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CALCULATIONS OF THE GUN AND COLLECTOR FOR ELECTRON COOLING SYSTEMS OF HIAF*

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Abstract

Two electron coolers are designed for the new project HIAF, one cooler with the highest energy 50keV is for the booster ring (BRing) to decreasing the transverse emittance of injected beams and another one with the highest energy 450keV is for the high precision Spectrometer Ring (SRing). In this paper the results of the gun and collector simulation for these two electron coolers are presented. After optimization, the gun can produce 2A profile variable electron beam. The one time collecting efficiency is higher than 99.99%. The results of electron motions in toroid calculated by a numerical method are also summarized in this paper.

INTRODUCTION

The new accelerate facility HIAF is under design at the Institute of Modern Physics (IMP) [1], Chinese Academy of Sciences, which aimed to provide high intensity heavy ion beams for a wide range of research fields, such as high energy density physics, nuclear physics, atomic physics and so on. It consists of three ion sources (two Superconductting Electron Cyclotron-Resonanceand (SECR) and a high intensity H^{2+} ion source(LIPS)), a superconducting Ion Linac as a injector (iLinac), a Booster Ring (BRing), a high precision Spectrometer Ring (SRing) and some terminals for experiments. The schematic layout of the HIAF facility is shown in Fig. 1

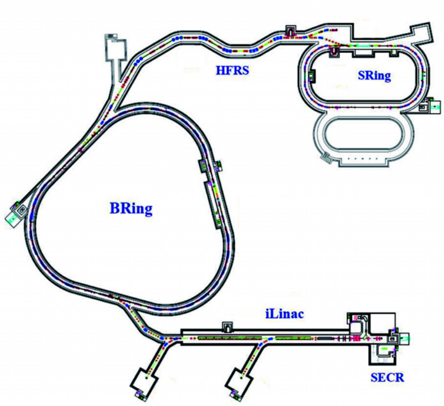

Figure 1: Layout of the HIAF accelerator facility.

Two magnetized electron cooling systems are planned to be used in the BRing and SRing to obtain intense ion beams and to improve beam quality [2]. The main parameters of these two cooler are summarised in Table 1.

Table 1: Main Parameters of Electron Coolers of HIAF

Parameters	BRing	SRing
Maximum energy [keV]	50	450
Electron beam current [A]	2	2
Cathode radius [cm]	1.3	1.3
Maximum B_{gun} [kGs]	2.5	4.0
Maximum B_{cool} [kGs]	1.5	1.5
Maximum $B_{coll.}$ [kGs]	1.7	2.0
Effective cooling length [m]	7.4	7.4
Angle of toroid [deg.]	90	90
Radius of toroid [m]	1	1

ELECTRON GUN

Electron guns designed for electron coolers of BRing and SRing have same geometry. The structure of the gun is shown in Fig. 2a. A convex cathode with the curvature radius equal to 48mm is used. A grid and an anode are used to control the electron beam current and the transverse distribution through changing the potential distribution nearby the cathode.

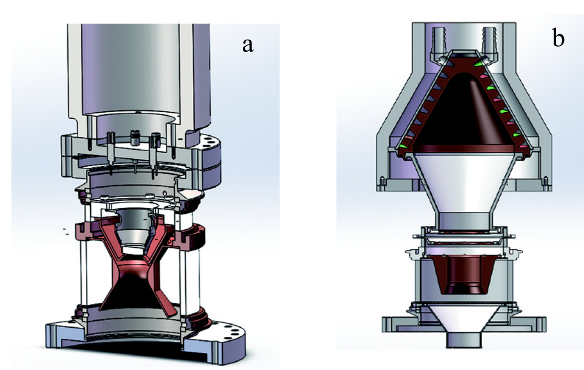

Figure 2: Structures of the electron gun and collector for cooler of HIAF.

Electron gun are calculated by code ULTRASAM [3]. Figure 3 shows the electron beam density distribution with different voltage on grid and anode relative to the cathode. The lines with different colours red, green, yellow and black respectively correspond the situation that voltage on grid equal to 2.5kV, 1.9kV, 1.7kV, 1kV and voltage on anode equal to 3.7kV, 7.7kV, 9.2kV, 13.7kV. When voltage is large enough, 2A parabolic beam and hollow beam can be produced by the gun.

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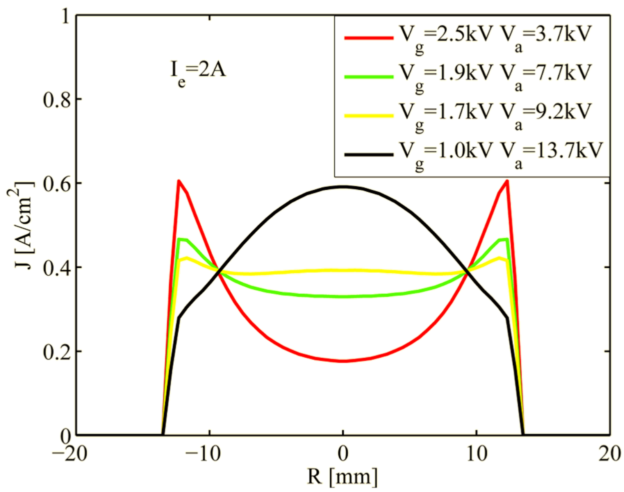

Figure 3: Electron beam current density distribution with different voltage on grid and anode.

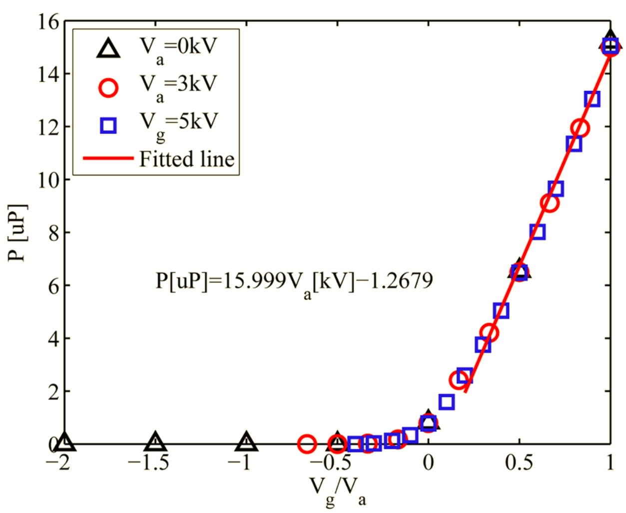

Figure 4: The variation of perveance with V_g/V_a.

Figure 4 shows the variation of the perveance with the ratio V_g/V_a (V_g is the voltage on grid relative to cathode, V_a is the voltage on anode relative to cathode). With the increase of the ratio V_g/V_a, the perveance of the gun increase. When V_g/V_a equal to 1 the perveance will reach about 15uP.

ACCELERATION AND ADIABATIC EXPANSION

To let the maximum energy of the SRing's cooler reach 450keV, an additional accelerating tube is designed. However, the energy of BRing's cooler so low (50keV) that only one additional accelerating electrode is enough. Figure 5 shows the models used to simulate SRing's cooler.

The transverse electric fields (E_r) at the r=1mm are calculated by ULTRASAM and also shown in Fig. 5. Calculations indicate that only the E_r at the end of the accelerating tube of SRing's electron gun has significant influence on the transverse electron beam temperature. To decrease the influence of the transverse electric field on the beam temperature, the field of the gun region is optimized and an additional coil is used to enhance the local field.

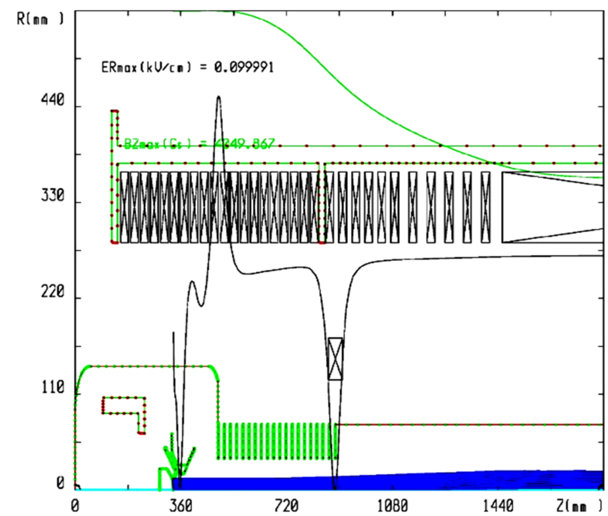

Figure 5: The geometry of the magnetic system for guns of SRing.

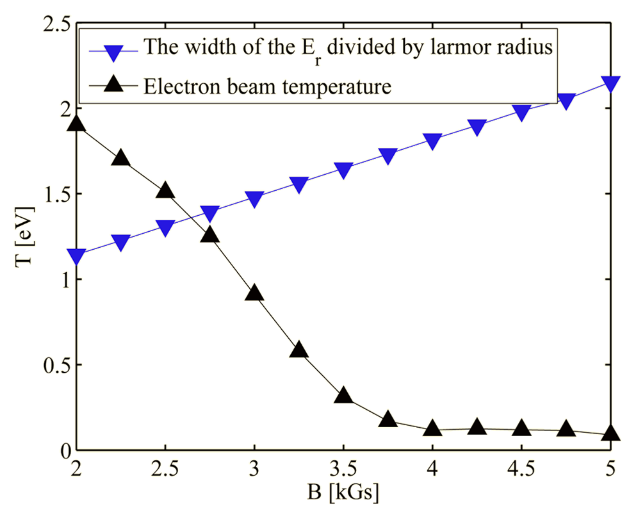

Figure 6: Dependency of the transverse temperature increase at the entrance of the toroid on the magnetic field in the gun region.

The temperature is calculated after beam is accelerated and adiabatically expanded. In calculations, the electron beam current is 2A, energy is 450keV and the magnetic field at entrance of toroid is 1kGs. The result is shown in Fig. 6. From Fig. 6 it can be found that when magnetic field in the gun region increases the temperature will decrease. One reason is that when the field increase the larmor radius of the electron beam will decrease, and beam will pass through the transverse field section more adiabatically, another reason is that the expansion factor of the system will increase when the field in gun section increase. Calculations indicate that when the field is larger than 4kGs, the field increasing will have less influence to the beam temperature, the temperature will keep at about 0.1eV. Therefore, for SRing's cooler the field in

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gun region for 450keV electron beam should not less than 4kGs. To further decrease the influence of E_r, the additional coil at the end of the accelerating tube should be used. More calculations show that with the help of the coil beam (2A 450keV) temperature can reach 0.05eV after the beam be adiabatically expanded.

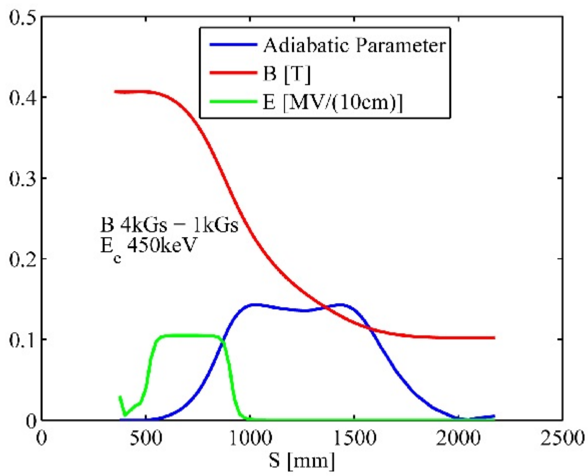

Figure 7: The adiabatic parameters for guns of SRing

Figure 7 shows the adiabatic parameter of SRing. It can be found that the adiabatic parameters are<<1 for the 450keV electron beam.

COLLECTOR

The structures of the collectors design for BRing and SRing's coolers are similar with the collector in the CSR. The magnetic systems for these two collectors are different with CSR's coolers, the maximum magnetic field is 1.7kGs for BRing's collector and the field is 2kGs for SRing's collector. Although the maximum magnetic field is different the magnetic systems in collector region is have same layout. One decelerating tube is used to decelerate beam energy to several keV for SRing's collector, for BRing's cooler the decelerating tube is not necessary.

Figure 2b and Figure 8 show the collector's structure, the layout of the magnetic coils, the field in the collector section and the beam profile in collectors. In calculation, the input beam energy are 50keV and 450keV for BRing and SRing's collector respectively, the beam current is 2A and the voltage on collector is 3.5kV relative to the cathode, the voltage on suppressor is -2kV relative to the collector, and the voltage on collector anode is same with the voltage on collector.

The efficiency of a collector can be estimated by following formula [4]

$$\frac{I_{loss}}{I_{beam}} = k(\frac{U_c}{U_0})^2 \frac{B_c}{B_0} \qquad (1)$$

Where U_{min} is the potential at the entrance of the collector, U_{coll} is the potential on the collector, B_c and B_0 are the magnetic fields on the surface of the collector and at the entrance of the collector, respectively. k is a constant.

When voltage on collector is 3.5 kV relative to the cathode, the voltage on suppressor is -2 kV relative to the collector, the $\frac{U_c}{U_0}$ will be 0.33, 0.40, and $\frac{B_c}{B_0}$ will be 0.03, 0.04 respectively for BRing and SRing's collector. Taking k to be 0.1 and using formula (1) the one time secondary electron escape rate can be obtained, and it is $3.3*10^{-4}$ for BRing and $6.4*10^{-4}$for SRing.

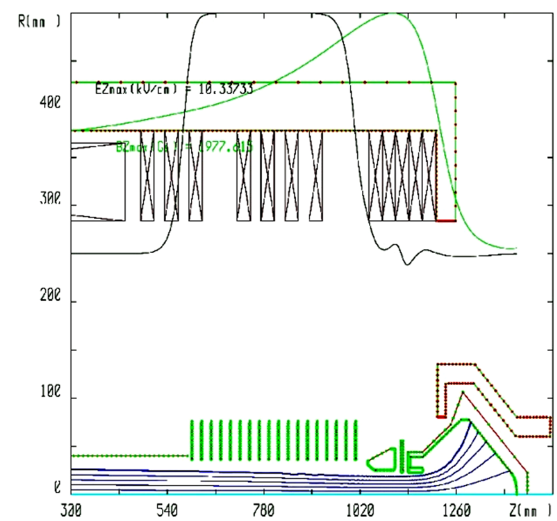

Figure 8: The collector structure of SRing, field in collector region, and beam profile in collector.

ELECTRON MOTION IN TOROID

Electron beams motion in toroid is calculated by a numerical method. The follow approximate equations are used to calculate the motion of electrons in the orthogonal curvilinear coordinate system to the magnetic field B in the center of the magnetic system.

$$\begin{cases} \dfrac{dV_t}{ds} = \dfrac{V_t}{2}\dfrac{\partial \ln B}{\partial s} + [(1-\dfrac{V_t^2}{c^2})\dfrac{eE_t}{\gamma m} - V_s^2 K]\dfrac{\cos\theta}{V_s} \\ \dfrac{d\theta}{ds} = \dfrac{1}{V_s}\{W_H - [\dfrac{eE_t}{\gamma m} - V_s^2 K]\dfrac{\sin\theta}{V_t}\} \\ \dfrac{ds}{dt} = V_s \\ V = \sqrt{V_s^2 + V_t^2} \end{cases} \qquad (2)$$

Where V_t is the transverse velocity of a electron, θ is the rotation angle around the field, V_s is the velocity along the field, K is the curvature of the B, E_n is the elec-

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tric field of the deflector used to compensate the electron beam drift in toroid.

Electron motion can be calculated by solving above equations. In calculations, the electron energy is equal to 450keV, the initial larmor velocity of electron is $1.38*10^7$cm/s. Figure 9 show the the dependencies of the Larmor rotation velocity V_t at the end of the toroid on the magnetic field of toroid. Lines with different colours are the results with different initial rotation angles θ =0, $\pi/2$, π, $2\pi/3$. It can be found that there are many magnetic field value can be selected to let the V_t be small. When the field increase the V_t will decrease. When field equal to 0.987kGs the 450keV electron will have a lowest larmor velocity increase after it passing the toroid.

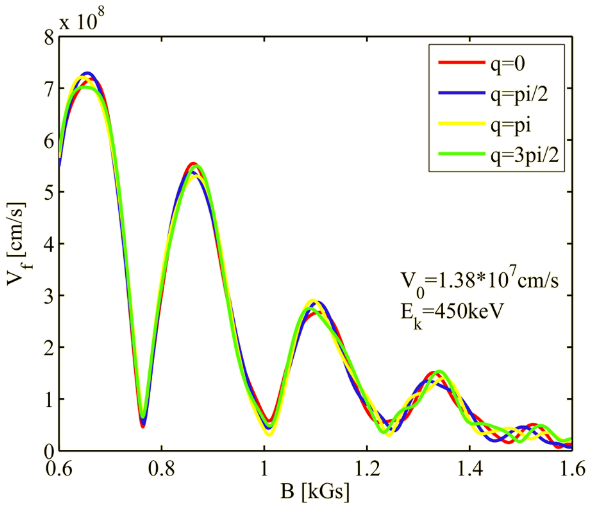

Figure 9: The dependencies of the velocity V_t on magnetic field.

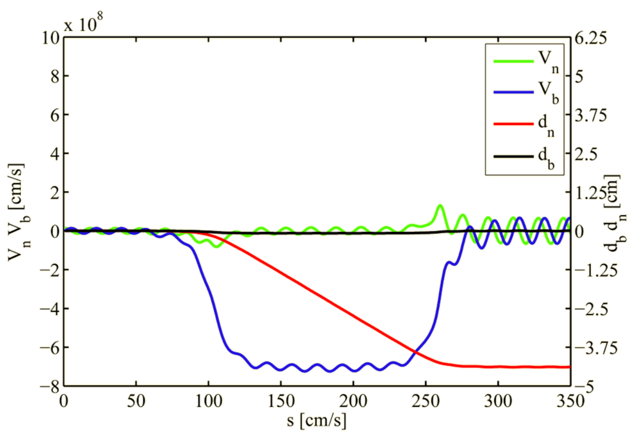

Figure 10: Variation of transverse velocity and electron displacements in two directions (without deflector).

Figures 10, 11 show the case without a electric deflector and the case with a deflector in toroid. It can be found that when there is no deflector there will be an about 4cm displacement after 450kev eletron beam passing though the toroid.

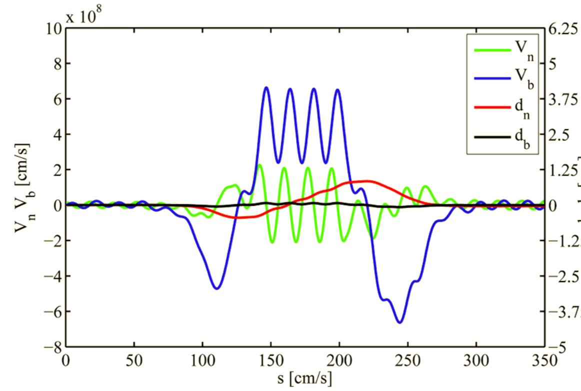

Figure 11: Variation of transverse velocity and electron displacements in two directions (with a deflector).

Further calculations indicate that when the optimum field is chosen the temperature increase will below 0.4eV for 450kev electron beam after it passing the toroid. For 50keV electron beam it's easy to let the beam temperature increase lower than 0.1eV when it passing the toroid.

CONCLUSION

The basic design of gun and collector for HIAF has been finished. The beam motion in gun and collector are calculated by code ULTRASAM. The guns can produce 2A profile variable electron beam. The transverse temperature of the electron beam is control lower than 0.1eV. The magnetic system is design for the gun and collector, and the adiabatic parameters are nearly 0.1 for highest energy electron beam. The one time collecting efficiency of the collector is about 99.99%. The electron motion in toroid is calculated by numerical method. After optimizing the magnetic field in toroid, the temperature increase will below 0.4eV for 450keV electron beam and below 0.1eV for 50keV electron beam after the beam pass though the toroid.

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