DESIGN STUDY OF THE ACR ELECTRON-COOLER FOR RIBF

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Abstract

The Accumulator Cooler Ring (ACR) is under investigation at present for a storage ring complex called MUSES (Multi-Use Experimental Storage rings) [1] in RI-Beam Factory (RIBF) Project at RIKEN. An electron cooler (EC) device with the type of field expansion is installed in ACR. Magnetic field in the gun section and the central is 4T and 0.2T respectively, and the electron beam energy is varied from 30keV to 250keV with a maximum current of 4.1A. The details of the most recent design and technological issues in the gun section, the central solenoid and the collector section are discussed.

1 INTRODUCTION

Electron cooler device is installed for the reduction of the phase space volume in addition to stochastic cooling device in ACR [2-4]. The maximum electron beam energy in ACR-EC is 250keV in order that the injected ion beam from the Superconducting Ring Cyclotron (SRC) with 400MeV/u can be treated in this device. The magnetic field in the gun section and the central solenoid is 4T and 0.2T respectively and therefore the expansion factor is 20. The cathode diameter is 12.7mm. The basic design in the gun section was reported in [3,4], where the considerations were made about the maximum voltage gradient near anode, the emission current density of the cathode and the vacuum level near cathode. The electron trajectories and the transverse electron temperature are calculated in this new design of gun section. Moreover, the discharge tests in strong magnetic field were carried out experimentally and some useful data for actual design were obtained.

Table 1 Parameters of ACR-EC

Acceleration voltage	30 – 250kV
Magnetic Field (gun/central)	4T / 0.2T
Field Uniformity (gun/central)	$5*10^{-4}/5*10^{-5}$
Cathode Diameter	12.7mm
Maximum electron current	4.1A
Gun Perveance	0.79μP
Anode-Cathode Voltage	30kV
Main Solenoid length	3.6m
Toroidal Angle / Radius	90deg / 1.5m
Collector Efficiency	> 99.98%

In the central solenoid it is necessary to reduce the transverse component of magnetic field to the order of 10^{-5} in the ratio of transverse component of the field and the longitudinal one because of the small angle spread of both electron beam and cooled ion beam. Since it appears difficult to achieve this accuracy by usual way of winding hollow-conductors due to the winding errors, we are going to adopt a new method developed in BINP [5].

The design of collector section was reported in [3,4]. The electron trajectories are calculated in the design. At the collector section special cares must be taken for preventing the secondary electrons, and some results were reported in [3,4]. The parameters of the ACR-EC are shown in Table 1.

2 GUN SECTION

2.1 Electron trajectories and transverse electron temperature

The basic design of the gun section has been slightly changed [3,4]. Electron trajectories and transverse electron temperature were calculated in the expanding magnetic field from 4T in gun section to 0.2T in central solenoid by EGUN code. Magnetic field data used in EGUN was fitted to the data including a magnetic shield by the combination of the analytical expression of solenoid coil without shield. By this way, we can obtain magnetic data with any accuracy in any short interval of

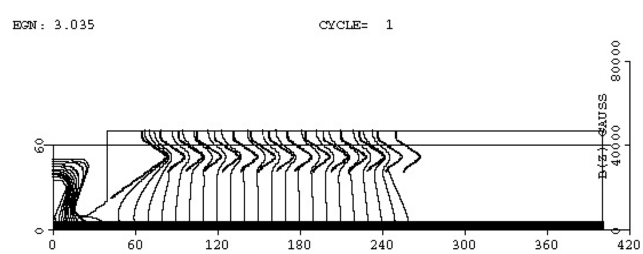


Figure 1: Electron trajectories in gun section with magnetic field 4T and acceleration voltage 250kV. (unit: mm in length)

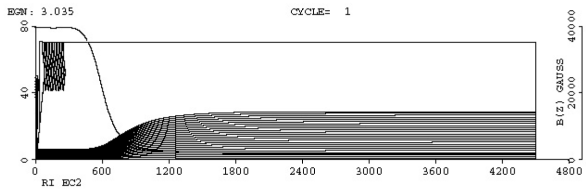
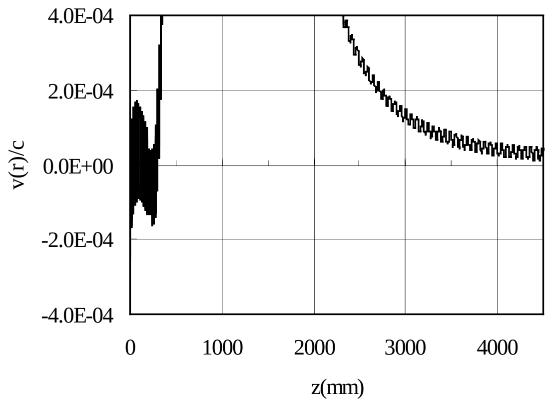
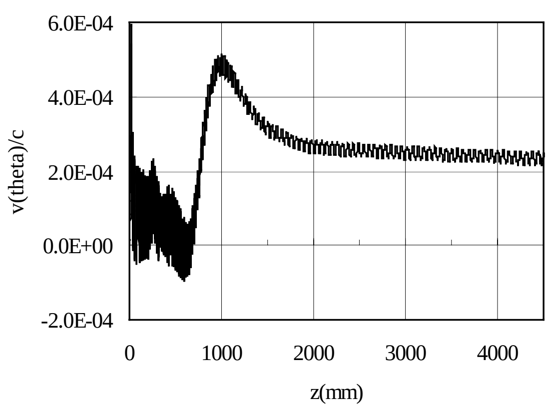


Figure 2: Electron trajectories in adiabatic expansion



(a)



(b)

Figure 3: Transverse electron velocity starting 6.2mm off axis. (a) is radial and (b) is azimuthal component.

axial length. At strong magnetic field the short interval for calculation is necessary for small Larmor radius. The electron trajectories in the gun section with final acceleration voltage 250kV and magnetic field 4T are shown in Fig.1. The perveance is 0.79 μP and the current is 4.1A with the cathode of 12.7mm in diameter. The magnetic field is decreased gradually from 4T at gun section to 0.2T in central section and the electron transverse electron temperature is expected to be decreased by adiabatic expansion. The electron

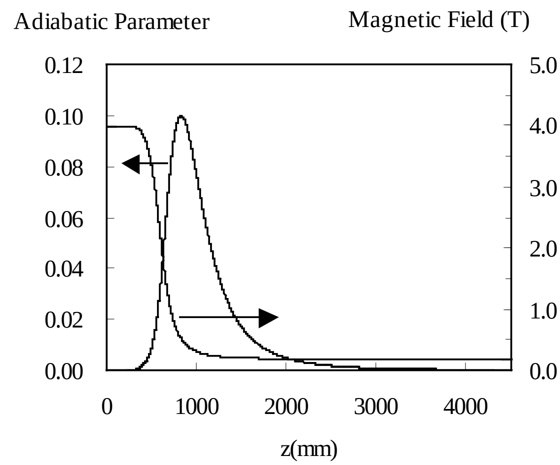


Figure 4: Adiabatic parameter and magnetic field

trajectories are shown in Fig.2. The radial and azimuthal components of electron velocity of the outermost trajectory are shown in Fig. 3(a) and (b). The electron transverse temperature of the outermost trajectory is about 20meV in the region of magnetic field 0.2T. Adiabatic parameter [2] and magnetic field distribution are shown in Fig. 4. The parameter is about 0.1 at maximum.

2.2 Experimental study of discharge under magnetic field

Both strong electric field and magnetic field are needed in the gun section. Of course it is necessary to avoid the occurrence of the Penning trap in the design of electrode, but there seems to be no study in the discharge properties in strong magnetic field so much other than this. So the experimental study was carried out for the investigation of the discharge limit under strong magnetic field in vacuum and SF6 gas [6]. A discharge test bench with a direct-cooled super-conducting magnet was designed and manufactured for this experiments. It turned out from the experiments that the discharge limit in vacuum between accelerating electrodes with the magnetic field of 4T decreases several tens percent, compared with the discharge limit without magnetic field. But it is not necessary to enlarge the gap between electrodes since there is an enough gap length in the design. In SF6 gas the magnetic field has no effect on discharge limit.

3 CENTRAL SOLENOID

The transverse magnetic component B_t in the central solenoid is determined by the following three conditions:

$$\frac{B_t}{B_0} \le \left(\frac{e^2 n^{1/3}}{E} \right)^{1/2}, \qquad (1)$$

$$\frac{B_t}{B_0} \le \sqrt{\frac{\varepsilon}{\beta_{cool}}} \quad , \qquad (2)$$

$$\frac{B_t}{B_0} \le \sqrt{\frac{T_e}{E}} \quad , \qquad (3)$$

where B_0=0.2T is the longitudinal magnetic field, E=250keV is electron energy, ε is emittance of cooled ion beam, β_{cool} is beta function in cooling section and T_e is electron transverse temperature. Equation (1) is related to the friction force and Eq. (1) and (2) is from the angle spread of cooled ion beam and electron beam respectively. From these conditions and some technological aspects we set as transverse components

$$\frac{B_t}{B_0} \le 5\times10^{-5} \qquad (4)$$

To achieve this condition in the usual way of winding hollow-conductors, the needed accuracy in position of each winding step is estimated to be within 0.05mm, and it is difficult. Now we are investigating the use of copper tube with winding spirals developed in BINP [5]. The position error of spirals manufactured by turning machine is much more small than the error in the winding of hollow-conductor, it is expected to realize the condition (4). According to some calculations of magnetic field distribution and the engineering investigation, this method is found to be promising.

4 COLLECTOR SECTION

The basic design has been reported already [3]. Now electron trajectories are calculated in EGUN. The initial condition in electron beam such as radial position, energy, current, etc is taken from the end point data in Fig 2. The result is shown in Fig 5.

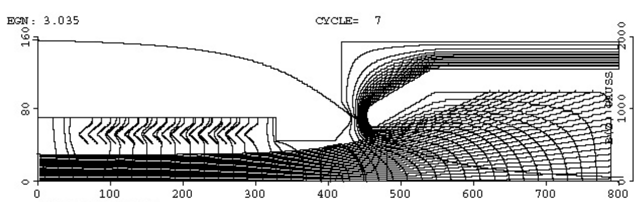


Figure 5: Electron trajectories in collector section

5 CONCLUSION

We have already investigated the main parts of EC device. The other sections, such as monitors, neutralization electrodes, power supply, control system, etc. are now in examination.

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