DESIGN OF THE ACR ELECTRON COOLER AT RIKEN

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Abstract

The radioisotope beam factory (RIBF) is under construction at RIKEN [1, 2]. In the RIBF, multi-use experimental storage rings (MUSES) consists of an accumulator cooler ring (ACR) and an electron-RI beam collider (e-RI Collider). The ACR is equipped with an electron cooler (EC). The cooling time is calculated using probable parameters. The 3 dimensional calculations of magnetic fields and beam trajectories has been carried out in order to obtain better configuration of the ACR-EC.

1 INTRODUCTION

The design of the EC for the ACR has recently been proposed and discussed [3]. It was found that it is not necessary to use the high magnetic field of a few Tesla in the gun section [4], because the ion lifetime is reduced due to the fast recombination of ions with low-temperature electrons. Moreover, the reduction of the electron transverse temperature from the cathode temperature of T_{cath}=100 meV to T_e= 5 meV produced by the magnetic expansion of the electron beam does not provide a significant advantage in terms of cooling time during the injection. Syresin et al. [5] reported that the magnetic expansion factor B_{gun} / B_{cool} from 1 to 8 is sufficient to cool the $^{92}U^{238+}$ coasting beam with the beam energy E = 100 MeV/u, the momentum spread $\delta p/p = \pm 1.5\times 10^{-3}$, and the vertical emittance $\varepsilon_v = 40\ \pi$ mm mrad. Here B_{gun} and B_{cool} are the magnetic field in the gun and in the cooling section, respectively.

On the basis of the previous ACR-EC design [3], we refined the design of the electron gun, the collector and the magnetic field strength [6] with the help of the computer simulation codes SAM [7] and EGUN [8].

In this paper the parameters obtained by those simulations in Ref. [6] are used for the estimate of the cooling time in the ACR experiments. For more detail calculations in the toroidal section, where we cannot suppose the axisymmetric configuration, the 3 dimensional simulation is employed to satisfy the requirement of the high uniformity of magnetic field.

2 ESTIMATE OF COOLING TIME

In Table 1 the new parameters of the ACR-EC are listed; the maximum B_{gun} is reduced from 4 T to 4 kG, and therefore the ratio of B_{gun} / B_{cool} is decreased to be 2.5 times smaller than the previous one. In the present design of electron gun, the electron transverse temperature is estimated by EGUN simulation, and it found the transverse temperature changes in the range from a few meV to a hundred meV inside 5 mm diameter beam. We assumed that the electron beam is emitted with the cathode temperature. Using these values of electron temperature, the cooling time, τ_{cool}, is calculated by BETACOOL for two species of ions in the MUSES experiment as shown in figure 1. The horizontal and the vertical cooling time, τ_h, τ_v, increase, when the horizontal emittance becomes larger and the vertical emittance keeps the constant value.

Table 1: Input parameters for EGUN

Electron beam current, A	~ 4
Electron energy, keV	~ 220
Cathode-anode voltage, kV	30
Cathode diameter, cm	2.57
Magnetic field in gun section, kG	4
Magnetic field in cooling section, kG	0.5 ~ 2

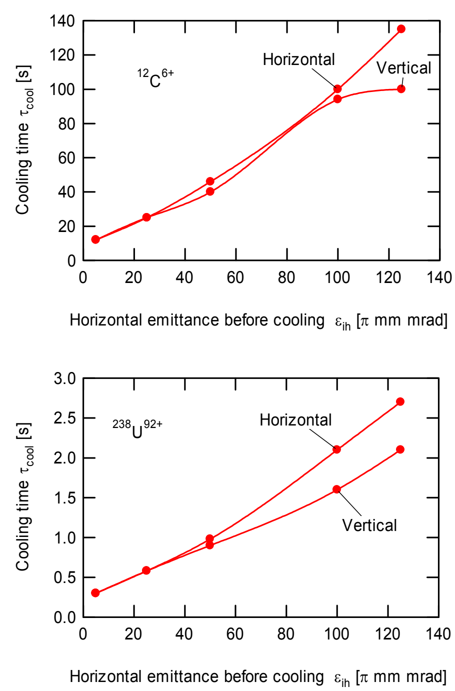

Figure 1: The dependence of cooling time on the horizontal emittance for (a) $^{12}C^{6+}$, 400 MeV/u, Ie = 4 A, and (b) $^{238}U^{92+}$, 100 MeV/u, Ie = 1 A. The initial ion beam has the parameters of $\delta p/p$ = 0.00015, ε_v = 40 π mm mrad, and the electron cooler $T_{e\perp}$ = 5 meV, B_{gun} = 4 kG, B_{cool} = 2 kG.

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The parameter survey has been carried out under the operating conditions of the ACR-EC in figure 2.

3 MODELING OF ELECTRON COOLER

3.1 Magnetic fields with magnetic shield

The overview of the ACR-EC is shown in Ref. [3]. The EC consists of three section; gun, toroidal, and collector section. The high magnetic field uniformity(the ratio of the transverse and the longitudinal field, $B_{\perp}/B$, is of the order of 10^{-5}.) is required in the cooling section of the ACR-electron cooler. Moreover, strictly speaking, the EC cannot suppose an axisymmetric solenoid. Thus more realistic model should be treated for the well understanding of the magnetic fields and the electron beam trajectories. The magnetic shielding is placed at the outside of the guiding solenoid and covers them from the gun section to the collector section. The toroidal section, which is the connection part between the gun and the cooling section, plays an important role for guiding and merging(or separating in opposite side) the electron beam with its temperature as low as possible. The solenoids with two different diameters in the toroidal section are supposed to be driven by two power supplies.

The 3 dimensional magnetic field calculation is performed using the TOSCA finite element program. In the case of B_{gun} = 4 kG and B_{cool} = 500 G, the magnetic field and the adiabatic parameter, $\xi = (\lambda_c/B)\ |dB/ds|$,[3] on the solenoid axis are shown in the figure 3. Here λ_c is the spiral length of the cyclotron motion and s is the position on the solenoid axis. The cathode of electron gun is set at s = 1.57 m. The adiabatic parameter has a reasonable value of 5×10^{-2} at most. Although the correction coils for the field compensation are placed near the connection between each section, the uniformity of the magnetic field

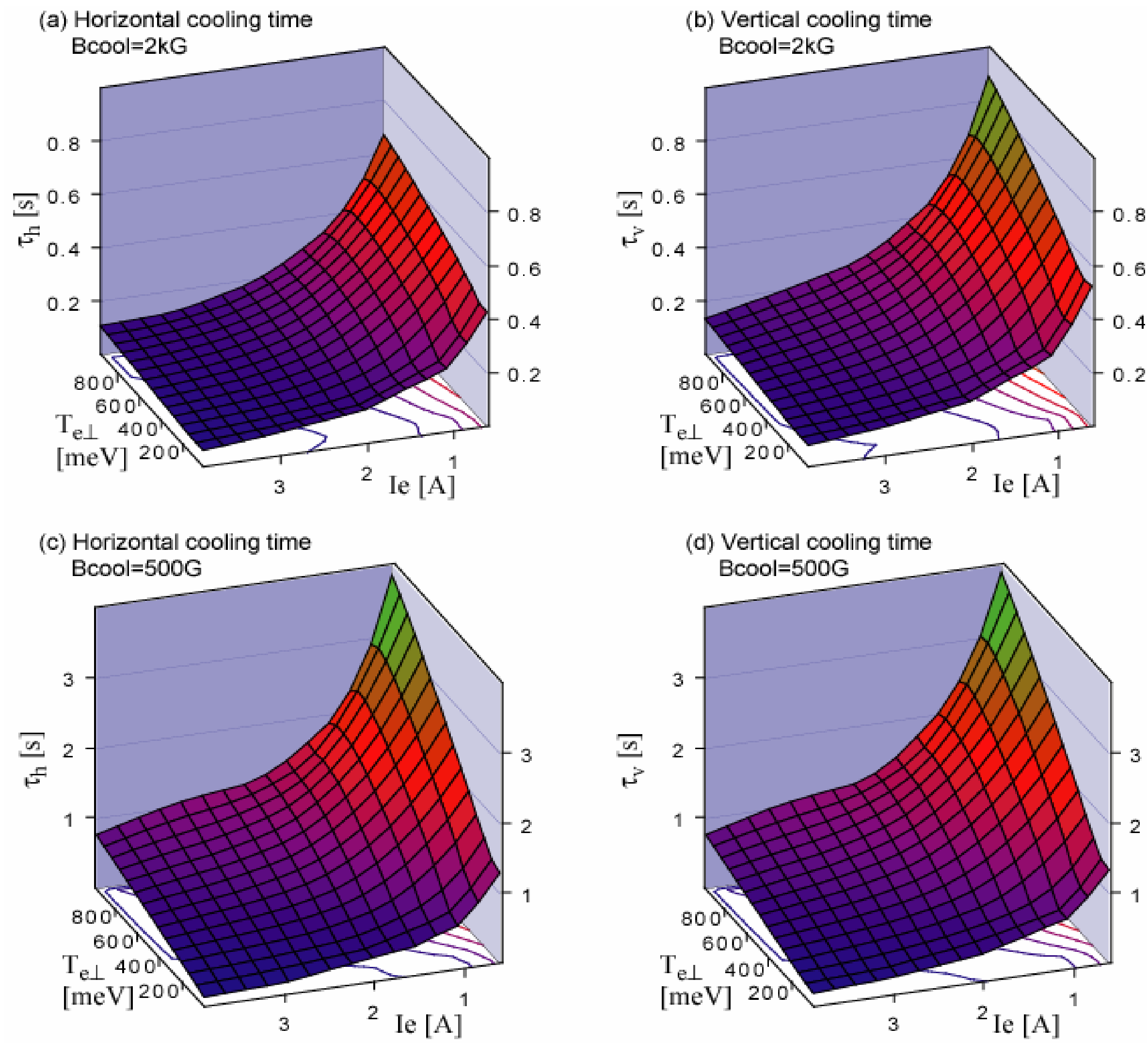

Figure 2: The dependence of horizontal and vertical cooling time for $^{238}U^{92+}$ on the transverse electron temperature and the electron beam current. The magnetic field in the cooling section was applied to 2 kG for (a) and (b), and 500 G for (c) and (d), respectively.

δB/B about 10^{-5} has not yet achieved near the edge of the cooling section. In the present design, it is found this field disturbance reduces the effective length of the cooling section from 3.6 m to 2.2 m.

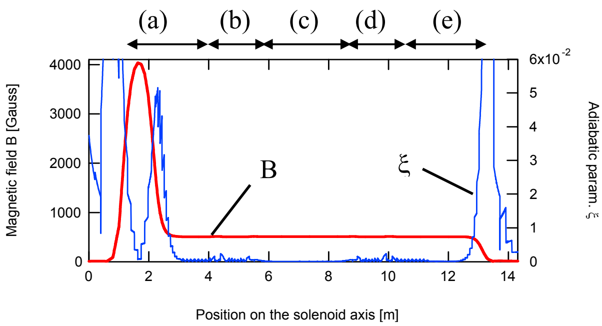

Figure 3: Magnetic field and adiabatic parameters on the solenoid axis; (a) gun section, (b) toroidal section, (c) cooling section, (d) toroidal section, and (e) collector section, respectively.

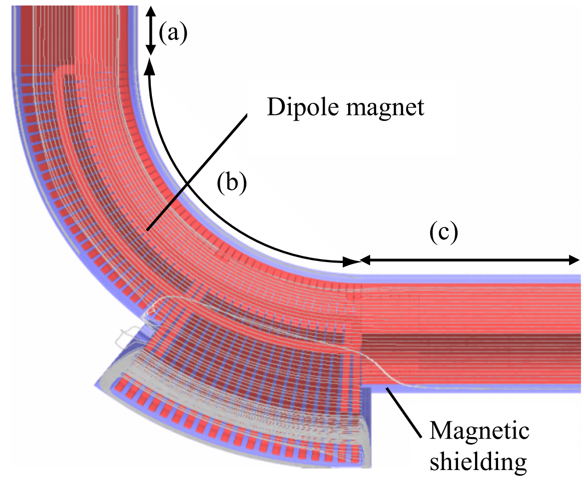

Figure 4: Flux lines started from the mid-plane of the cooling solenoid and the large diameter solenoids. The notations of (a), (b), and (c) are indicated in the figure 3.

3.2 Particle tracking

Figure 4 shows the magnetic flux lines are superimposed on the cross sectional view of the EC behind the mid-plane. The 90-degree dipole magnet is installed inside the guiding solenoids in the toroidal section in order to suppress the drift motion across the magnetic fields and control the electron beam position. The single particle tracking has been carried out using this structure. The electron at the energy of 220 keV is emitted from the cathode position of electron gun on the mid-plane. After passing through the toroidal section, the misalignment of the electron particle position is about 1.39 cm away from the mid-plane, but it is well aligned up to about 4.38×10^{-4} cm by optimising the *Bl* value of dipole field.

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