ELECTRON COOLING AT ACR IN MUSES PROJECT

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Abstract

The Accumulator Cooler Ring (ACR) is proposed for a storage ring complex called MUSES (Multi-Use Experimental Storage rings) in RI-Beam Factory Project at the Institute of Physical and Chemical Research (RIKEN) . In combination with a stochastic cooling, the electron cooler with an adiabatically expanded beam is expected to improve the quality of the ion beam in ACR [1]. The electron gun with the magnetic field 5T and the acceleration voltage 300kV was investigated in calculation. And the electron trajectories in the adiabatic expansion with the magnetic field from 5T at gun to 0.2T at cooling section was also calculated. The electron transverse velocity are shown to become 1/5 due to the adiabatic expansion.

1 INTRODUCTION

Electron cooling has been proven to be one of the effective methods to reduce the phase space volume of particle beams in the accelerators. A scheme of adiabatic transverse expansion has been chosen to achieve lower electron transverse temperature than that directly from a cathode.

It is well known that the average transverse energy $<E_{trans}>$of the ensemble of electrons divided by the axial magnetic field is adiabatic invariant:

$$<E_{trans}>/B = \text{const.}$$

Therefore, by changing the strength of solenoid field from the gun section to the interaction region adiabatically, namely the length of field change is much larger than electron gyration radius, the transverse temperature of the electron beam could be reduced by a factor of B_f/B_i where subscript f indicates the final value and i the initial value.

2 DESIGN PARAMETERS FOR ELECTRON COOLER

The electron kinetic energy Ee can be determined by the nominal energy of the ion beam Ei according to the following relation:

$$Ee[MeV] = (\varepsilon_e/\varepsilon_i)\ Ei[MeV],$$

where ε_e = 0.511MeV and ε_i = 931.501MeV/u. The ion energies in ACR range from 100MeV/u to 500MeV/u, which translate to electron energies from 55keV to 274keV. We set the maximum acceleration voltage to be 300kV.

The beam diameter of 50mm is derived from the requirement to cover the horizontal sizze fo ion beams (maximum emittance of 125π mm mrad and horizontal betatron function of 5m.) An axial magnetic fiels of 0.2T is chosen to satisfy magnetization condition for the lightest ions and the expansion factor of 25 corresponds to the field 5 T in the gun section. The maximum available current is determined by the perveance of the gun which is fixed by the geometry and the extraction potential which is practically limited by the electrical discharge limit. In our case the current of 4 A is considered to be viable. The length of the cooler is 3.6 m within a perimeter of 168.48m. All the relevant parameters are summarized in Table.

3 ELECTRON GUN

The electron gun with the magnetic field 5T and acceleration voltage 300kV was investigated in EGUN code and the result is shown in Fig.1. Electron beams from the cathode with 5mm in radius are accelerated without expansion in the strong magnetic field. Anode - Cathode voltage is 30kV and the number of acceleration electrode is 18. The acceleration voltages are equally divided by these electrodes. The perveance is 0.79µP in this calculation and the current is 4A.

Next the electron trajectories in the field expansion type of electron cooler was calculated with the electron gun shown in Fig.1 and the result is shown in Fig.2. The electron beams expand according to the reduction in magnetic field and the beam radius with 5mm at the cathode becomes 25mm at cooling section. The magnetic field on axis used in this calculation was represented by the combination of the analytical expressions of solenoid coil. The parameters of these solenoid coils were adjusted so that

Table Parameters of Electron Cooler

Acceleration voltage		300kV
Magnetic field	(Gun)	5T
	(Cooling section)	0.2T
Cathode diameter		10mm
Beam diameter in cooling section		50mm
Current		4A
Perveance		0.79µP
Anode-Cathode voltage		30kV
length of cooling section		3.6m

the flatness in the magnetic field (|dB/B|) in the gun section and the cooling section become within $5.0*10^{-4}$.

The radial and azimuth velocity of the electron starting 5.5mm off axis are shown in Figs.3 (a) and (b) respectively. These velocities increase at the transition region in magnetic field (z = 1000 - 2500mm) and decrease at cooling section. The velocity spread at gun section gradually decreases and becomes 1/5 at cooling section.

4 ADIABATIC PARAMETER

Figure 4 shows the adiabatic parameter χ, which is defined as

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

λc is the spiral length of the cyclotron motion:

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

Ee is the electron energy pararell to axis. Adiabatic conditon is $\chi << 1$. The adiabatic parameter in this electron cooler is 0.1 in maximum and relatively large. This is due to high acceleration voltage. But Figure 3 (a) and (b) show the transverse velocity decreases adiabatically in this calculation.

5 CONCLUSION

Electron trajectories and the transverse velocities were investigated in the electron cooler for ACR with the magnetic field 5T in the gun region and 0.2T in the cooling section and 300kV accelerating voltage. The calculation shows that the fluctuations of the transverse velocity reduce to 1/5 at cooling section owing to the adiabatic expansion.

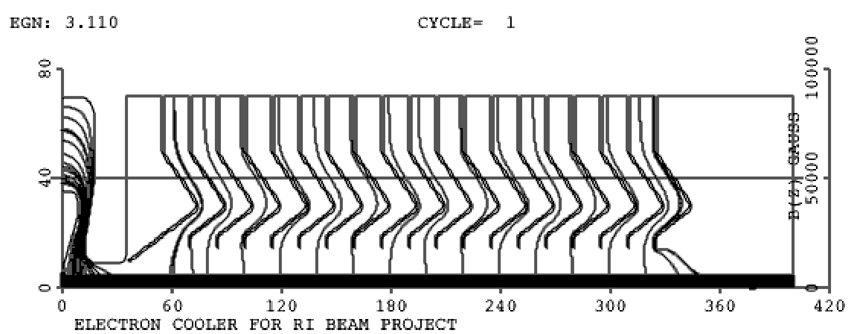


Figure 1: Electron gun with magnetic field 5T and acceleration voltage 300kV (unit: mm in length)

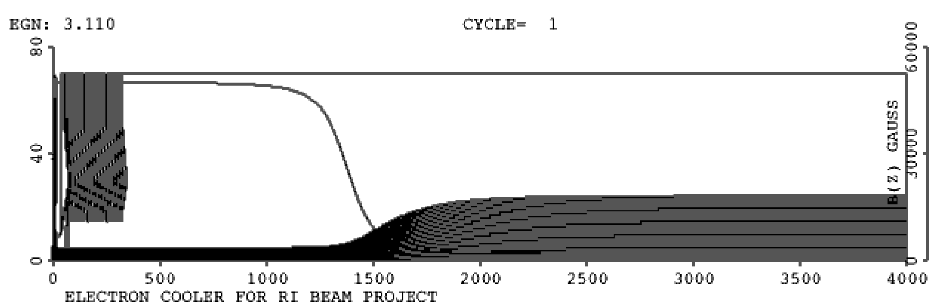
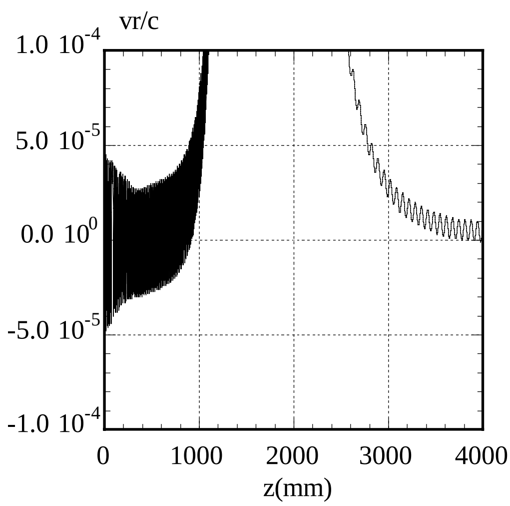


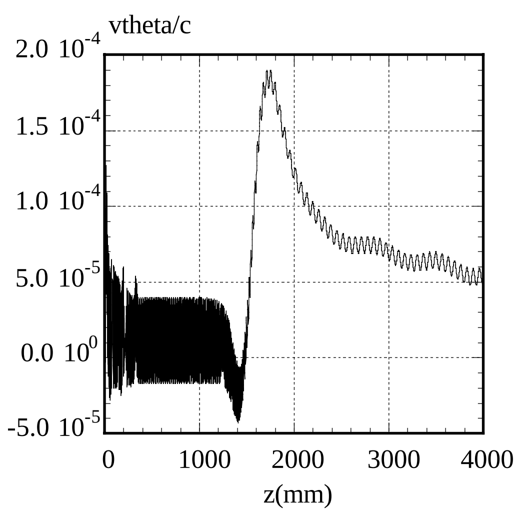
Figure 2: Electron trajectories in adiabatic expansion (unit: mm in length)

REFERENCES

[1] Y.N.Rao et at., Electron cooling at ACR, Proceeding of EPAC '96.



(a)



(b)

Figure 3: Transverse electron velocity starting 5.5mm off axis. (a) is radial and (b) is azimuthal velocity.

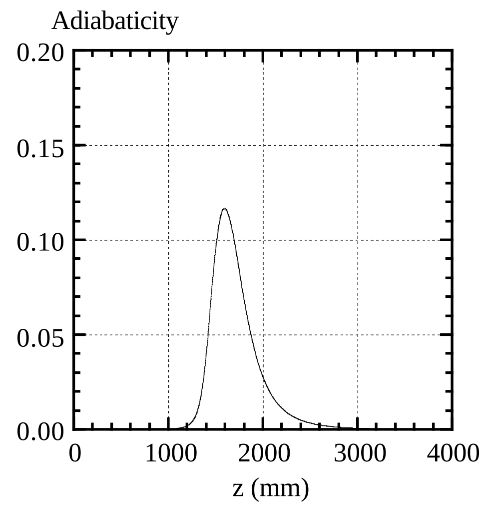


Figure 4: Adiabaticit parameter in this electron cooler