LAYOUT AND OPTICS FOR THE RHIC ELECTRON COOLER*

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Abstract

As part of a luminosity upgrade it is planned to add an electron cooling section to the RHIC accelerator. Existing electron coolers operate at low beam energies and use a continuous electron stream. The ion energy of 100 GeV/u in RHIC requires an electron energy of 55 MeV. Therefore the RHIC cooler uses a linac with energy recovery for the electron acceleration. Short bunches exiting the linac section are stretched longitudinally to reduce the momentum spread and space charge effects in the cooling section, and compressed afterwards for deceleration and energy recovery in the linac. This report describes the design of the electron beam transport and simulation results.

INTRODUCTION

The RHIC accelerator provides collisions of ions from protons to gold. The particles are injected through a chain of pre-accelerators including a Tandem accelerator for ions and a linac for (polarized) protons, a booster and the AGS synchrotron. The normalized transverse emittance in RHIC is 10 mm mrad for ions. Future extensions of the accelerator complex include a pair of electron coolers (for the "blue" and "yellow" rings) which will be used to fight the degradation of the bunch length and emittance due to intra beam scattering over the duration of a fill and even increase the luminosity by decreasing the transverse emittance.

To achieve this task the RHIC electron coolers have to work at storage energies of 100 GeV/u. This corresponds to an electron energy of 55 MeV. The usual techniques of generating such electron beams (like a Pelletron) cannot be used. Instead, a super-conducting linac is appropriate and energy recovery is used to reduce the resulting beam power of 5 MW to manageable levels before dumping the beam.

A first study was performed in collaboration of BNL and Budker Institute of Nuclear Physics [1]. The design laid out in this study has since been improved, the biggest change being the replacement of a DC electron gun by a photocathode RF gun.

This report presents the improvements to the layout and optics of the RHIC Electron Cooler.

OVERVIEW

The layout of the cooler is shown in Figure 1. The electron beam is created in the photo-cathode RF gun shown in red in the picture. A bunch charge of 10 nC is assumed and the energy after the gun is 2.5 MeV. Using a pair of dipole magnets with a deflection angle of 3 degrees each the beam is injected into the super-conducting linac, consisting of four 5 cell 700 MHz cavities and two 2100 MHz cavities. The beam is accelerated to 55 MeV. It passes a weak dipole magnet which will extract the beam after energy recovery. A matching section with six quadrupoles is used to achieve the required phase advances for the transport of magnetized beam. The "stretcher" increases the bunch length from 1.5 cm to 7 cm, with a 200 MHz cavity at the end to reduce the energy spread of the beam. This cavity needs to be in a location with zero dispersion to maintain magnetization and emittance of the beam. The electron beam is then injected into the cooling section where it merges with the ion beam. The cooling section includes two 13 m long solenoids with a matching section between them to maintain magnetization. A second 200 MHz cavity introduces the opposite energy spread, so that the following "compressor" section (identical to the stretcher) reduces the bunch length to 1.8 cm. The beam passes the 3 degree magnet mentioned above, however, the beam energy is now 25 times higher so that the beam is only deflected by a tenth of a degree. The path length is adjusted so that the beam is shifted by 180 degrees relative to the accelerating phase of the cavity and is therefore decelerated while passing through the cavities. With a beam energy of now 2.5 MeV the dipole magnet mentioned above deflects the beam into the beam dump.

DETAILS

Injection into the cavities

At the entrance of the linac the low energy beam and the high energy beam must be merged. This is accomplished by a dipole magnet that deflects the low energy beam by 3 degrees while the high energy beam is not effected significantly. The dipole creates dispersion which reduces the magnetization of the beam. Since the momentum distribution of the electrons is changed in the linac the dispersion must be compensated locally. Therefore a pair of dipoles is used with solenoid focusing to create a 180 degree betatron phase advance between them. In order to avoid coupling the focusing is done with a so called Stabenov magnet: two solenoid coils with opposing fields.

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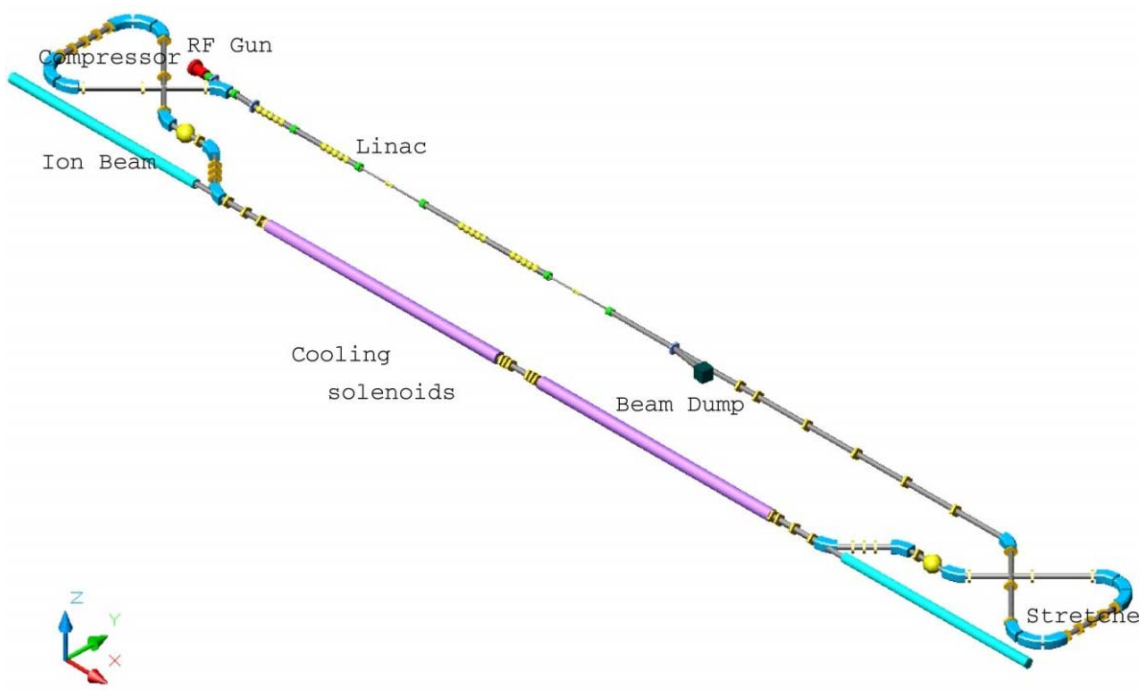

Figure 1: Schematic overview of the RHIC electron cooler. The magnetized electron beam is accelerated in a recirculating super conducting linac and stretched to the required bunch length in an extra loop in the arc that also serves as a transfer line into the solenoid. At the exit of the solenoid a second arc reduces the bunch length to its original value and transports the beam back to the linac for energy recovery. (graphic by S. Bugros)

Harmonic energy correction

The bunches have a length of ± 15 degrees in the 700 MHz system. The head and the tail therefore see a smaller acceleration field than the center of the bunch. In order to flatten the energy spread in the electron beam two 2100 MHz cavities decelerate the beam and do so much more in the middle than in the head and tail. The system also minimizes energy spread due to space charge.

Stretcher/Compressor

The stretcher lengthens the electron beam which has two purposes: First, together with a 200 MHz cavity it rotates the bunch in longitudinal phase space to reduce the energy spread of the electron bunch. For such rotation the path length in the stretcher should be only a function of the momentum deviation of the electrons. The path length deviation through the stretcher is:

$$\Delta L = \int \frac{x_\beta(s) + \frac{\Delta(s)p}{P} D}{\rho(s)} ds$$

where $x_\beta(s)$ is the betatron motion of the particle, $D(s)$ is the dispersion function and $\rho(s)$ is the bending radius in the dipoles. By using a mirror symmetric layout with 180 degrees phase advance between the inner dipoles the contribution of x_β to the integral is zero The optics of the stretcher is shown in figure 2

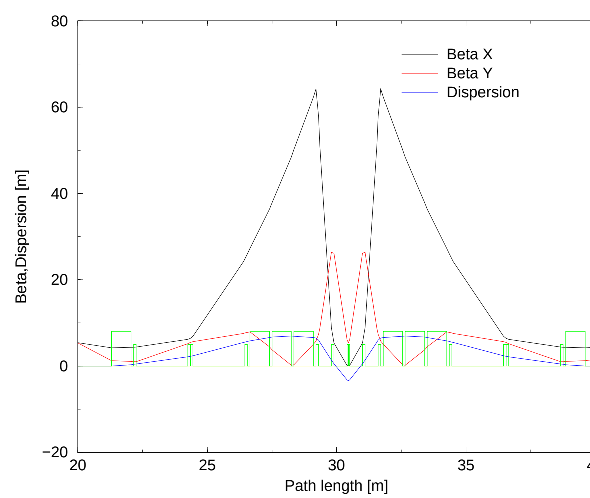

Figure 2: Optics of the stretcher/compressor

The second function of the stretcher is to reduce the density of the electron beam and therefore to reduce the space charge effect of the electron beam on the ion beam.

Cooling solenoid and coupling compensation

The length of the cooling section is approximately 30 meters. For engineering reasons the cooling solenoid is split into two parts. To preserve electron beam magne-

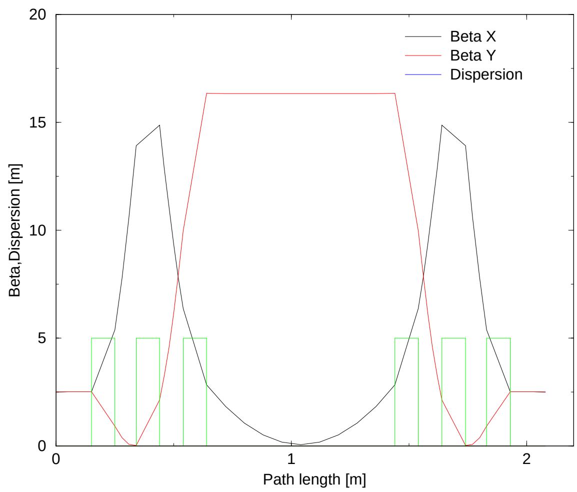

Figure 3: Optics of the matching section between the cooling solenoids

tization an appropriate matching section between the two solenoids is required. In reference [2] this matching is accomplished by a short focusing solenoid in the middle of the gap.

Using a solenoid for the focusing preserves axial symmetry and requires that the field of the two cooling solenoids have the same direction. This is a source of coupling for the ion beam and rotates the spin if RHIC accelerates polarized protons. To avoid these detrimental effects an alternative scheme has been developed consisting of a quadrupole matching section between the solenoids. Using quadrupoles for focusing allows having opposing fields in the cooling solenoids. The matching section must provide a phase advance of 180 degrees in the horizontal direction and 360 degrees in the vertical direction. Figure 3 shows the optics for the matching section. Figures 4 and 5 show the difference of the two methods.

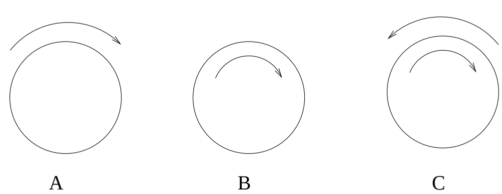

Figure 4: Maintaining beam magnetization across solenoid gaps. Focusing with solenoid: A - the fringe field of the first cooling solenoid creates a vortex. B - Focusing with a short solenoid reproduces the same vortex at the entrance of the second cooling solenoid. C - the fringe field stops the vortex.

PARMELA RESULTS

The electron optics has been checked with the tracking program PARMELA [3]. PARMELA includes the space charge forces at low energies and is used to optimize the beam parameters. Without alignment error PARMELA predicts inside the cooling solenoid a transverse temperature of 1500 eV and an energy spread of $8 \cdot 10^{-5}$. None of the tracked particles was lost before reaching the beam dump.

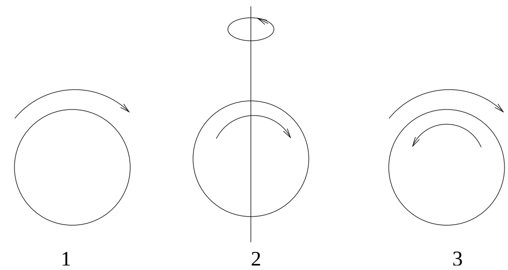

Figure 5: Maintaining beam magnetization across solenoid gaps. Focusing with quadrupole: 1 - the fringe field of the first cooling solenoid creates a vortex. 2 - A quadrupole section rotates the vortex around the vertical axis. 3 - the fringe field of the second cooling solenoid stops the vortex.

CONCLUSION

The design of the RHIC electron cooler is still ”work in progress”. A transverse temperature to less than 1000 eV should be achieved to obtain the desired cooling rates. We are confident that this goal can be reached by careful emittance compensation. Also, a careful study of field and alignment errors is necessary.

REFERENCES

[1] V. Parkhomchuk, I. Ben-Zvi: Electron Cooling for RHIC, C-A/AP/47

[2] A. Burov et al.: Optical principles of beam transport for relativistic electron cooling, Phys. Rev. Special topics - Accelerators and Beams, Vol 3, 094002 (2000)

[3] K. R. Crandall, L. Young, H. Billen, LANL