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DESIGN OF THE SRING ELECTRON TARGET

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Abstract

An electron target is proposed for high precision experimental measurement at the SRing (Spectrometry Ring) of HIAF (High Intensity heavy ion Accelerator Facility). It provides low temperature electron beam with a few meV for DR (Dielectronic Recombination) experiments at the energy of 1-80 keV. For such a low temperature, the conventional method is adopted by magnetic adiabatic expansion with a factor of 30 after acceleration within 1.2T longitudinal magnetic field at gun section. In this paper, the design optimization of the electron target is introduced.

INTRODUCTION

The Spectrometry ring (SRing) is an in-building dedicated experimental storage ring of the accelerator complex High Intensity heavy-ion Accelerator Facility (HIAF) [1]. It is designed to operate in four modes of the isochronous for time-of-flight nuclei mass measurement, of the internal target for gas-jet experiment, of the normal for Schottky nuclei mass measurement and atomic spectrometry study, and of the stacking. Collision of storage electron-cooled (E-cooled) ions with the cold electron beam is proposed at the SRing for Dielectronic Recombination (DR) spectroscopy measurement of Li-like, H-like, and He-like highly charged heavy ions when fruitful results have been obtained at HIIRFL-CSR electron cooler [2, 3]. Figure 1 shows layout of the SRing.

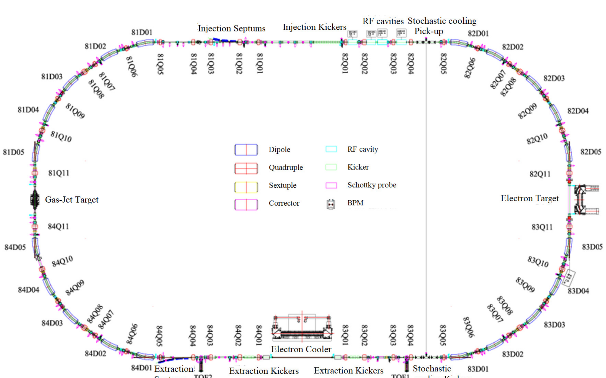

Figure 1: Layout of the Spectrometry Ring.

An electron-target (E-target) is dedicated to the DR experiments. It merges the cold electron beam of transverse temperature $kT_{e\perp}$ 5 meV and longitudinal one $kT_{e\parallel}$ 0.1 meV with the circulating e-cooled ion beam within 2.24 m length the target section. Electrons start from a 10 mm thermionic cathode, and accelerated to the energy range of 10-80 keV within the 1.2 T guiding magnetic field. Then the electron beam get the transverse temperature reduced by a transverse expansion with a factor of 30 along the guiding field. After transition through magnetic bending coils in the toroid, electrons are merged with the circulating highly charged ions in the target solenoid. Collisions between cold electrons and e-cooled storage ions make DR spectrometry investigation possible. After interaction with ions in the target section, the electrons are bent away from the circulating ion beam through electron plates in the Toroid, and finally dumped into the collector after deceleration.

Table 1: Main parameters of SRing and E-target

SRing Nor-2 optics	
Circumference	277.3 m
Typical ions	$^{197}Au^{(76-78)+}$, $^{238}U^{(89-92)+}$
Beam Intensity	$10^4 - 10^8$
Rigidity	3.5-15 Tm
Energy	85-835 MeV/u ($^{238}U^{92+}$)
Accepted ϵ_h/ϵ_v, $\delta p/p$	120/30 $\pi mmmrad$, $\pm 1.1\%$
E-cooled ϵ_h/ϵ_v, $\delta p/p$	0.2/0.2 $\pi mmmrad$, $\pm 1 \cdot 10^{-4}$
E-Target parameters	
Electron energy	10-80 keV
$kT_{e\perp}$ in experiment	5 meV
$kT_{e\parallel}$ in experiment	0.1 meV
n_e in experiment	$2 \cdot 10^6$ cm^{-3}
Cathode diameter	10 mm
Expansion factor	30
B_s at target	0.04 T
B_s at gun/collector	1.2/0.2 T
Cooled beam σ_x/σ_y	4.7/3.7mm
Vacuum pressure	$1 \cdot 10^{-9}$Pa
Aperture through target	275 mm
$\beta_x/\beta_y, D_x$ at target	18 m/17 m, 4.7 m
Target solenoid length	2.24 m
E-target total length	5.5 m
E-target orientation	horizontal

For DR experiments, the SRing will operate in the Nor-2 optics mode within the magnetic rigidity 3.5-15 Tm. As a feature of the e-target, ion beam will been cooled down with $\sigma_x/\sigma_y = 4.7/3.7mm$ at target section, that makes it possible for the colder electrons in a small radius to collision with the e-cooled ions.

Besides, three isochronous modes are designed at SRing and secondary beam in target section has the largest horizontal envelope 261 mm when the transition energy $\gamma_{tr} = 1.43$. This limit the minimal aperture at the target section. In

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additional, available height in SRing tunnel limit e-target orientation to horizontal. The main parameters of SRing and E-target are summarized in Table 1.

MAGNETIC FIELD SYSTEM

In order to reduce the electron beam temperatures as much as possible and improve the technical feasibility of the e-target, we redesigned the magnetic field at gun section. It focuses on reducing the longitudinal temperature by accelerating electrons within 1.2 T gun solenoid and thus shortening the length of acceleration tube to 0.46 m from 1.2 m in the old design [4]. Meanwhile, the expansion magnetic field is also optimized at the junction to Toroid. Figure 2 shows the axial field B_s distribution and overall coils arrangement along the electron beam orbit coordinate s.

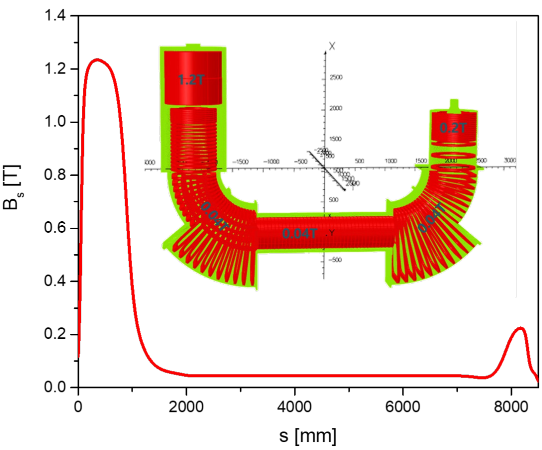

Figure 2: Axial magnetic field variation along electron trajectory and overall arrangement of coils from gun to collector.

The electron gun solenoid consists of two identical normal-conducting coils with bore diameter 220 mm and total length 0.96 m. The 1.2 T axial magnetic field covers a range of 0.5 m for electrons generation and acceleration. The expansion solenoid consist of 20 coils and decrease the magnetic field to 0.04 T from 1.2 T. The two 90° Toroids consist of 40 coils and have the axial fields 0.04 T with a distortion requirement less than 1%. The optimized field in target solenoid is also 0.04 T but with straightness requirement less than $1 \cdot 10^{-4}$ within the effective length 1.6 m. The magnetic field increases gradually in transition toward the collector. It reaches a maximum 0.2 T at entrance of the collector cup and then drops to 0.003 T at the bottom.

ADIABATICITY PARAMETERS AND ELECTRON TEMPERATURE

To reduce heatings of electron beam caused by the radical electric field in acceleration and variation of the magnetic field during expansion, the conventional adiabaticity approaching is used to suppress these affects [5–7] . Along the trajectory of electron beam, the acceleration section in the coordinate interval of 0.5-1.0 m, and the expansion is at range of 1.0-2.2 m. Figure 3 shows the dependence of longitudinal acceleration parameter ξ_{acc} and transverse expansion α_{exp} upon the axial magnetic field B_s and axial electric fields E_s along the electron trajectory coordinate s.

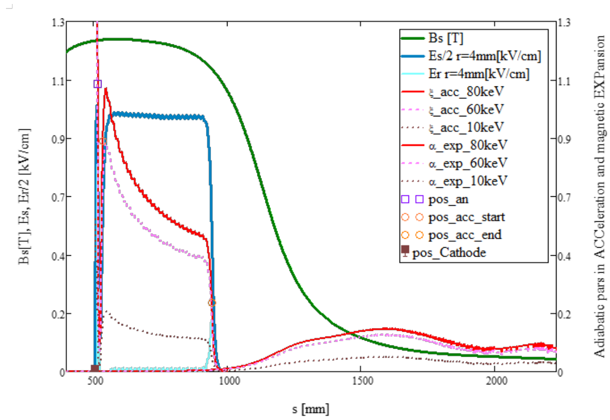

Figure 3: Parameters variation for longitudinal acceleration (0.5-1.0 m) and transverse expansion (1.0-2.2 m) at the minimal energy 10 keV (brown dot curve), the maximal 80 keV (red solid curve) and 60 keV (pink dashed curve) along the electron orbit coordinate. In additional, positions of cathode, anode, acceleration tube are also marked by block symbols.

Adiabatic Acceleration

The longitudinal adiabaticity means the relative energy change of electron should be faster than the electron plasma relaxation time $1/\omega_p$ in acceleration, i.e. the parameter $\xi_{acc} = (1/\omega_p) \cdot (1/E_k)|dE_k/dt|$ is smaller than 1. Here, E_k is kinetic energy and ω_p denotes plasma frequency of electron. The acceleration parameters in Fig. 3 give the maximum at entrance of acceleration tube with 0.2, 0.8 and 1.04 at energies of 10 keV, 60 keV and 80 keV respectively.

In additional, calculation shows the longitudinal temperature is not very dependent on the acceleration parameter [8] with a dependence of 2.2 μeV/0.1 near 1.04 at 80 keV.

Adiabatic Expansion

The transverse adiabaticity means the relative change step of magnetic field is larger than the cyclotron length λ_c when expanding electron beam along the axial, i.e. the expansion parameter $\alpha_{exp} = (\lambda_c/B_s) \cdot |dB_s/ds|$ is smaller than 1. The expansion parameters in Fig. 3 give the maximum in the middle of transition section with 0.05, 0.14 and 0.16 at energies of 10 keV, 60 keV and 80 keV respectively.

Electron temperatures

Using the above design of magnetic and electric field and other typical parameters from the two HIRFL-CSR coolers, we calculate the electron temperatures change with kinetic energy at the target section. Figure 4 shows the result within the overlap area limited by the e-cooled ion beam. They meet the design in Table 1.

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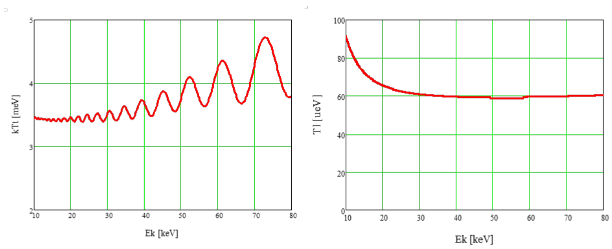

Figure 4: Transverse temperature kTt and longitudinal kTl variation with kinetic energy within overlapped area.

ELECTRON GUN AND COLLECTOR

Since 200 mA uniform profile electron beam at is required by DR experiment, a thermionic gun of two-electrode Pierce type are adopted. The cathode is flat with 10 mm diameter and will work at 750 °C with 1.8 μP perveance. The anode has a horn-shaped structure with 10 mm distance from cathode. The overall cross-section of electron gun and acceleration tube is shown in Fig. 5.

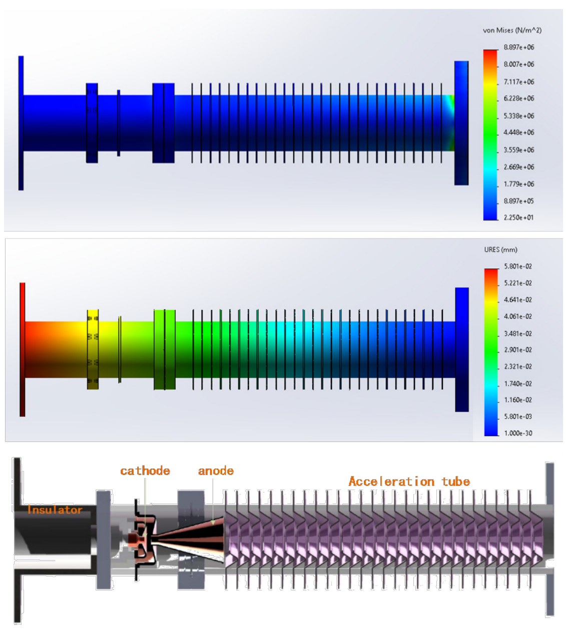

Figure 5: Internal structure (bottom), stress (top) and deformation (middle) of electron gun and acceleration tube.

Besides, the stress and deformation are also evaluated because of horizontal orientation. The results shows that when unsupported, the maximum von Mises stress 32 Mpa locates at the root of acceleration tube, which is smaller than the criterion 8.9 Mpa for ceramic, and the maximum deformation 0.06 mm at the top of electron gun is within acceptable range as well.

The collector electrodes consist of anode, suppressor, and collection cup. It is almost a copy HIRFL-CSR cooler except for minor modifications upon orientation change. In addition, since different deflection of electrostatic and magnetic are used in the two Toroids, the collector secondary emission coefficient will has the order of 1-2 $\cdot$ 10^{-3}. Figure 6 shows the collector structure and coils arrangement.

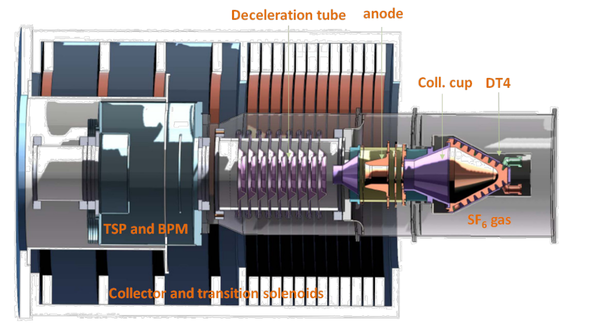

Figure 6: Structure of collector and transition sections.

CONCLUSION

The acceleration and magnetic expansion are optimized for a lower temperatures of electron beam and the improvement at technical feasibility when the SRing e-target is oriented horizontally. The calculated temperature at target section meet the requirement. Some confirmed components have been processed while some detailed optimization is still in progress.

ACKNOWLEDGEMENTS

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REFERENCES

[1] B. Wu *et al.*, “The design of the Spectrometer Ring at the HIAF”, *Nucl. Instr. and Meth. A*, vol. 881, p. 27-35, 2018.

[2] V. Bocharov, *et al.*, ”HIRFL-CSR electron cooler commissioning”, *Nucl. Instr. and Meth. A*, Vol.532, p. 144-149, 2004.

[3] Z.K. Huang *et al.*, “Dielectronic recombination experiments at the storage rings From the present CSR to the future HIAF”, *Nucl. Instr. and Meth. B*, vol. 408, p. 135-139, 2017.

[4] J. Li *et al.*, “Preliminary Design of Electron Target for SRing at HIAF”, *Proceedings of COOL 2017*, p. 40-43, 2017.

[5] T. Tanabe, *et al.*, ”A liquid-helium-free superconducting electron cooler at the storage ring TARN II, *Nucl. Instr. and Meth. A*, Vol.441, p. 326-328, 2000.

[6] H. Danared, *et al.*, ”Studies of electron cooling with a highly expanded electron beam”, *Nucl. Instr. and Meth. A*, Vol.441, p. 123-133, 2000.

[7] F. Sprenger, *et al.*, ”The high-resolution electron–ion collision facility at TSR”, *Nucl. Instr. and Meth. A*, Vol.532, p. 298-302, 2004.

[8] T. SchmoKöller, *et al.*, ”Numerical simulation of the adiabatic acceleration ofelectron beams TSR”, *Nucl. Instr. and Meth. A*, Vol.441, p. 50-53, 2000.

[9] A. Bubley *et al.*, “Low Energy Electron Cooler for the NICA Booster”, *Proceedings of COOL 2017*, p. 22-24, 2017.