

OPTICS OF A TWO-PASS ERL AS AN ELECTRON SOURCE FOR A NON-MAGNETIZED RHIC-II ELECTRON COOLER*

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Abstract

Non-magnetized electron cooling of RHIC requires an electron beam energy of 54.3 MeV, electron charge per bunch of 5 nC, normalized rms beam emittance of 4 mm-mrad, and rms energy spread of $4e-04$ [1]. In this paper we describe a lattice of a two-pass SRF energy recovery linac (ERL) and results of a PARMELA simulation that provides electron beam parameters satisfying RHIC electron cooling requirements.

INTRODUCTION

The electron cooling of RHIC is the main element of the luminosity upgrade which has been called RHIC II [2]. The present design of high energy electron cooling for RHIC will use classical (non-magnetized) electron cooling [3]. Using 54 MeV electrons, it will be the first attempt to cool a collider at storage-energy; and it will be the first cooler to use a bunched electron beam and a linear RF accelerator as the electron source

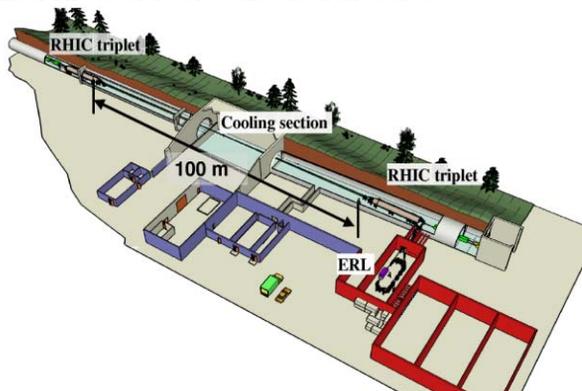


Figure 1: Layout of the RHIC high-energy electron cooler.

The layout of the RHIC electron cooler based on an Energy Recovery Linac located in the 2 o'clock Interaction Point (IP2) is shown in Figure 1. A single ERL will be used to cool both independent RHIC rings [4]. First, the outgoing beam from ERL is matched with ion beam in Yellow ring there the co-propagating electron and ion beams travel for about 100 meters interact and cool ion beam. The electron beam is separated from the ions of the Yellow ring at the left end of the interaction region, it then makes a turn about carefully designed to match the electron beam again to the ion bunches of the Blue ring both in time and in beam parameters and then

*This work was supported by BSA, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE and by a sponsored research grant from Renaissance Technologies Corporation.

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merged with the ion beam of the Blue ring. The electrons cool the Blue ring ions traveling clockwise (right in the figure) and then separated and returned to the ERL.

THE HIGH BRIGHTNESS ELECTRON INJECTOR

The electron injector is a critical part of any ERL that has to deliver low emittance and high charge per bunch.

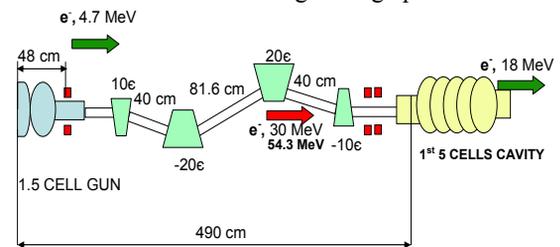


Figure 2: Schematic layout of SC RF Injector for the RHIC ERL electron cooler facility.

The electron cooler injector (see Fig. 2.) consist of 1 1/2 cell superconducting RF (SRF) gun with photocathode located in the half-cell, a solenoid, four chevron dipoles (split focusing) [5] and two opposing solenoids (in order to match the electron beam with linac entrance more accurately).

SRF Gun

The frequency of the gun will be 703.75 MHz, or the 75th harmonic of the 9.383 MHz bunch spacing frequency of RHIC II. To operate in CW mode with 50 mA current and 4.7 MeV kinetic energy beam the gun should supply about 250 kW power in to the beam. Low RF power losses in SRF guns and high peak electric field near the cathode followed by the emittance compensation scheme make SRF guns ideal injectors for high current low emittance applications.

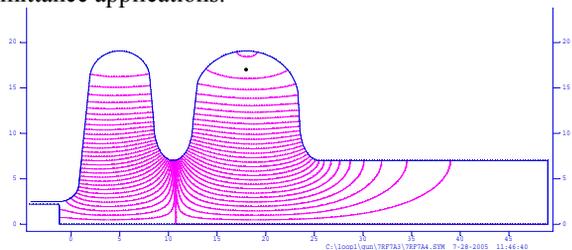


Figure 3: SUPERFISH calculation of the electron gun.

To keep the beam from the growing in size shortly after being emitted from the cathode, a focusing element in close proximity to the cathode is very desirable. A cathode recess provides an electric RF focusing near a cathode region where the space charge force is most significance. The 1 1/2 cell gun mode using for simulations with recessed cathode is shown on Fig. 3.

Merger system

One of the critical systems of the injection line is the merger of the low energy- and high energy beams. As the low energy beam is strongly affected by space charge, the merger must be designed to minimize a degradation of this emittance. A typical system of this type has two properly spaced focusing solenoids are used for the emittance compensation.

The injection energy is not recovered; it is just the ERL energy gain which may be recovered. Thus the use of a low injection energy permits a smaller investment of (unrecovered) power for gun and a low dumped beam energy. The original emittance compensation schema [6] does not include any dipoles between RF gun and linac (or booster cavity). Focusing of the bending magnets in the merging section has significant effect on the low energy electrons. Different focusing in vertical and horizontal planes (astigmatism) makes impossible simultaneous emittance compensation. Hence, the use of chevron dipole magnets with equal focusing strength in x- and y- directions is necessary. Previous comparison of several different merger systems shows that only for the zigzag system the horizontal beam emittance (the plane where the dispersion is excited) equals the vertical one [7].

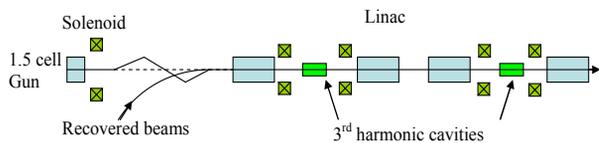


Figure 4: The test bed system for optimization injection part.

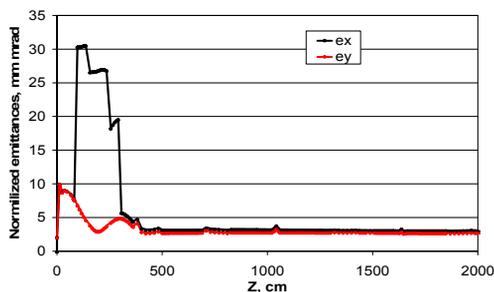


Figure 5: Evolution of the projected normalized transverse emittances rms in the test-bed system for beer-can distribution 5nC per bunch (horizontal beam emittance at the 54.3 MeV is 3.1 mm mrad, vertical - 2.8 mm mrad).

In order to save simulation time, a simple test-bed system was devised which skips the high-energy magnetic system of the ERL but concentrates instead on the low energy side, which includes all the merging and space-charge critical elements. The test-bed system consist of the full scheme injector (the object of study in this test-bed) followed by first pass through the linac and second time pass through the linac again without the return loop between the two passes (Fig. 4).

The performance of a SRF photo-injector has been studied using SUPERFISH (to calculate the electric and magnetic fields) by PARMELA [8] (to calculate the beam dynamics).

The normalized emittance evaluation in the test-bed system for beer-can initial distributions is shown on Fig. 5. The effective emittance jump caused by the dispersion excited by first dipole magnet is well compensated by other dipoles downstream in the zigzag system. More optimization of electron cooler injector can be found in [9].

TWO PASS ERL LAYOUT

The schematic layout of a two pass ERL for the RHIC electron cooler is shown on Figure 4. The superconducting RF (SRF) Gun (1) produces 5 nC 4.7 MeV electron beam. The beam goes through the merger (2) comes into SC RF Linac (3) to be accelerated first time up to 30 MeV. The 30 MeV beam makes two achromatic 180 degrees bends (4, 4') and returns to the linac (3) a second time to get acceleration to 54.5 MeV. The 54.5 is transported to the RHIC (5) for cooling ion beam in both rings. The used 54.5 MeV electron beam is returning back (6) into the linac (3) in a decelerating phase. The kinetic energy is put back into the cavity and is used to accelerate the next electron bunch. After the first deceleration to 30 MeV the beam goes through the same two 180 degrees achromatic bends (4, 4') again. In the last pass through the linac the beam gives back the rest of the energy to cavities and goes to the beam dump (7) at the injection energy of 4.7 MeV.

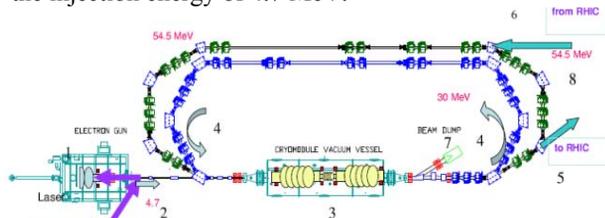


Figure 6: Schematic layout of the two-pass ERL for the RHIC electron cooler facility: (1) SRF gun. (2) Injection merger line. (3) SRF linac. (4, 4') 180° achromatic turns. (5, 6) Transport lines to and from RHIC. (7) Ejection line and beam dump. (8) Short cut -beam line for independent ERL operation.

Each 180 degrees bends of the first loop (Fig 4) (4) and (4') consists of three 60 degrees dipole magnets with three independent quadrupole magnets between them. The quadrupoles between the dipoles makes the bends achromatic and isochronous. At relatively high energy (30 MeV for first loop and 54.3 for second loop) space charge effects on the beam dynamics become very small. In first approximation a linear matrix approach can be used for the layout design and for matching the electron beam from the linac to the return loop. A zero longitudinal dispersion of the whole loop makes the longitudinal motion in first order very simple.

The present design of a second loop lattice has a short-cut (8) (Fig. 6.) to drive electron beam directly to the linac in a decelerating phase without reaching the cooling region.

This short-cut will be used for independent tests of the ERL without interference with RHIC operation.

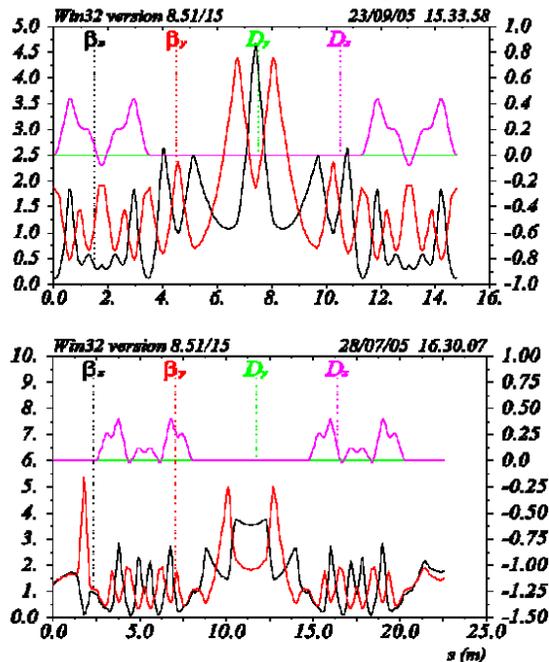


Figure 7: The optic functions in the first (top figure) and in the second loop with short-cut (bottom figure).

The MAD8 output lattice functions for first and second pass from linac exit to next entrance to the linac are shown on Figure 7.

There is also a dispersion free section between two 180 degrees bends where the beam will be accurately studied before sending it to the electron cooling section of RHIC.

Table 1 Electron beam parameters for RHIC-II electron cooling: required and simulation result

Parameter	Requirement	Simulati
Kinetic energy	54.34 MeV	54.34 MeV
Charge per bunch	5.0 nC	5.0 nC
Average current	10 mA	10 mA
R.m.s. emittance normalized	<4 mm mrad	3.2 mm mrad
R.m.s. momentum spread	<4·10 ⁻⁴	3.6 10 ⁻⁴
R.m.s. bunch length	~1 cm	0.78 cm

PARMELA is used for simulation of the beam dynamics from the cathode through the ERL loops to the beam dump. The initial electron beam distribution is a beer-can, with full length of 92 psec and a radius of 5.5 mm. Results of these simulations are shown on Fig.8. Beam parameters at the cooler work energy are summarized in Tab.1.

CONCLUSIONS

The start-to-end PARMELA simulation of the beam dynamics demonstrates that two passes ERL based on

SRF injector can provide electron beam with required parameters for RHIC e-cooling project.

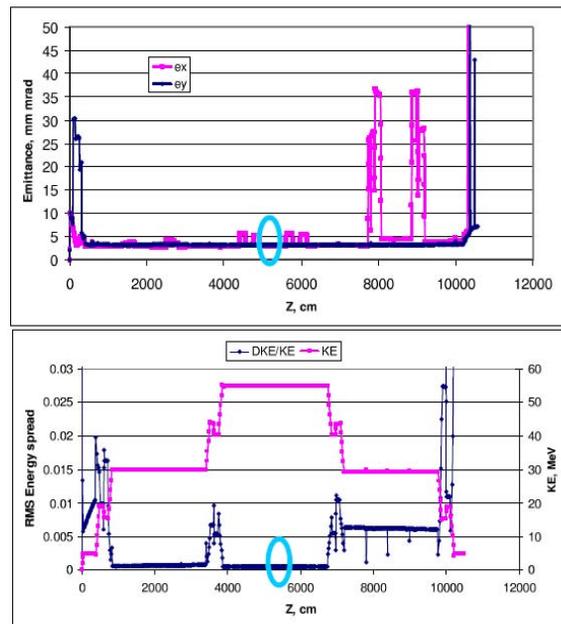


Figure 8: Result of PARMELA simulation in two passes ERL for electron cooler. Normalized emittances (top figure) RMS energy spread and kinetic energy (bottom figure). The cyan circle points to the location of the cooling section evolution kinetic energy 54.3 MeV $e_x/e_y=3.0/3.2$ mm mrad energy spread $3.6 \cdot 10^{-4}$

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