AN ELECTRON-COOLER-DESIGN FOR THE S-RING AT NIRS

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Abstract

A small ring project for heavy ions has been started at NIRS. In this synchrotron, an electron cooler is installed to deliver a low emittance beam at any energy range, a high intensity beam using cool-stacking technique, and deliver a short-bunched beam through cooling and a phase rotation technique. The electron cooler consists of two toroid magnets with a radius of 650 mm, a cooling solenoid with a length of 900 mm, an electron gun with high perveance, and highly efficient collector system. A magnetic field of the cooling solenoid is 0.05 T, and the maximum magnetic field expansion ratio is 6. A design of the electron cooler is presented.

1 INTRODUCTION

At National Institute of Radiological Sciences (NIRS), a small ring project for heavy ions has been started in 2001 [1]. The small ring (S-ring), whose circumference is less than 25 m, has been designed to supply heavy ion beams with a charge to mass ratio of 1/2 ranging of energy from 1 to 24 MeV/n. In the S-ring, an electron cooler is installed to cope with various requirements of the experimental users. By use of an electron cooler, we can deliver (1) a low emittance beam both in transversally and longitudinally at any energy range, (2) a high intensity beam through cool-stacking technique, and (3) a short-bunched beam using cooling and phase rotation technique. The synchrotron is optimised for the electron cooler. The total length for the electron cooler is 2.4 m, except for the space of the steering magnets to correct a beam orbit deflected by the toroidal field. A horizontal and a vertical beta function in the centre of a cooling solenoid are 1.3 and 2.0 m, respectively, when a super-periodicity of the ring is chosen to be 1. In the cooling solenoid region, the dispersion free is achieved by applying the DBA (Double Bend Achromatic) lattice structure. The main function of the electron cooler is to minimise an injection beam with a large emittance made by the multi-turn injection. In the HIMAC injector, a repetition frequency of the pulsed beam is 3 Hz. Therefore, we should cool the injection beam enough less than 300 msec to achieve a cool-stacking method. A design of the electron cooler for the S-ring is presented.

2 DESIGN OF THE ELECTRON COOLER

2.1 General Layout

Figure 1 shows the layout of the S-ring cooler. The cooler is designed as small as possible, because we have the restriction of the installation space in the s-ring. The total length for the electron cooler is 2.4 m. A bending radius and an angle of the equilibrium electron orbit in the

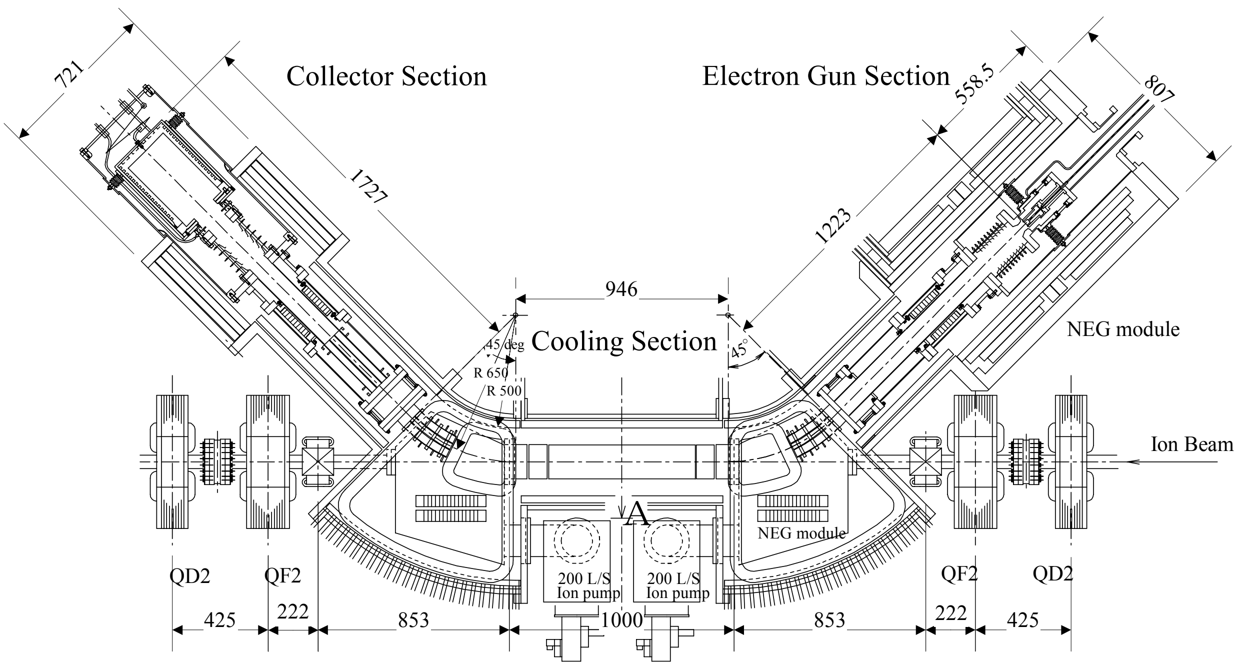


Figure 1: The layout of the S-ring cooler.

toroid magnets are chosen to be 0.65 m and 45 degree, respectively. Therefore, we can keep the cooling section of 0.9 m. The length of the cooling section occupies around 4 % of the ring circumference. A magnetic field of the cooling solenoid is 0.05 T, and the maximum field of a collector solenoid is 0.15 T to prevent the secondary electrons produced in a collector moving backward. The maximum electron beam current at the injection energy, 6MeV/n for ion, is 0.4 A and the maximum magnetic-field expansion-ratio is 6. In this condition, a cooling time of a carbon beam with an emittance of 64 πmm.mrad is estimated to be 0.7 sec. The inner diameter of the solenoid coil is determined to be 0.3 m, considering the space of correction coils and the assemblies for bake-out. The aimed vacuum pressure in the cooling section is designed to be less than 10^{-8} Pa. To achieve such a low vacuum pressure, the whole vacuum chambers in the electron cooler, including the gun and the collector is designed for withstanding the bake-out temperature up to 200 degree in centigrade. Some heaters for bake-out are installed around the vacuum chambers. Two sets of NEG pumps and two external ion pumps are attached directly with toroid chambers. To evacuate the gun and the collector section, other two sets of NEG pumps are installed. The total pumping speed is around 4000 litres/sec in He. From the exit of the acceleration tube to the entrance of the deceleration tube, the electric shield made of stain-less steel mesh to keep a grounded potential surrounds an electron beam path. Electrostatic bending deflectors and a Wien filter are applied for compensation of centrifugal drift motion to avoid problems of secondary electrons. Each electrostatic-bending deflector is installed in a toroid magnet, and a Wien filter is installed between a collector and a toroid magnet. The required electric field of the deflector and Wien filter is 0.9 kV/cm and 1.25 kV/cm, respectively. Main parameters of the electron cooler are listed in table 1.

Table 1: Main parameters of the S-ring cooler

Length of the cooling solenoid (m)	0.9
Magnet field in cooling section (T)	0.05
Radius of an electron beam in a toroid (m)	0.65
Electron energy (keV)	3 - 30
Maximum beam current (A)	0.4 – 2
Field expansion ratio Bgun/Bsol	1 - 6
Electron beam size in the central region (cm)	3.8
Gun parameters	
Voltage in accelerating tube (kV)	30
cathode diameter (cm)	1.54
Gun perveance (μA/$V^{3/2}$)	1.75
Electron current at 3.3 keV (A)	0.39
Current density at 3.3 keV (A/cm^2)	0.2
Electron current at 30 keV (A)	2.0
Current density at 30 keV (A/cm^2)	1.1
Anode accelerating voltage (kV)	10
Max. field of the gun solenoid (T)	0.3
Collector parameters	
Collector voltage (kV)	5.0
Repeller voltage (kV)	5.0
Max. field of the collector solenoid (T)	0.15
Collector inner diameter (cm)	22.0

2.2 electron gun section

An electron gun section consists of three electrodes: a flat cathode which diameter is 1.54 cm, an anode with a Pierce shape, and an acceleration tube. A layout of the gun section is shown in Fig.2. An adiabatic expansion scheme was chosen to decrease a transverse electron temperature. The peculiarity of this gun is to obtain a high electron-beam density at the injection energy, corresponding to the electron energy of 3.3keV. The maximum beam current at injection energy and the maximum magnetic field expansion ratio is determined to be 0.4 A and 6 from the simulation results respectively [3]. The maximum current is restricted by the space charge effect, and the maximum expansion ratio is determined by the reduction of a current density. The electron temperature of radial direction in the cooling section is 2 meV, the thermal cathode temperature is less than 25 meV, and the azimuthal temperature is 100 meV, respectively, at the following conditions: the magnetic field of the gun solenoid of higher than 2 kG, electron beam current of 0.4 A, and electron energy of 3.3 keV. The maximum electric field of the cathode gap is about 15 kV/cm on radius of 1.8 cm at the electron energy of 30 kV.

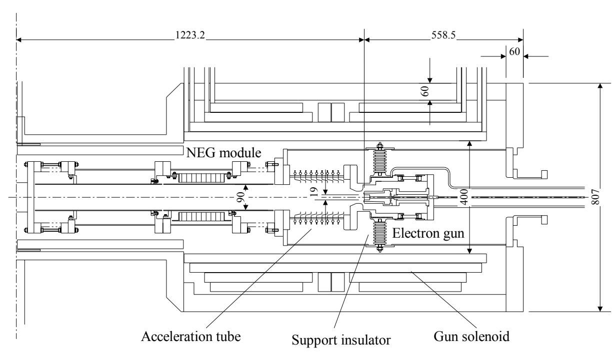


Figure 2: Layout of the gun section of the S-ring cooler.

2.3 collector section

The collector section consists of a deceleration tube, a repeller electrode, and a collector electrode. Figure 3 shows the layout of the collector system. The collector electrode is a Faraday cup. The repeller electrode has a diaphragm shape, and its perveance is higher than that of tube shape. A magnetic shielding is used in this collector to realise the fast magnetic field expansion inside a collector cup. The magnetic field in collector section is 1.5 kG, 1/2 of the field strength in the gun section.

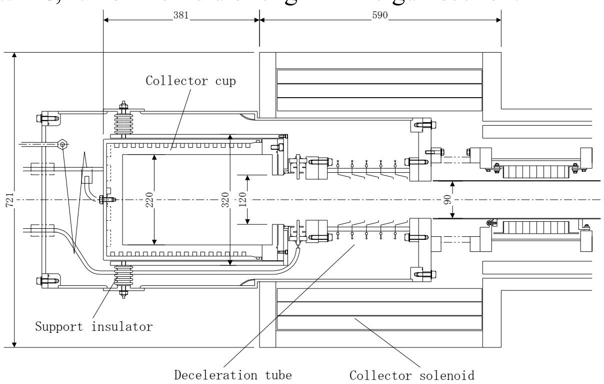


Figure 3: Layout of the collector section of the S-ring cooler.

2.4 Field quality of magnets

A high-quality magnetic field is required for the magnets of an electron cooler. The allowable magnetic-field error is estimated to be less than 10^{-4} in the transition region between toroid and solenoid and less than $5\cdot10^{-5}$ in cooling solenoid. Additional correction coils placed on the boundary of transition region permit to disturb the transverse magnetic field in this region up to the level of 5E-4. Additional correction dipole coils can reduce the magnetic field in central region.

2.5 field analysis

Shortening the transition region is to lengthen the cooling section. To investigate the magnetic field behaviour in the transition region, Three-dimensional simulation was carried out with TOSCA. The calculation model is shown in Fig.4. The field calculation was done from the centre of the cooling solenoid to the centre of the toroid magnet. Figure 5(a) and 5(b) show the longitudinal magnetic field along the electron beam axis and a transverse magnetic field perpendicular to the electron beam axis, respectively. In the figures, the boundary between the solenoid and toroid is located in 460 mm at a horizontal axis of abscissa. The transition length from toroid to solenoid is about 200 mm. The transverse field shape at the end of the model, about 750mm from centre, is rather large from our expectation.

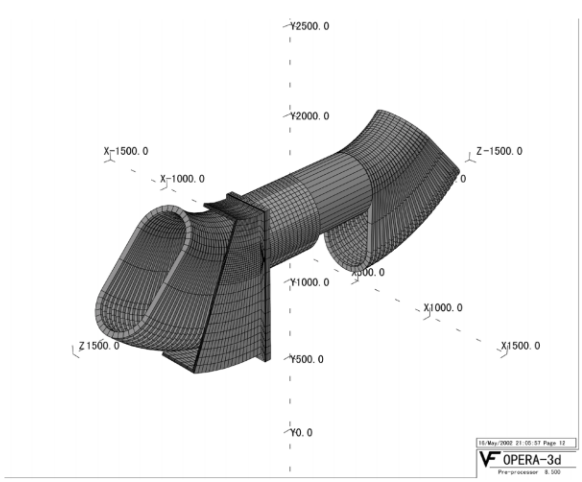
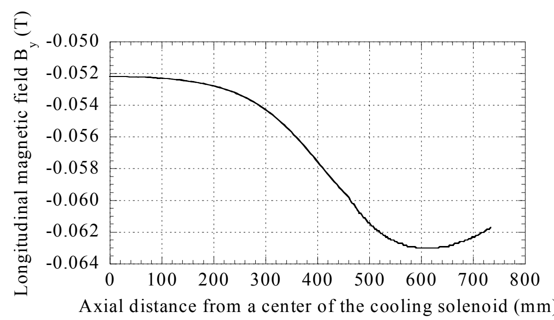


Figure 4: A calculation model for the three-dimensional magnetic field calculation.

(a)



(b)

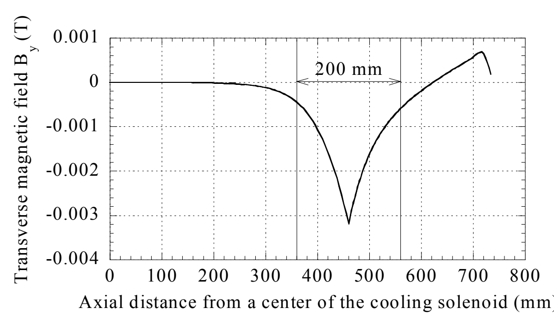


Figure 5: Results of the three-dimensional magnetic field calculation along the electron beam axis. (a) The longitudinal magnetic field along the electron beam axis, (b) The transverse magnetic field perpendicular to the electron beam axis. The transverse magnetic field in the horizontal direction, not shown in this paper, is negligible small around the area.

3 ACKNOWLEDGEMENT

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