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PRELIMINARY DESIGN OF ELECTRON TARGET FOR SRING AT HIAF*

J. Li†, L. J. Mao, X.D. Yang, J. C. Yang, M.T. Tang, L. X. Zhao, H. Zhao, Z. K. Huang, S. X. Wang
Institute or Modern Physics, CAS, Lanzhou, China

Abstract

A 13 Tm multifunction storage ring dedicated to nucleon and atomic experiment research - the SRing (Spectrometry Ring) is a significant part of the new heavy-ion research complex - HIAF (High Intensity heavy ion Accelerator Facility). In additional to an electron cooler and a gas internal target planned at the SRing, a beam of low temperature electron is also required to collide with the storage beam and to cool the decelerated ion beam at low energy. A magnetic adiabatic expansion is proposed to attain a low temperature by applying a 1.2 T longitudinal magnetic field upon the thermionic cathode at the electron gun. In this paper, preliminary design of the electron target is introduced.

INTRODUCTION

The High Intensity heavy-ion Accelerator Facility (HIAF) is a new heavy ion accelerator complex under detailed design by institute of modern physics [1]. Two typical particles of $^{238}U^{35+}$ and proton is considered in the design. The particles derive from a Superconducting Electron Cyclotron Resonance (SECR) ion source or an intense proton source, and are accelerated mainly by an ion linear accelerator (iLinac) and an booster ring (BRing). The iLinac delivers H_2^+ at 48 MeV and $^{238}U^{35+}$ at 17 MeV/u for the BRing that has a maximal rigidity of 34 Tm. The H_2^+ is stripped into proton at the entrance of the BRing, after accumulation combined with two-plane painting and then is accelerated to the top plateau of 9.3 GeV. The $^{238}U^{35+}$ is injected into the BRing by multi-turn two-plane painting scheme, after accumulation with the help of electron cooling, then accelerated to 0.2-0.83 GeV/u for extraction. At beam line of the HIAF FRagment Separator (HFRS), the ejected $^{238}U^{35+}$ is stripped into $^{238}U^{92+}$ and injected to the Spectrometer Ring (SRing) for high precision physics experiments. In addition, five external target stations of T1 - T5 are planned for nuclear and atomic experimental researches with an energy range of 5.8-830 MeV/u for the typical $^{238}U^{35+}$ beam. Global layout of the HIAF complex is illustrated in Fig. 1.

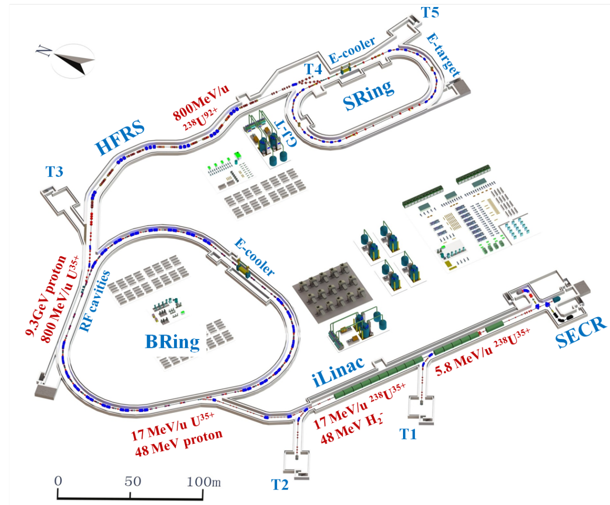

Figure 1: General layout of the HIAF complex.

Overview of the SRing

The SRing is a 15 Tm spectrometer ring designed to collect secondary particles or stripped highly charged heavy ions like $^{238}U^{92+}$ that derive from bombing the internal targets at HFRS. The typical particle of $^{238}U^{92+}$ and proton can been stored at the upper limit of energy at 0.83 GeV/u and 9.3 GeV respectively. In addition, the deceleration to a low energy of $^{238}U^{92+}$ to 30 MeV/u is also planned for atomic physics experiments. The ring has three operational modes of normal for cooling helped experiments with long life-time secondary particles, of internal for atomic physics experiments with electron-target (e-target), gas internal-target (GJ-Target), or laser cooling, and of isochronous for mass measurement of unstable nucleon with lifetime at tens of microsecond. Both electron cooler (e-cooler) and stochastic cooling system will be installed at the SRing. The e-cooler occupies one of the two longer straight section with a length of 11.2 m. The two shorter straight section are assigned to the e-target and gas-jet target. Main parameters of $^{238}U^{92+}$ at the SRing are listed in Table 1.

Table 1: Main Parameters of $^{238}U^{92+}$ at the SRing

Circumference	270.5 m
Magnetic rigidity	2-15 Tm
γ_{tr}	1.43-1.84
Energy	30-830 MeV/u
Acceptance ($H/V, \delta p/p$)	$40/40\pi mmmrad$, ±15‰

Electron Cooling System for SRing

The e-cooler at SRing has a maximal energy of 460 keV that can cool the storage beam to an relative energy spread of $3 \cdot 10^{-5}$ and transverse emittances of $0.1\pi mmmrad$ at 0.83 GeV/u. The high precision measurement in dielectronic recombination (DR) experiment requires a continuous cooling at low energy. RF cavities are used to decelerate the storage beam. The cooling in DR experiments is mainly performed by the 460 keV e-cooler. In addition to act as a target, the e-target system also provides another approach of cooling that can cool the storage ion beam with energy up to 109 MeV/u.

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† lijie@impcas.ac.cn

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Experiments at E-target

Collision of storage ions with e-target at the SRing is mainly proposed by DR experiments on study of very heavy ions of H^- like

$$e^- + U^{91+}(1s) \rightarrow U^{90+}(2l_jl_{j'})^{**} \searrow \downarrow \quad U^{90+} + photon \tag{1}$$

and ions of Li^- like

$$e^- + A^{q+}(1s^22s_{1/2}) \rightarrow A^{(q-1)+}(1s^22p_jnl_{j'})^{**} \downarrow \quad A^{(q-1)+} + photon \tag{2}$$

where q is the charge state, and A represents element. The double-asterisk denotes an intermediate doubly excited state in the process. The e-cooler is responsible for continuous cooling of collision ion beam and the e-target provide the low temperature electrons of energy detuned for the DR measurement or a supplementary cooling. Particularly, the transverse temperature of electron beam with order of milli-electron volts is demanded by the DR experiment while that of e-cooler is tens of times larger.

Besides, an electron density larger than $1.0 \cdot 10^6 cm^{-3}$ is also expected by DR experiment. The stored ions and electron beam overlap along the 1.3 m length of interaction solenoid. The de-excited $A^{(q-1)+}$ ions are collected at e-target downstream after the dipole magnet when they are separated from the A^{q+} storage beam.

Table 2: Main Parameters of E-target Set-up

General Parameters	
Electron energy	1-60 keV
Maximal detuned energy	±10 keV
HV ripple	$\pm 1 \cdot 10^{-5}$
Electron beam current (thermionic)	200 mA
Cathode diameter	10 mm
Maximal expansion factor	30
Magnetic field at electron gun	1.2 T
Magnetic field at collector	0.1 T
Magnetic field at interaction solenoid	0.04-0.1 T
Maximal electron beam diameter	55 mm
Interaction solenoid length	1.3 m
E-target installation length	4.5 m
β_x/β_y at interaction section	21.6 m/15.3 m
Vacuum pressure	$1 \cdot 10^{-9}$Pa
Typical Parameters for DR	
Expansion factor	25
Transverse electron temperature	5 meV
Electron beam density	$2 \cdot 10^6$ cm^{-3}
Field at interaction section	0.048 T

E-TARGET SYSTEM

The framework of e-target set-up follows the design of an traditional electron cooler [2]. It mainly consists of a thermionic cathode electron gun section, two 90 deg toroid, an electron-ion interaction solenoid, and an collector section. The choice of thermionic cathode owing to its long lifetime and simplicity in maintain comparing to the photo-cathode. Main parameters of the e-target are listed in Table 2.

Electron Gun and Collector Solenoids

On achieving the low temperature electron beam, we use a routine solenoid that can produce a magnetic field strength of 1.2 T. Typical field strength at interaction section in our design is 0.048 T. This allows an expansion of the electron beam with a factor of 25. The expansion also decrease the transverse electron beam temperature 25 times lower than that of the cathode, i.e. ~ 5 meV at electron-ion interaction section. According to our calculation, the maximum power consumption by gun solenoid is 57.6 kW that will be cooled by water at a flow rate of 0.9 l/s. It is worth mentioning in Fig. 2 that the inner aperture of the gun solenoid is 120 mm that will limit size of electron beam. Thereafter, we set the cathode diameter as 10 mm.

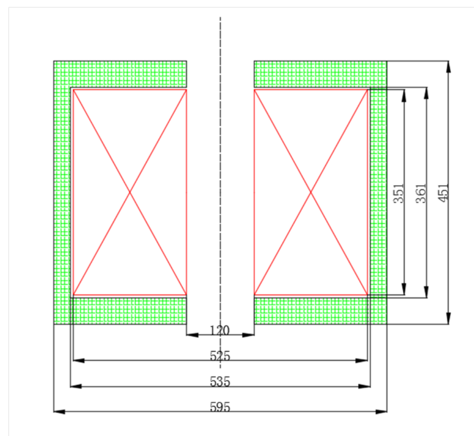

Figure 2: Cross section of the gun solenoid.

The guiding magnetic field at collector is set as 0.1 T. This allows an electron beam transport with a diameter of 34.6 mm at its maximum. That is 20 mm smaller than the aperture at the collector entrance. The heating power derives from electron beam bombing the collector will be taken away by cooling water.

Guiding Magnetic Field and Bending in Toroid

The first consideration on selecting the optimized guiding magnetic field strength for toroid and interaction section is the attainable lowest transverse electron temperature in transport. The 90 deg bending of electron beam in toroid is a primary contribution after the adiabatic expansion.

Considering the routine design of e-cooler [2], we calculate contributions the parallelism from longitudinal field and added electro-static field for bending transport in the 90 deg toroid. In the following calculation, we set the electron start from four different phase advance of $0, \pi/2, \pi, 3\pi/2$ in Larmor procession. The electrons have an kinetic energy

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of 60 keV, an initial transverse temperature of 93 meV on cathode and adiabatic expanded temperature of 5 meV [3].

Figure 3 shows the calculation result of transverse electron temperature dependence upon the magnetic field strength after toroid in the case of with (upper) and without (lower) the electro-static bending field. The calculation shows that the transverse electron temperature has low value of 16 meV at 0.0495 T in the case with a electro-static deflector, and around 20 meV at 0.041 T, 5 meV at 0.048 T at the case of without the electro-deflector. This can been explained by the temperature contribution from $\vec{E} \times \vec{B}$ drift.

On the other hand, the success experience of e-coolers at HIRFL-CSR and LEIR [2, 4, 5] show that bending with electro-static field can remarkably improve the collection efficiency. Thus, we take 0.04 T as the design minimal magnetic field strength for operation and 0.05 T as an optimized field when DR experiment is performed. Therefore, a dipole magnetic field is adopted to bend electron from electron gun to the interaction section and an electro-static deflector is used for bending in the toroid at collector side aiming at a higher collection efficiency.

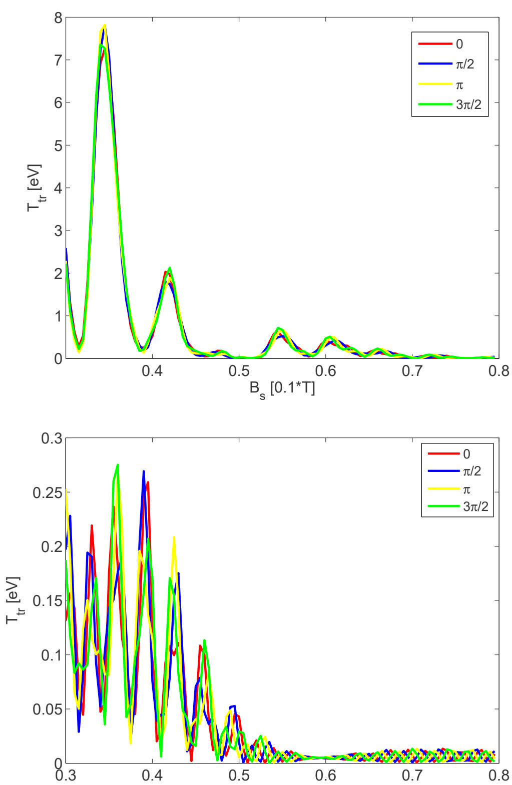

Figure 3: Dependence of transverse electron temperature upon the longitudinal magnetic field strength after toroid with (upper) and without (lower) the bending electro-static field. Electrons start from different initial phase advance of $0, \pi/2, \pi, 3\pi/2$ in Larmor procession.

Adiabatic Expansion of the Electron Beam

The electron beam dynamics from gun to toroid is calculated by USAM code [6]. As a typical case, the field strength around 1.17 T at electron gun and magnetic adiabatic expansion contribute a low temperature when 0.048 T guiding field is applied at the interaction section. The magnetic field strength B_s variation long the longitudinal axis s is shown by the black line in Fig. 4. The cathode temperature is set as 93 meV according to the derived result in e-cooler operation at main ring of the HIRFL-CSR [3]. Without the electro-static deflector, the transverse electron temperature T_{tr} and adiabatic parameter $\xi = (\lambda_c/B_s) \cdot |dB_s/ds|$ variations along the longitudinal axis are shown in Fig. 4 where λ_c is the electron gyro wavelength. It is also shown in fig. 4 that the approach of low temperature electron beam less than 4 meV is attainable at the current design.

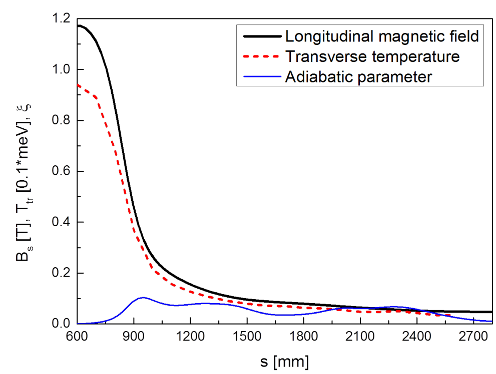

Figure 4: Variation of Longitudinal magnetic field B_s, transverse electron temperature T_{tr}, and adiabatic parameter ξ along the longitudinal coordinate s.

CONCLUSION

An 1.2 T routine solenoid and adiabatic expansion is adopted to attain a beam of low temperature electrons for DR experiment at the SRing with an thermionic cathode being adopted. We introduce the preliminary design of e-target system. The calculation shows that the result matches the requirement to e-target in DR experiment.

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REFERENCES

[1] J.C. Yang *et al.*, “High Intensity heavy ion Accelerator Facility (HIAF) in China”, *Nucl. Instr. and Meth. B*, vol. 317, p. 263-265, 2013.

[2] V. Parkhomchuk, "Development of a New Generation of Coolers with a Hollow Electron Beam and Electrostatic Bending", *AIP Conference Proceedings*, Vol. 821, 249-258, 2005.

ISBN: 978-3-95450-198-4 doi:10.18429/JACoW-COOL2017-TUP08

[3] J. Li *et al.*, "Oxide-cathode activation and surface temperature calculation of electron cooler", *High Power Laser and Particle Beams*, Vol.23, p. 499-502, 2011.

[4] X. D. Yang *et al.*, "Commissioning of electron cooling in CSRm", *Chinese Physics C*, Vol.33(2) p. 18-21, 2009.

[5] G. Tranquille *et al.*, "Cooling result from LEIR", *Proceedings of COOL 2007*, p. 55-58, 2007.

[6] A. Ivanov *et al.*, ULTRASAM - 2D code forsimulation of electron guns with ultra-high precision", *Proceeding of EPAC2002*, p. 1634-1636, 2002.