Maximum electron current	2.0 A
Gun solenoid field	4.0 kGs
Cooling solenoid field	1.5 kGs
Collector solenoid field	2.0 kGs
Effective cooling length	7.4 m
Vacuum chamber diameter	200 mm
Vacuum	2.0×10^{-11}
Total power consumption	700 kW

MAGNETIC SYSTEM

A high-quality magnetic field is required, the allowable magnetic field homogeneity is estimated to be less than 10^{-4} in the cooling section and 10^{-3} in other sections, respectively. To satisfy these requirements cooling solenoids is made from pancake coils with possibility to incline each on the down support points [3]. In addition, based on the experience of COSY cooler [4], two types of coils with opposite direction of winding are used to decrease the transverse magnetic field components. Photo of coils is shown in Fig. 3.

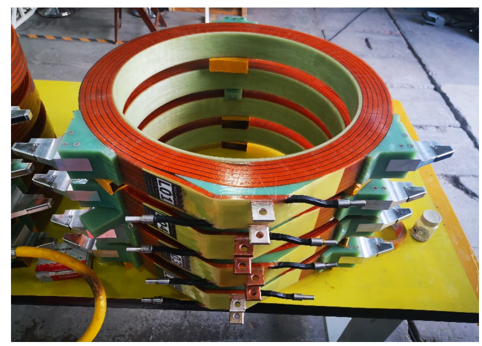

Figure 3: cooling section coils.

To achieve the magnetic field homogeneity requirement, the relative angle between the magnetic field axis and the geometric symmetrical axis must be smaller than 2.0 mrad [5]. A device with two orthogonal Hall probes was developed to measure the angle of coil, as shown in Fig. 4. The longitudinal and radial magnetic field components can be measured Hall probes respectively. Generally, the longitudinal magnetic field is a constant value. The radial magnetic field distribution can be measured by rotating the probes. The angle is calculated by the ratio of the radial magnetic field amplitude to the longitudinal magnetic field component. The direction of the angle is determined by the position of the maximum radial magnetic field.

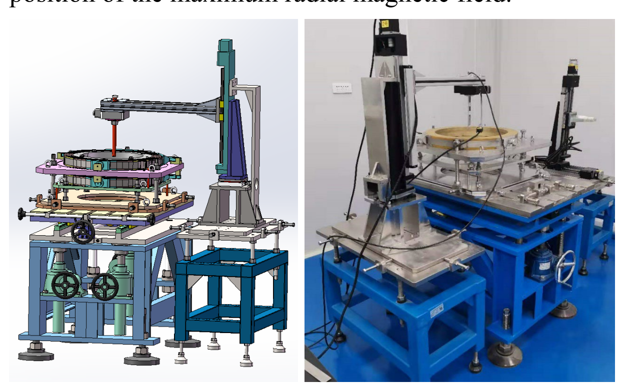

Figure 4: 3-D structure design of the magnetic field measurement platform (left) and photo of device (right).

Figure 5 shows a magnetic field measurement of one coil with the current of 150 A. It was measured ten times at each position, then calculated the average value and its deviation. The probe rotates with the step of 15°. In this measurement, the radial magnetic field amplitude is B_r=0.167 82 ± 0.000 61 Gs, the longitudinal magnetic field is B_s=130.859 ± 0.0023 Gs, the maximum radial magnetic field is appeared

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at the position of 101°. Therefore, the calculated angle between the magnetic field axis and the geometric symmetrical axis of the coil is θ=1.28 ± 0.10 mrad. In the SRing electron cooler, the measurement would be done for each coils of the cooling section, then an arrangement of all coils will be made according to the measurement results to minimum the transverse magnetic field component in the cooling section.

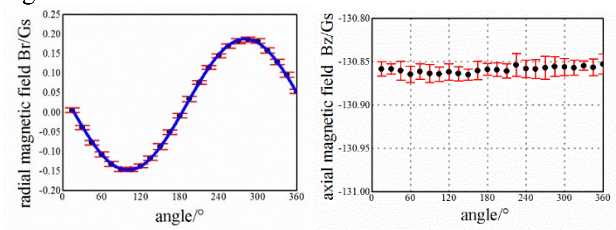

Figure 5: the measurement of the radial (left) and longitudinal (right) magnetic field components of the coil with current of 125 A.

GUN AND COLLECTOR

Electron beam up to 2.0 A is required in SRing cooler. An electron gun with a thermionic cathode is designed which is like the guns for CSR electron coolers from BINP. It can provide a variable profile electron beam to supress an "electron heating" caused by a small fractions of intensive cooled ion beam in centre [6].

A oxide cathode coated BaSrCa(CO_3) on the surface of Ni base is used for the gun [7], as shown in Fig. 6. The diameter of cathode is 29 mm. The maximum electron emission current density up to 1.3 A/cm^2 with the temperature of 800°C was achieved at a test bench. A lifetime measurement is given in Fig. 7. An estimate of cathode lifetime with 0.5 A/cm^2 (for HIAF cooler requirement) would be larger than 10^5 hours.

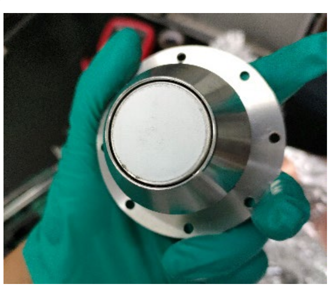

Figure 6: the assembling cathode for HIAF cooler.

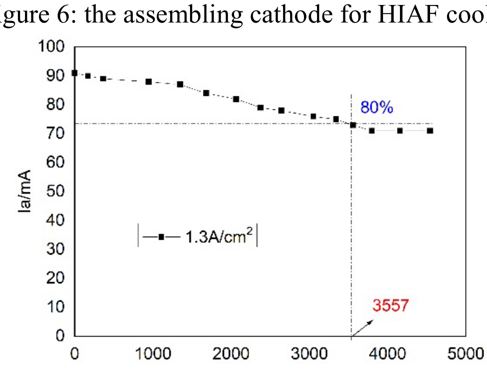

Figure 7: the lifetime measurement of the cathode (it was measured with a Φ3mm cathode NOT the real cooler cathode).

It is necessary to check the vacuum property of the gun and collector before the installation. A heat chamber is used to make a uniform temperature distribution on the ceramic rings during heating process, as shown in Fig. 8. The gun and collector were heated from 20°C to 180°C linearly within 30 hours, and then keep it for 48 hours. Finally, return to the room temperature with a rate of -5°C/h. A titanium getter pump is turned on for few minutes at last. A vacuum condition of 4.3×10^{-12} is obtained, which is satisfy to the SRing requirement.

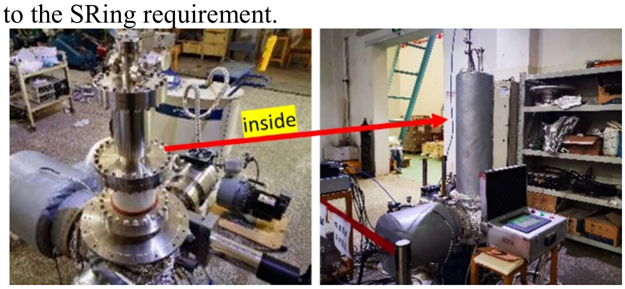

Figure 8: the assembling cathode for HIAF cooler.

The gun and collector have been operated in the test bench, as shown in Fig. 9. The test bench is built to measure the gun perveance, the collector efficiency, the electron beam profile and so on. The collector is installed on the top because it is much heavier than the gun. The electron beam is controlled by three groups of coils. A scanning wire is installed near the entrance of the collector.

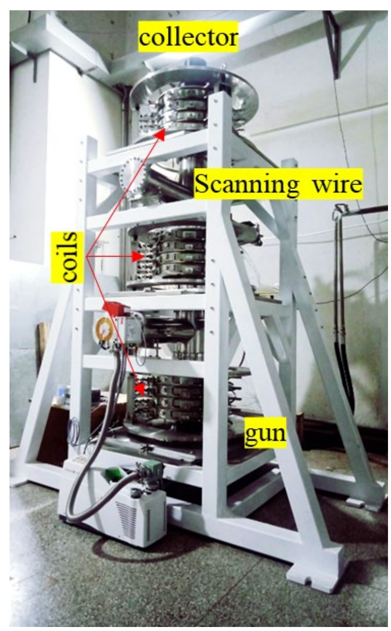

Figure 9: the gun and collector test bench for HIAF cooler.

The measured dependence of the gun perveance on the ratio of grid to anode voltages is shown in Fig. 10. The ratio means different electron beam profiles. A "hollow" electron beam can be obtained with a larger ratio. In the beginning, a 65 W heating power is used for the cathode activation. The measured perveance shows that the electron emission current density is much lower than the simulation results. After that, 120 W heating power is applied for a reactivation process. The final measurement shows an agreement with the simulation result.

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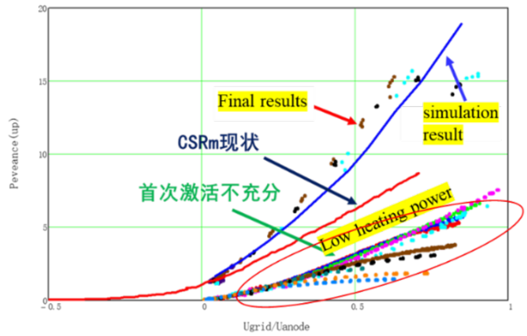

Figure 10: the gun perveance measurement on test bench.

The collector efficiency is measured with a small electron beam current on the test bench. As a device without bending magnetic field, electrons reflected from the collector can be collector again. Therefore, the measured collector efficiency is much better than the simulation results, as shown in Fig. 11. Both simulation and measurement show that the collector efficiency decrease with an increasing of suppressor voltages. The suppressor is used to create a voltage "bucket". Electrons reflected from the collector can be suppressed since the energies are smaller than primary electrons' energies [8]. However, deep "bucket" could reflect the primary electrons at the entrance of collector cup. Therefore, a drastic decreasing with a very lower suppressor voltages was observed.

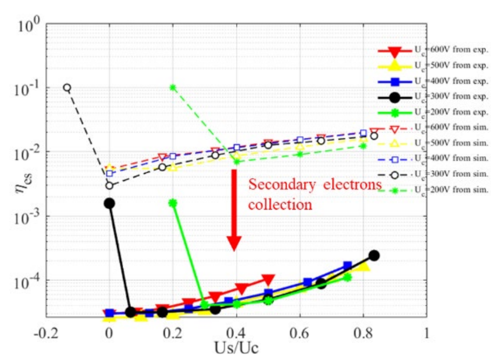

Figure 11: the collector efficiency measured on the test bench. The secondary electrons collection is not included in the simulation work.

CONCLUSION

The HIAF project is the biggest heavy ion accelerator project under-construction in China. A traditional DC magnetized electron cooler is used to improve luminosities for internal target experiments. Based on the CSR coolers designed by BINP, a 450 keV cooler is designed at IMP. The main components including coils, the electron gun and the collector are manufactured. The preliminary tests show that main parameters are satisfied to the SRing cooler requirements.

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