Electron Coolers in MUSES project

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Abstract

As a part of new experimental facilities in the Radio Isotope Beam Factory (RIBF) project at RIKEN, the Multi-Use Experimental Storage rings (MUSES) complex will have three electron coolers (ECs). The Accumulator Cooler Ring (ACR) which is used for both the accumulation and cooling of RI beams and various experiments has a conventional one which is presently under development. Two middle energy ECs (Max electron beam energy of 2 MeV) are planned to be constructed in the Double Storage Rings (DSR). The design issues of ACR cooler and some prospects of DSR coolers are discussed.

1 Introduction

In the ACR, an EC device is used for both more efficient injection and various experiments using cooled ion beams. A scheme of adiabatic transverse expansion [1] has been chosen for the ACR-EC to further reduce electron transverse temperature than that utilizes no beam expansion. The ion energy in the ACR range from 60 to 400 MeV/u which corresponds the electron beam (e-beam) energy for the EC from 30 to 250 kV. The maximum current from a 12.7 mm cathode is 4.1 A with a gun perveance of 0.79 μ P. A superconducting solenoid in the gun section generates a magnetic field of 4 T which corresponds to a factor of 20 in adiabatic expansion. The design of the gun section is described in Sec. 2 and that of the collector is given in Sec. 3. Effects of the toroidal section on the electron beam are examined in the following section.
As for the DSR cooler, the design concepts and preliminary design parameters are given in Sec. 5 before conclusion.

2 Gun Section

2.1 Cathode/Anode and Acceleration Tube

The highlight of the ACR cooler design is in the area of the gun section which utilizes a He-free superconducting solenoid producing 4T. In terms of cost and field uniformity of the solenoid, smaller gun and acceleration tube are preferred. However, without the possibility of placing vacuum pumps in the vicinity of a cathode, high vacuum conductance must be maintained through the section to ensure ultra-high vacuum (UHV.) Poor vacuum would cause; contamination of the cathode surface, lowering the discharge limit due to high voltage (HV), and increase of unnecessary radiation hazard. The cathode diameter is 12.7 mm to keep the maximum voltage gradient in the area of the cathode/anode less than 50 kV/cm. Both Egun [2] and SAM [3] are used to examine the behavior of e-beam to optimize the design. Figure 1 shows a result of EGUN simulation with the current design.

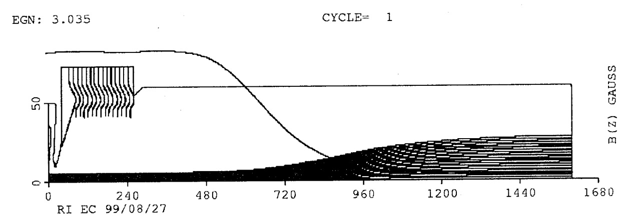

Fig. 1: EGUN simulation of the electron gun section

2.2 Magnetic Shielding

The rough design of magnetic shield and solenoids are conducted by SAM and more extensive FEM calculations followed. Optimization of the design is directed to the following characteristics: uniformity of the field over the acceleration area, minimization of the shield thickness, and reduction of the adiabatic parameter, which is defined as

$$\chi = \frac{\lambda_c}{B}\left|\frac{dB}{dz}\right| \tag{1}$$

where B is the solenoid magnet field and λ_c is the spiral length of the cyclotron motion:

$$\lambda_c = \frac{2\pi\sqrt{2m_e E_e}}{eB}. \tag{2}$$

A cross-sectional view of the design of an electron gun, acceleration tube, a superconducting solenoid, a warm solenoid, and a magnetic shielding are delineated in Fig 2. The magnetic field distribution and the adiabatic parameter are shown in Fig. 3.

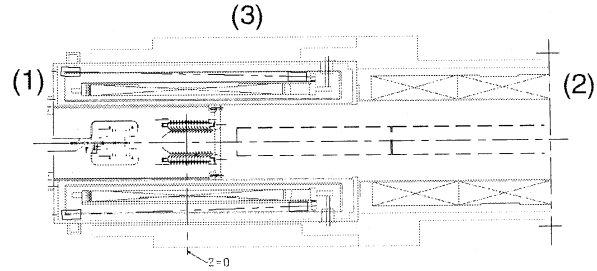

Fig. 2: Layout of (1) a superconducting solenoid, (2) a warm solenoid and (3) a magnetic shielding.

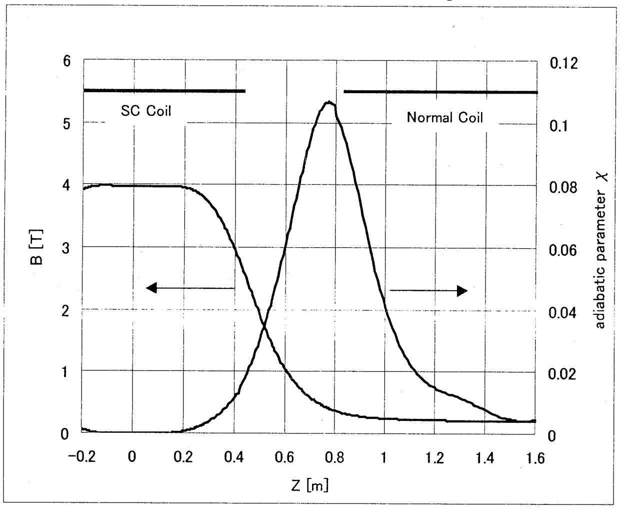

Fig. 3: The longitudinal magnetic distribution and the adiabatic parameter.

2.3 Toroidal Section

The electrons obtain additional perturbation, when they pass through the toroidal sections. This perturbation is observed for electrons which are displaced from the equilibrium axial trajectory. When the electrons pass through a toroidal magnet, the additional drift velocity appears [4]:

$$v_{dT} = \frac{\gamma m v^2}{\mathrm{Re}\, B}\frac{x}{R} = v\frac{\rho}{R}\frac{x}{R}, \tag{3}$$

where $\rho = v / \omega_B$ is the gyration radius, R is the radius of the axial electron trajectory in the toroidal section, x is radial coordinate. Hence, the discontinuity of the magnetic field at the entrance/exit of toroidal magnets creates additional transverse temperature which can be reduced by increasing the toroidal radius and decreasing the adiabatic parameter at the entrance/exit of toroidal magnets.

3 Collector Section

The initial design of the ACR collector was based upon the TARN II collector. Various improvements have been incorporated during the past year. The geometry of the new collector section is given in the Fig. 4.

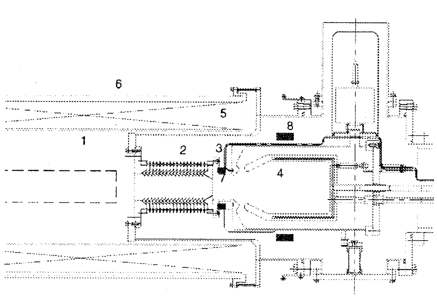

Fig. 4: The design of the collector. 1 is the drift chamber, 2 deceleration tube, 3 repeller, 4 collector electrode, 5 the solenoid of electron cooling, 6 magnetic shielding, 7 a permanent magnet coil placed on the collector entrance, and 8 is a permanent magnet coil placed on the collector surface.

The ratio of the current density of the reflected secondary electrons that escape a collector to that of the incoming beam is proportional to [4]:

$$\frac{\dot{j}_{ref}}{j} \cong \frac{\sigma_e}{\pi}\left(\frac{\varphi_{\min}}{U_{col}}\right)^2 \frac{B_{col}}{B_{\varphi\min}}, \tag{4}$$

where j is the incoming beam current, $\sigma_e \approx 1$ is the secondary emission coefficient, B_{col} is the magnetic field on the collector surface, and $B_{\varphi min}$ is the magnetic field in the region of minimum potential value. Types of modifications applied are as follows:

- The collector diameter is increased to reduce the magnetic field on the collector surface, B_{col}.
- To increase $B_{\varphi min}$, the permanent magnet coil is placed inside the repeller electrode with the magnetic field of 2 kG.
- A permanent magnet coil is placed on the collector surface to reduce B_{coll}.
- The collector radius is reduced at the entrance to shift the position of the virtual cathode to the region in higher magnetic field.

The collector perveance is estimated as $P_{col} = I / U_{col}^{3/2} \approx 25 \sim 30\ \mu A / V^{3/2}$. The permanent magnets produce a negative radial magnetic field on the collector surface in the region 44cm<z<51 cm (so called magnetic-insulated region). Consequently, the current loss was reduced by an order of magnitude compared to the old design.

4 Diagnostic systems and other issues

A diagnostic set-up for an e-beam can be separated in two categories of devices - the conventional and the special ones. The conventional diagnostic devices measure the following quantities: electrode potential, e-beam current, e-beam loss current. The special devices are used for the measurement of the transverse electron temperature, the parameters of the neutralized electron beam, and the characteristics of secondary electrons and ions. The details of the designs have yet to be worked out.

Table 1 shows the latest parameters of the device and cross-sectional view of the whole EC system is shown in Fig. 5.

Table 1: Parameters of ACR-EC

Acceleration Voltage	30 ~ 250 kV
Magnetic Field (gun/cooling)	4 T / 0.2 T
Field Uniformity (gun/cooling)	$1\times10^{-4} / 2\times10^{-5}$
Cathode Diameter	12.7 mm
Maximum E-Beam Current	4 A
Gun Perveance	0.79 μP
Anode-Cathode Voltage	30 kV
Main Solenoid length	3.6 m
Toroidal Angle / Radius	90° / 1.5 m
Collector Efficiency	> 99.98 %

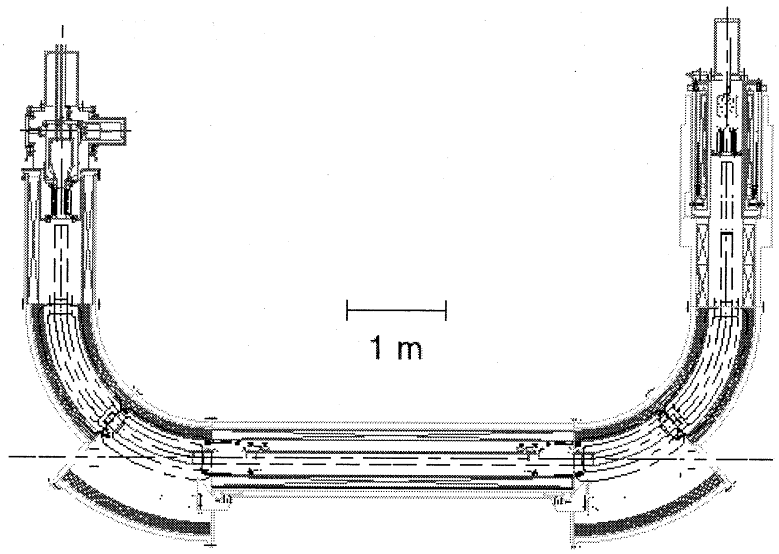

Fig. 5: Cross-sectional view of the MUSES-ACR EC

5 DSR Cooler

5.1 General Considerations

Electron cooling system is planned at DSR to suppress beam instabilities and to make a short bunched ion beam. Combination of beam-beam interaction with cooling is considered to be a way to suppress beam-beam instability and to increase the maximum achieved value of beam-beam parameter up to 0.02. In this case the luminosity of electron-ion collisions can be increased at least 4 times that without cooling [5]. Another goal of the electron cooling at DSR is to compensate the ion beam heating due to intrabeam scattering process. The luminosity of the ion-ion and ion-electron collisions increases when the ion beam is bunched. The presence of the electron cooling stabilizes the bunching process of the intensive ion beam.

5.2 Design Issues

Medium energy ECs are the subject of active R&D programs all over the world. We are considering to adopt the configuration tested at BINP[6]. It is a typeical configuration for an EC with recuperation of the e-beam energy. The design of the high-voltage power source is based on the rectifier of the ELV-accelerator, which is used for industrial applications. All the HV elements are placed inside a common gas system including the vessels for, rectifier, accelerating and decelerating tubes. The HV stability in these experiments was about 1% which is insufficient for ECs. Therefore the special measures to stabilise HV is required. Use of an electrostatic accelerator such as pelletron or disktron is another possibility[7,8]. The preliminary design parameters of DSR-EC is given in Table 2.

Table 2: Parameters of DSR-EC

Acceleration Voltage	50 ~ 2000 kV
Magnetic Field	0.1~0.15T
Cooling Section Length	4.8 m
E-beam Diameter	10 mm
Maximum E-Beam Current	1 A
Magnetic Field Homogeneity	1×10^{-4}
Current Stability	5×10^{-4}
Power Consumption	100 kW
Magnetic Field Alignment	25μm/m
Collector Efficiency	> 99.98 %

6 Conclusion

Designs of electron coolers in MUSES project are described. ACR cooler is in its final stage of designing. DSR cooler design is still being investigated as of Sep. 1999.

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