DEVELOPMENT OF MUSES ELECTRON COOLER AT RIKEN

M. Nishiura*, T. Tanabe, T. Katayama, RIKEN, 2-1 Hirosawa, Wako-shi, Saitama, 351-0198, Japan
E.Syresin, Joint Institute for Nuclear Research, Dubna, Moscow region 141890, Russia
I. Watanabe, Toshiba Corporation, 20-1 Kansei-Cho, Tsurumi, Yokohama, 230-0034, Japan

Abstract

The radioisotope beam factory (RIBF) is under construction at RIKEN [1]. The RIBF has multi-use experimental storage rings (MUSES) [2], which consists of an accumulator cooler ring (ACR) and an electron-RI beam collider (e-RI Collider). The electron cooler (EC) device is equipped for the ACR. On the basis of the previous ACR-EC, we refined the design of the electron gun and the magnetic field strength with the help of the computer simulation codes.

1 INTRODUCTION

In order to cool RI beams in the ACR, the stochastic cooler device (SC) is used in the first phase (it will take about 100 ms). After the pre-cooling by the SC, the RI beams reach less than 0.1% in momentum spread and 0.1 π mm-mrad in transverse emittance by the stochastic cooling and the electron cooling.

The design of the electron cooler for the ACR has recently been proposed and discussed [3]. Although the strong magnetic expansion was considered to allow us to study the atomic and the molecular physics, it was found not to be necessarily to use the high magnetic field of a few Tesla in a gun section [4]. Syresin et al. [5] reported the electron beams cooled by the magnetic expansion factor B_i / B_{cool} from 1 to 8 is sufficient to cool $^{92}U_{238}$ coasting beam with E = 100 MeV/u,, $\delta p/p = \pm 1.5$ mrad, and $\varepsilon_v = 40$ π·mm·mrad. Here B_i and B_{cool} are the magnetic field in a gun and in a cooling section, respectively. As shown in Table 1, the design parameters of the ACR-EC are changed; B_i / B_{cool} decreases 2.5 times smaller than that of the previous design. When the following relation $k_B T_\perp = (B_{cool}/B_i)/\ k_B T_{\perp i}$ is used and the initial transverse temperature $T_{\perp i}$ is equal to the cathode temperature T_{cath}, $k_B T_\perp$ in the cooling section is roughly estimated to increase from 5 meV(previous value) to 12 meV(this time).

In this paper we carried out the computer simulation by using SAM [6] and EGUN [7], and refined the design of the electron gun and the magnetic field strength.

*mn@postman.riken.go.jp

2 HARDWARE DESIGNS

2.1 Electron Gun

The beam current of 4 A at the energy of 250 keV is required for an electron gun. A tungsten cathode of 1.31 cm diameter is used. The cathode spec is given as the current density of 3.16 A/cm^2 at the working temperature of 1050 °C. As the results of endurance test for the cathode, the electron gun could be operated for more than 2000 hours at the electron current of a few A under B_i = 1.35 kG and B_{cool} = 500 G, and it was found that this cathode satisfies our desired ability.

Table 1. ACR-ring parameters [4]

Circumference, m	134.788
Ion energy, MeV/u	60-400
Beam acceptance, ε_{acep}, π·mm·mm	125/40
Maximum momentum spread, %	±1
Emittance of injected beam,ε_{inj}, π·mm·mm	5/40
Initial momentum spread, %	±0.15
Beta function in cooler (hor./vert.), m	4/14.34
Length of EC solenoid, m	3.6
Magnetic field in cooling section, kG	0.5-2
Magnetic field in gun section, kG	2-4
Magnetic expansion factor	1-8
Electron beam current, A	4
Electron energy, keV	30-250

2.2 Comparisons between SAM and EGUN codes

An electron gun proposed for the ACR-EC consists of three electrodes: a flat cathode, a Pierce electrode, and an anode. The dispenser cathode is 2.75 cm diameter. The cathode-anode gap is biased at 30 kV. The electron beam will be finally accelerated up to 220 keV by an acceleration tube (National Electrostatics Co.), and introduced into the cooling section through a toroid section. For simplicity, the toroid section is ignored for our simulation.

In order to design the electron gun for the ACR-EC, the computer simulations have been carried out by using SAM and EGUN codes. The input parameters are shown in Table 2.

Table 2 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

The magnetic field on the beam axis is calculated by *MATHEMATICA*® [8] in r - z coordinate. The solenoid field must decrease gradually from the e-gun to the cooling section within the adiabatic expansion. The adiabatic parameter used here is less than 4×10^{-2} under the condition of B_i / B_{cool} = 4kG/0.5kG.

Figure 1 shows the electron beam trajectories.

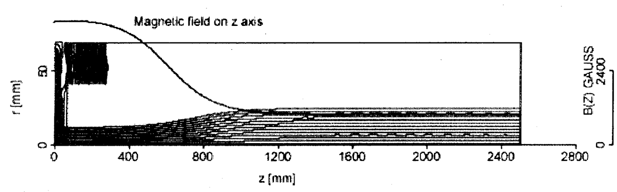

Fig. 1 The electron beam trajectories from the electron gun to the cooling section, which are calculated by EGUN code in the case of B_i / B_{cool} = 4kG/1kG.

Figure 2 shows the dependence of the transverse temperature E_{tra} on B_{cool} calculated by SAM and EGUN. The transverse temperature by SAM tends to be lower than by EGUN at the beam edge. In both cases E_{tra} becomes less than 1 eV at the beam edge, and less than 100 meV at r = 5.436 mm.

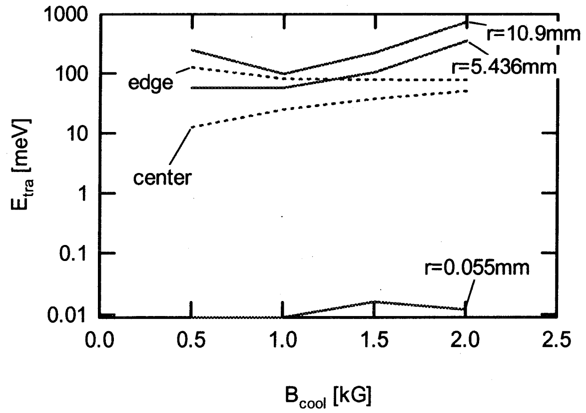

Fig. 2 Transverse electron energy in the cooling section calculated by SAM (dotted lines) and EGUN (solid lines). The value of r indicates the radial beam position at the dispenser cathode.

2.3 Design Issue of Anode

The electron gun mentioned above is designed to keep a high vacuum and to prevent the beams from hitting the anode. It is desirable that electron beams for an EC have a low transverse temperature. Since the initial velocity of electrons emitted from the cathode dominates the final transverse temperature, the electric field in front of the cathode should be parallel to the cathode surface.

The conductance of the anode A2 (133 sec^{-1}) becomes the same level as that of the A1 (112 sec^{-1}) to reach ultra-high vacuum of less than 10^{-8} Pa. The beam edge keeps the clearance of 8 mm from the A2. The electron beam current reaches 5A at the anode voltage of 30 kV.

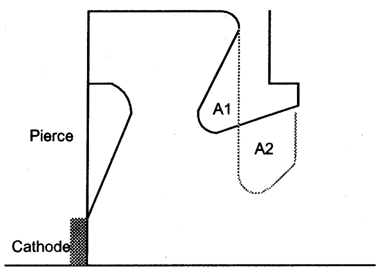

Fig. 3 Cross sectional view of previous anode shape (A1) and modified anode shape (A2).

Two configurations for anode shapes are compared using the EGUN code. Figure 4 shows the dependence of the transverse temperature in the cases of A1 and A2. The value of E_{tra} at the beam edge dropped from 1 eV to 100 meV. At B_{cool} = 2 kG, the transverse temperature at the beam edge is lower than that at 5.436 mm. In our case, the cathode temperature is equal to or more than the transverse temperature. When T_{cath} = 0.1eV and B_i / B_{cool} = 1, the transverse temperature would be less than 200 meV. From the beam trajectory, the electron beam increases the radius of 35 mm under the condition of B_i / B_{cool} = 8 by the expansion and the drift. This spec of the electron gun is acceptable for our purpose.

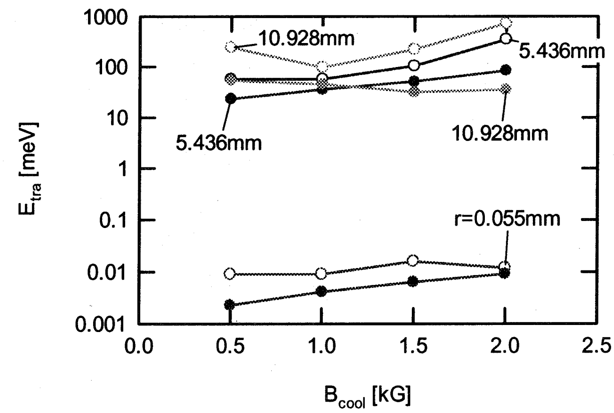

Fig. 4 Dependence of the transverse temperature on the magnetic field in the cooling section. Open and closed circles indicate the cases of A1 and A2, respectively.

2.4 Collector Section

Tanabe et al. have already proposed the collector design for the ACR-EC in Ref. [9]. The same design is used for the beam trajectory calculation, as shown in Fig. 8. The initial beam parameters are taken from the final beam parameters calculated above in the case of B_i / B_{cool} = 4kG/(2 ~ 0.5kG). When the expansion factor is higher, the beam radius is very close to the deceleration tube radius. In order to avoid beams hitting the wall and the electrodes, the focus lens should be placed before the beams passing through the deceleration tube.

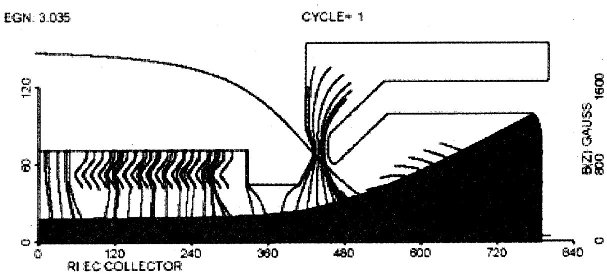

Fig. 5 Electron beam trajectories for B_{gun} = 4 kG, B_{cool} = 2 kG, B_{col} = 2 kG.

3 FUTURE PLAN

The present status of the ACR-EC has been presented in this paper. In the near future, we will accomplish the following plans:

- Development of a precise magnetic field measurement system (resolution of 10^{-5}) of solenoids from the e-gun to the collector.
- 3D simulation for electron beams and magnetic fields by MAFIA code [10]. (The preliminary result of magnetic field is shown in Fig. 6.)

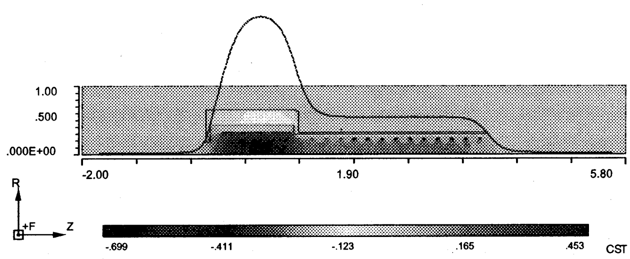

Fig. 6 Profile of the magnetic field near the electron gun calculated by the MAFIA code. The red curve shows the magnetic field on the z-axis in the z component. The magnetic shield is drawn in green.

5 REFERENCES

[1] Y. Yano et al., the proc. of Cyclotrons 2001.
[2] T. Katayama et al., p.529, the proc. of EPAC'98
[3] T. Tanabe et al., NIM A441, 104(2000).
[4] T. Tanabe et al., the proc. of Cooling workshop 2001, Germany.
[5] E. Syresin et al., the proc. of Cooling workshop 2001, Germany.
[6] M. Tiunov, B. Fomel, and V. Yakovlev, Preprint INP, Novosibirsk, 85-159.
[7] W. H. Herrmannsfeldt, SLAC-226, 1979.
[8] Radia(ESRF), http://www.esrf.fr/
[9] T. Tanabe et al., the proc. of PAC'99.
[10] MAFIA(CST), http://www.cst.de/