OPTICS FOR HIGH BRIGHTNESS AND HIGH CURRENT ERL PROJECT AT BNL*

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Abstract

An energy recovery linac (ERL), under development at Brookhaven National Laboratory [1,2], will push ERLs further towards high current and high brightness beams. This R&D ERL will operate in two modes: a high current mode and a high charge mode. In this paper we present a lattice of the machine and PARMELA simulations from the cathode to the beam dump. We discuss the design considerations and present main parameters for various modes of operation.

INTRODUCTION

The R&D ERL facility at BNL aims to demonstrate CW operation of ERL with average beam current in the range of 0.1 - 1 ampere, combined with very high efficiency of energy recovery. Flexible lattice of ERL provides a test-bed for testing issues of transverse and longitudinal instabilities and diagnostics of intense CW e-beam.

Two operating modes are envisaged, namely the high current mode and the high charge mode. The high current (0.5 A) mode will operate electron bunches with normalized emittance of about 1 mm mrad, 1.4 nC charge per bunch at 350 MHz rep-rate. In this case, the energy at gun exit is limited by the available RF power to 2.5 MeV. In high charge mode electron beam will consist of bunches with charge up to 10nC per bunch at 10MHz repetition rate, and with about 10 mm mrad normalized emittance. The energy at the exit of the gun in this case will be limited to about 3.5 MeV by the maximum field attainable in the super-conducting gun itself.

ERL OPTICS: FROM THE CATHODE TO THE BEAM DUMP

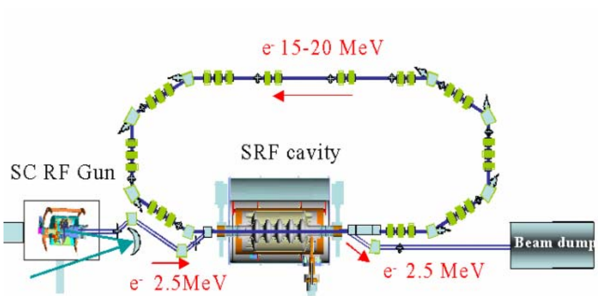

Figure 1: Layout of the R&D ERL.

The R&D ERL schematically is shown in Fig.1. Electrons are generated and accelerated in superconducting half-cell gun to about 2.5-3.5 MeV. They are injected into the ERL loop through the merging system, which incorporate an emittance compensation [3]. The SRF linac accelerates electrons up to 20 MeV. Accelerated electron beam passes through two achromatic arcs and a straight section between them, and returns to the same linac. The path-length of the loop provides for 180 degrees change of the RF phase, causing electron deceleration in the linac (hence the energy recovery) down to 2.5 MeV. Decelerated beam is separated from the higher energy beam and is directed to the beam-dump.

Super Conductive RF Gun

The first important component of the ERL, which determines the attainable parameters of the electron beam, is the gun. For R&D ERL the superconducting 703.75 MHz RF (SCRF) gun was selected. The maximum energy gain for high current mode of operation with this gun will be limited available RF power from 1 MW CW klystron. The gun design with a short 8.5 cm cell was chosen in order to provide reasonably high electric field at the cathode at this low accelerating voltage. To provide effective damping of high order mode (HOM) this gun has enlarged transition section with radius changing form from 5 cm to 9.5 cm. More details on the SCRF gun and its photocathode system can be found elsewhere [4].

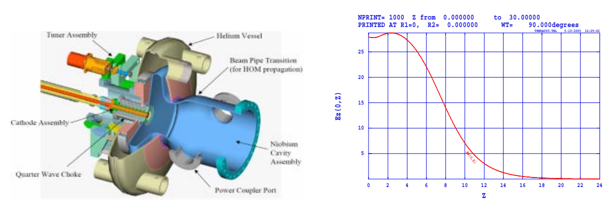

Figure 2: SC RF Gun shape and electric field on the axis (results of the SUPERFISH [5] simulation).

Injection and Zigzag Merging System

It is well known how to create emittance compensation scheme for axial symmetric systems without dipole magnets [6]. In an ERL the merger, which has at least one dipole, brakes the axial symmetry. Moreover, dipoles in the merging system excite the transverse dispersion, which gives the strong coupling between longitudinal and transverse phase space. We use chevron dipoles with equal focusing in vertical and horizontal directions to keep focusing more or less axially symmetric.

One of the novel systems that we plan to use for the R&D ERL is a merging system providing achromatic condition for space charge dominated beam and compatible with the emittance compensation scheme. We

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call it Z-system. In contrast with typical achromatic systems, such as a compensated, chicane, the Z-system (Fig. 3) also provides achromatic condition of a particles whose energy is changing along trajectory. The detailed description of the Z-system and its principles of operation can be found in [7].

In contrast with traditional chicane, where horizontal emittance suffers a significant growth as result of bent trajectory, in the Z-system the emittances are equal to each other (see Fig.4) and very close to the base-line, i.e. emittance for a straight pass.

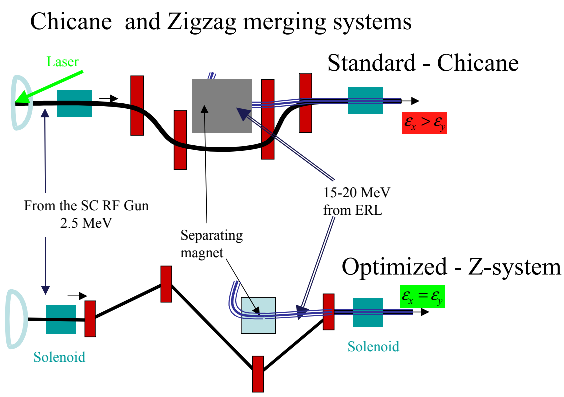

Figure 3.Schematics of traditional chicane and Zigzag-system (Z-system) for merging system of low and high energy beams in an ERL.

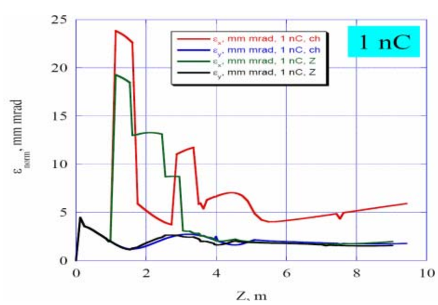

Figure 4: Results of PARMELA simulation for 1nC. Horizontal and vertical projected emittances are shown by red and blue curves for a chicane, and by green and black line for the Z-system, correspondently.

Two solenoids are used for transverse focusing in injection channels. Longitudinal motion is determined by the initial phase at the cathode, accelerating voltage and the space charge. Space charge increases a negative energy chirp from heat to tail of the electron bunch and makes it longer. Some ballistic compression can be uses to partially compensate for this effect by a positive energy chirp at the gun exit. Fig. 5 shows the energy gain in the gun as a function of the initial phase of the electrons. We have chosen the initial phase of 12 degrees at the middle of positive energy gain slope.

Achromatic Arcs

The lattice of the ERL loop controls the parameters of a symplectic transport matrix:

$$\begin{bmatrix} x \\ x' \\ y \\ y' \\ -c\delta t \\ \delta E/E \end{bmatrix}_{s2} = \begin{bmatrix} m11 & \mathbf{m12} & ... & .... & ... & D_x \\ m21 & m22 & ... & ... & ... & D'_x \\ ... & ... & m33 & \mathbf{m34} & ... & D_y \\ ... & ... & m43 & m44 & ... & D'_y \\ ... & ... & ... & ... & m55 & \mathbf{m56} \\ ... & ... & ... & ... & ... & m66 \end{bmatrix} \cdot \begin{bmatrix} x \\ x' \\ y \\ y' \\ -c\delta t \\ \delta E/E \end{bmatrix}_{s1}$$

which affect the stability and operation conditions of the ERL. The lattice of the loop is intentionally chosen to be very flexible for the R&D ERL to be a test-bed of new ampere-range of beam currents in ERL technology.

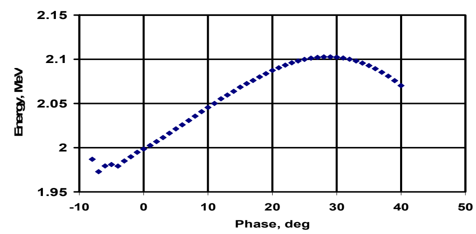

Figure 5: Energy at the exit of the gun versus initial phase.

The adjustable part of the lattice has two arcs and a straight section. Each arc consists of the two 60-degrees chevron dipoles, two 30-degrees dipoles with parallel ages, and three quadrupole triplets. The bending radius of 20 cm was chosen for the dipoles to provide a possibility to use visible part of synchrotron radiation (SR) from 20 MeV electron beam for beam diagnostics. For the above parameters, the critical wavelength of SR is about 2 micrometers, which provides plenty of light in the red part of the visible spectrum.

The chevron 60-degrees dipoles split the focusing between vertical and horizontal directions in the dipoles. The quadrupole triplets between the dipoles allow us to control the value and the sign of longitudinal dispersion, while keeping the arcs achromatic. Eight quadrupoles in the dispersion-free straight section provide for matching of the β-function and for choosing the desirable phase advances independently in horizontal and vertical planes.

Optical functions for one ERL lattice are shown in Fig.6. The m_{12} and m_{34} elements are controlled independently using eight quadrupoles in the dispersion-free straight section.

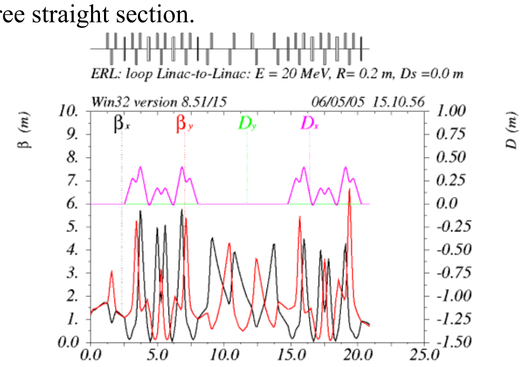

Figure 6: Lattice β and D functions of the R&D ERL for the case of zero longitudinal dispersion $D_s = m_{56}$.

High charge per bunch and relatively low energy in the ERL loop require start-to-end simulation including space charge effects. We used PARMELA [8] for simulation of the beam dynamics from the cathode through the ERL loop to the beam dump. Results of these simulations for 1.4 nC charges per bunch are shown on Figs.7-9. The beam parameters are summarized in Tab.1.

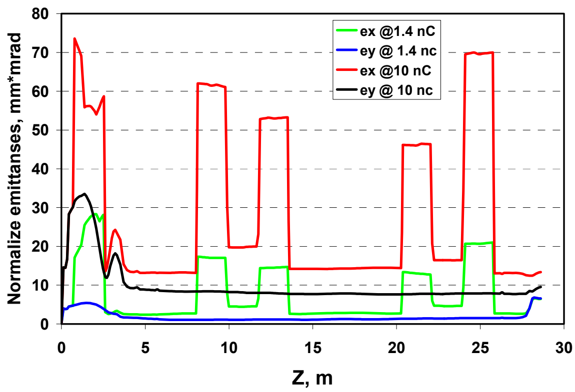

Figure 7: Transverse normalized emittances evolution for different beam charges: 1.4nC, 10 nC.

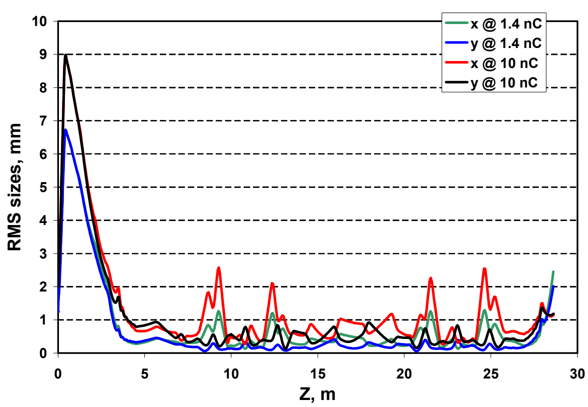

Figure 8: RMS sizes of the electron beam evaluation for different beam charges: 1.4nC, 10 nC.

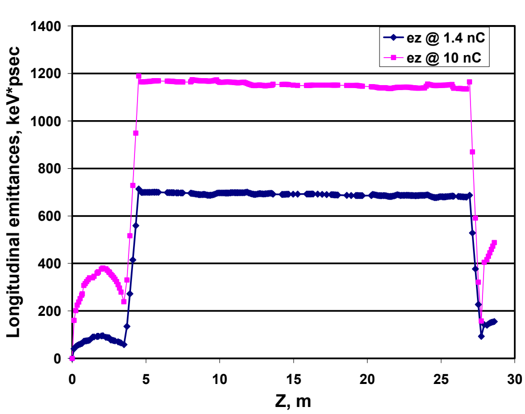

Figure 9: Longitudinal emittances evolution for different beam charges: 1.4nC, 10 nC.

CONCLUSION

The results of the design studies of the R&D ERL and start-to-end PARMELA simulation are very promising and provide the close-to-realistic predictions for this challenging facility.

Table 1: Electron Beam Parameters

Mode of operation	**High charge**	**High current**
Initial bunch length, ps	70	45
Initial beam radius, mm	4.0	2.5
Field on the cathode MeV/m	44.2	27.8
Injection energy, MeV	3.7	2.5
Maximum beam energy, MeV	21	20
Average beam current, A	0.2	0.5
Bunch rep-rate, MHz	10	350
Charge per bunch, nC	10	1.4
Normalized emittances (x/y) @2.5 MeV, mm*mrad	13.4/9.2	4.1/4.1
Longitudinal emittance @2.5 MeV, [*3-rd harmonic taking out*], psec*keV,	240 [*62*]	58 [*19*]
Normalized emittances (x/y) @20 MeV, mm*mrad	14.5/7.8	2.5/1.3
Longitudinal emittance @20 MeV, [*3-rd harmonic taking out*], psec*keV	1140 [*183*]	700 [*42*]

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