HIRFL-CSR ELECTRON COOLING DEVICES

X. D. Yang, H. W. Zhao, J. W. Xia, W. L. Zhan, B. W. Wei
Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou, 730000, China
V.V. Parkhomchuk
Budker Institute of Nuclear Physics (BINP), Novosibirsk 630090, Russia

Abstract:

Electron cooling devices for HIRFL-CSR were under construction through collaboration between BINP and IMP [1]. The main parameters, design points and progress of the cooler devices will be presented. The electron motions in the gun region, adiabatic expansion region, toroid region and collector region were simulated with the help of numerical calculation. Cooling times of the typical heavy ions with injection energy were calculated with aid of the code. The prototypes of solenoid coils at the cooling section were fabricated and measured, the results show that the transverse components of the magnetic field for single coil is less than 2×10^{-4}.

1 Introduction

Heavy Ion Research Facility in Lanzhou –Cooling Storage Ring (HIRFL-CSR)[2] consists of two rings, the main ring (CSRm) will be used to accelerate, cool and accumulate heavy ion beam, the experimental ring (CSRe) will be used as an experimental terminal. There is one electron cooler for each ring. The main parameters of the coolers are summarized in Table 1.

Table1. CSR Electron Cooler Parameters

Parameters	CSRm	CSRe
Ion Energy [MeV/u]	10-50	25-500
Electron Energy [keV]	4-35	10-300
Electron beam current [A]	3 (1.0A@5.5keV)	
Additional transverse temperature [eV]	0.1	0.1
E beam radius at cooling section [cm]	2.5	2.5
Cathode radius [cm]	1.25	1.25
Expansion factor	1- 4	1- 10
Max. magnetic field in gun region [kG]	2.4	5
Magnetic field in collector region [kG]	1.2	1.2
Mag. field at cooling section [kG]	0.6-1.5	0.5-1.5
Length of cooling section [m]	4.0	4.0
Effective cooling section length [m]	3.4	3.4
Parallelity of cooling solenoid field	$\le1\times10^{-4}$	$\le1\times10^{-4}$
Deflection angle of toroid [deg.]	90	90
Deflection radius of toroid [m]	1.0	1.0

All the coils in the cooler solenoids and toroids are pancake shape [3], in this case, the position and angle of each coil with respect to the system axis could be adjusted easily.

A new type electron gun [4] will be considered in this cooling device. The cathode will consist of two parts, the inner part is a round plate and the outer one is a ring, they will be powered separately. In this way, the electron beam diameter can be changed and a hollow beam could be formed. On the other hand, a special control electrode with negative potential relative to the cathode can be used to cut the outer part of the electron beam[5].

2 Magnetic field error

In order to obtain the tolerance requirement of magnetic field homogeneity of solenoids in electron cooling devices, the source of the magnetic imperfection and its influence on the transverse temperature of electron beam was investigated by means of numerical simulation [6], and the space charge effect of electron beam was taken into account. The calculated result shows that the influence of imperfection of magnetic field will be negligible when the relative magnetic field perturbation is less than 1×10^{-3}. The electron transverse energy as a function of relative perturbation amplitude at different beam current are illustrated in Fig.1.

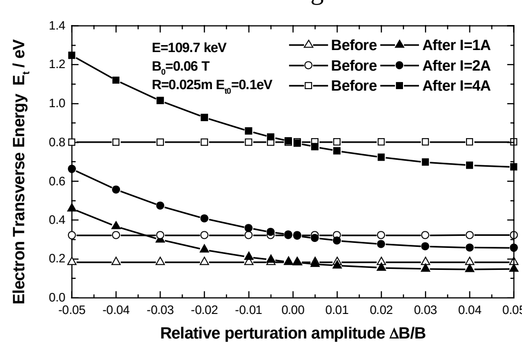

Figure 1: Electron transverse energy as a function of relative perturbation amplitude at different beam current

3 Adiabatic expansion of electron beam

The temperature of electron beam is an important parameter in electron cooling device. Transverse temperature could be reduced when an electron beam passes through a magnetic field with negative gradient. Adiabatic expansion of electron beam moving in different magnetic fields with different energy and current was studied by computer simulation[7]. The result shows that in the adiabatic expansion region the transverse temperature of electron beam is reduced by a factor equal to the ratio between the initial and final magnetic field strengths, provided that the field change is adiabatic with respect to the cyclotron motion of the electrons. The electron transverse energy as a function of expansion factor at different beam current is shown in Fig.2.

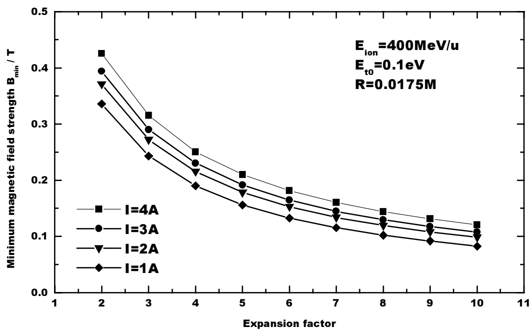

Figure 2: Electron transverse energy as a function of expansion factor at different beam current

4 Toroid

The electron beam is deflected into and out interaction region by toroid in the electron cooling device. The magnetic field distribution in toroid and at the interface among toroid and solenoids is very complicated. The properties of the magnetic field in the toroid give rise to a change in the transverse energy of the electron.

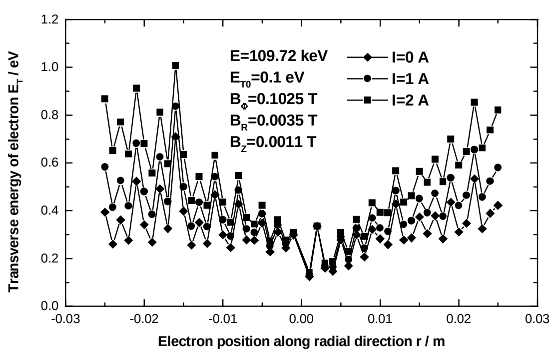

Figure 3: Electron transverse energy distribution along radii at different beam current

A code was developed to study the spatial distribution of electron transverse energy in the beam as it moves through the toroid[8]. The space charge effect was taken into account in the code. The simulation results show that the increase of the transverse energy could be minimized when the ratio between the central length of the toroid and the electron cyclotron wavelength is an integer. Fig.3 and Fig.4 demonstrate the electron transverse energy distributions along the radial and azimuth direction after pass through the toroid.

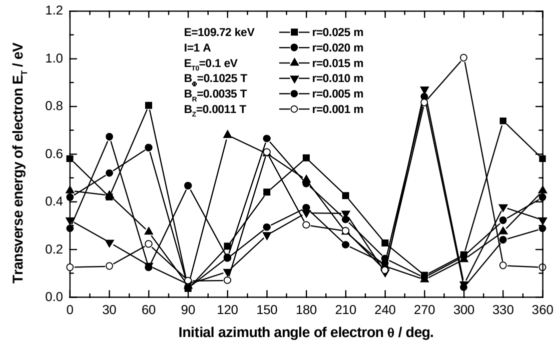

Figure 4: Electron transverse energy azimuth distribution

5 Collector

High efficiency collector is favorable for stable operation of an electron cooling device and regulation of high voltage power supply. The dependences of collector efficiency on the geometric, electrical and magnetic factors are investigated[9]. The result shows that high efficiency can be obtained under appropriate parameter setup. The loss current with respect to primary beam current is less than 1×10^{-4}, the efficiency is higher than 99.99%. The relative loss current of collector as a function of magnetic field ratio is presented in Fig.5.

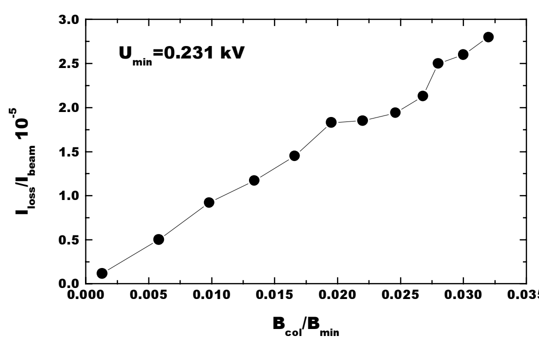

Figure 5: Relative loss current of collector as a function of magnetic field ratio

6 Cooling

With the help of electron cooling code, the influence of the main parameters of electron cooling device on the cooling time was simulated, cooling times of $^{238}U^{91+}$ ion with the energy $400MeV/u$ at different parameters were calculated[10], and the factors which influence the cooling time were analyzed. The cooling time as a function of electron density is indicated in Fig.6.

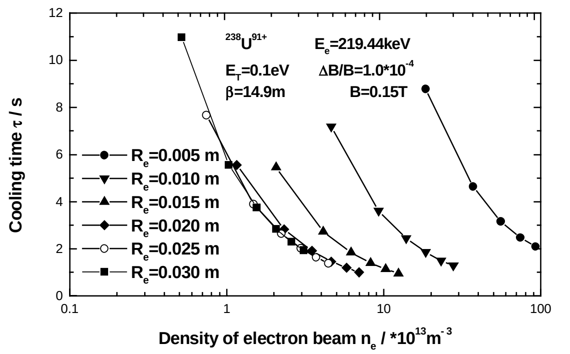

Figure 6: Cooling time as a function of electron density

7 Prototype of coil

The prototypes of high precision solenoid coils in the electron cooling device were fabricated by special techniques. Two coils were placed in two parallel, concentric planes, the lower coil was fixed, and the upper coil can be rotated concentrically. The transverse component of the magnetic field in the coils was measured with the high resolution Hall sensor, The deviation between the magnetic axis of coils and the geometric axis of the reference plane was less than 1×10^{-3} after adjustment. Fig. 7 is the results.

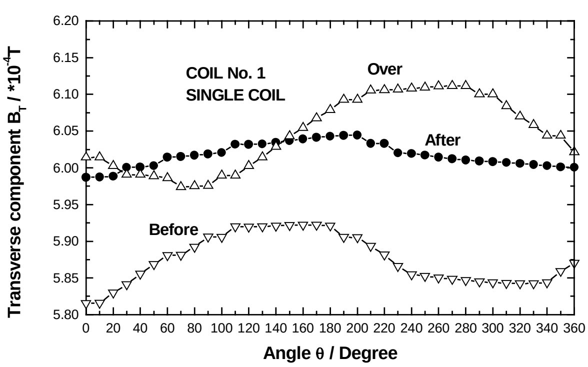

Figure 7:Transverse magnetic field components of single coil

REFERENCES

[1]. V. N. Bocharov, A. V. Bubley, M. E. Veis et al Physical and Technical Requirements to the Design of Coolers for the Storage Ring Facility CSR (Lanzhou), Novosibirsk, 1999.

[2]. J. W. Xia, W. L. Zhan, B. W. Wei et al, This conference.

[3]. E. I. Antokhin, V. N. Bocharov, A. N. Bubley et al Conceptual project of an electron cooling system at an energy of electrons of 350 keV. Nuclear Instruments and Methods in Physics Research A441 (2000)87-91.

[4]. D. G. Myakishev, B. N. Sukhina, Calculation of the gun and collector for electron cooling system EX35 and EX300, Proceedings of EPAC 2000, Vienna, Austria, 1384-1386.

[5]. B. N. Sukhina, E. I. Antokhin, V. N. Bocharov et al, Projects of an Electron Cooling Systems at an Energy of Electrons of 35 and 300 keV for IMP (Lanzhou), Proceedings of EPAC 2000, Vienna, Austria, 2480-2482.

[6]. X. D. Yang, M. T. Song, J. W. Xia et al, Influence of the magnetic Imperfection on the Transverse Temperatue of Electron Beam, Nuclear Physics Review (in Chinese) Vol.18, No.2, (2001)219-223.

[7]. X. D. Yang, M. T. Song, J. W. Xia et al, Adiabatic Expansion of Electron Beam, High Energy Physics and Nuclear Physics (in Chinese) Vol.24, No.12, (2000) 1179-1184.

[8]. X. D. Yang, M. T. Song, J. W. Xia et al, The Motion of Electron Beam in Toroid, High Power Laser and Particle Beam (in Chinese) Vol.13, No.2, (2001) 223-227.

[9]. X. D. Yang, M. T. Song, J. W. Xia et al, Collection of Electron Beam, High Power Laser and Particle Beam (in Chinese) Vol.12, No.2, (2000) 245-248.

[10]. X. D. Yang, V. V. Parkhomchuk, Parameters Optimization of HIRFL-CSR Experiment Ring Electron Cooling Device, High Power Laser and Particle Beam (in Chinese) Vol.12, No.6, (2000) 771-775.

[11]. X. D. Yang, Y. He, H. W. Zhao, et al Manufacture and Magnetic Field Measurement of High Precision Solenoid Coils for HIRFL-CSR Electron Cooling Device, High Power Laser and Particle Beam (in Chinese), to be published.