BEAM DYNAMICS SIMULATION FOR THE COMPACT ERL INJECTOR

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Abstract

An injector, which consists of 500 kV photo cathode DC gun, two solenoid magnets, buncher cavity, three super conducting RF cavities and merger section to return pass, has been designed for the compact ERL project as a test facility for future ERL light sources. Our target is emittance smaller than 1 mm·mrad with bunch length shorter than 1 mm at the exit of the injector. In the design works, two types of merger are investigated using a particle tracking code with space charge calculation. By optimization of beamline parameters, we have obtained minimum emittance of 0.58 mm·mrad with bunch length of 0.6 mm after the merger section.

INTRODUCTION

The compact ERL, cERL, is a project to test an energy recovery linac (ERL) with 65-125 MeV and 100 mA electron beam to establish technologies required for future ERL light sources [1]. To generate high quality synchrotron radiation in the future ERL light sources, the performance of the ERL injector, which has critical components, a photo cathode gun and super conducting cavities, is very important. Since an electron beam with -77 pC bunch charge and 1.3 GHz repetition rate has lower energy less than 10 MeV in the injector, space charge effect plays an important role in emittance compensation. Our target value of emittance is less than 1 mm·mrad with bunch length of 1 mm at the exit of the injector. In this paper, we present design and beam dynamics simulation for the cERL injector.

DESIGN OF INJECTOR

The cERL injector consists of 500 kV photo cathode DC gun (DCG01), two solenoid magnets (SLA01 and SLA02), buncher cavity (BCA01), super conducting RF cavities (SCA01, SCA02 and SCA03), five quadrupole magnets (QMA01 - QMA05) and merger section. The layouts of the injectors is shown in Fig. 1, and the field maps of the components in the injector, which were calculated by Poisson Superfish, are shown in Fig. 2. In this study, we carried out the beam simulation for two different types of merger with an injection angle of 16°. One is a merger, which consists of three rectangular magnets with the bending angles of -16°, 16° and -16°, and two quadrupole magnets. The other one is a merger, which consists of three sector magnets with the bending angles of -19°, 22° and -19°. For the sector type merger, the second magnet (BMA02) has the edge angle of 20° to satisfy an achromatic condition

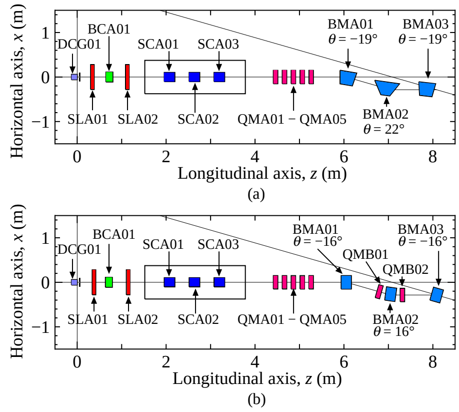

Figure 1: Layout of the cERL injectors with (a) sector bending magnets, and (b) rectangular bending magnets. Both the injection angles to the main linac are 16°.

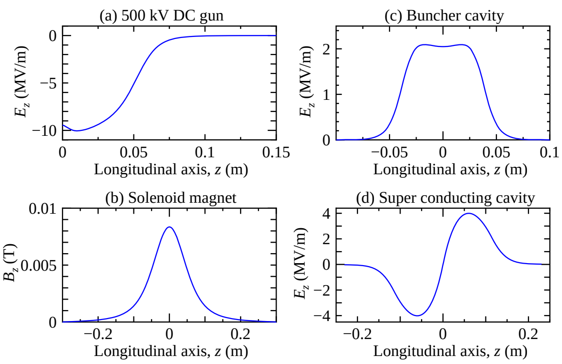

Figure 2: Field maps for the simulations of the cERL injector.

after the exit of merger. The sector type merger is more simple than the rectangular type, but the larger bending angles of the bending magnets in the sector type merger disadvantages the compensation for emittance growth caused by longitudinal space charge dispersion [2, 3]. In order to investigate the effect of merger type, the beamline parameters were optimized using a particle tracking code, GPT [4], and multi objective method [5].

BEAM DYNAMICS SIMULATIONS

GPT has two programs to calculate 3D space charge effect. One is point-to-point method, which calculates Coulomb force directly. The other one is mesh based method, which includes efficient 3D space charge ef-

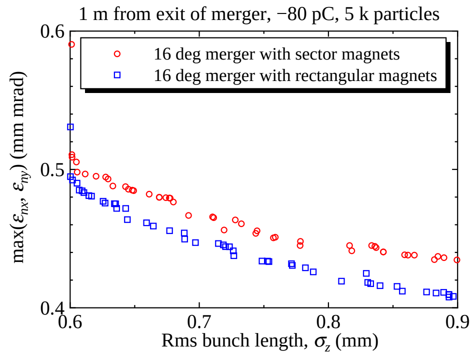

Figure 3: Optimization results with sector type magnets and rectangular type magnets. The emittance and the bunch length were calculated at 1 m from the exit of merger.

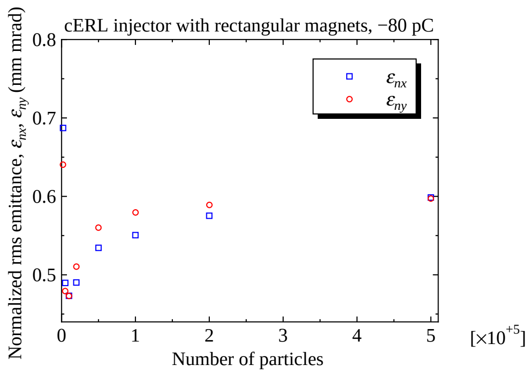

Figure 4: Effect of number of macro particles on the emittance. The emittances were calculated at 1 m from the exit of merger with rectangular type magnets.

fect treatment based on non-equidistant multi-grid Poisson solver. In this study, we used the mesh based method to save the CPU time. However, the original mesh based method requires larger number of meshes to calculate the emittance more accurately in the merger section for smaller number of macro particles. To improve this effect, we developed enhanced space charge routine, which has a transformation of rotation in the rest frame [6]. Using the enhanced routine, we can improve the accuracy of the emittance calculation with smaller number of particles in the merger section. In the optimization of the beamline parameters, we used the enhanced routine with 5 k particles to save CPU time. After the optimization with 5 k particles, more accurate simulations with 200 k particles were carried out.

RESULTS

Optimization of beamline parameters

In the optimization, the following 19 beamline parameters were varied to minimize the transverse emittances, and the rms bunch length at 1 m from the exit of merger. σ_{x0} is the initial rms laser spot size, σ_{t0} is the initial rms laser pulse width, B_{SLA01} and B_{SLA02} are the magnetic fields of the first and second solenoid magnets, V_{BCA01} is the accelerating voltage of the buncher cavity, $E_{acc,SCA01}$ and $E_{acc,SCA02}$ are the accelerating field of the first and second super conducting cavities, ϕ_{SCA01}, ϕ_{SCA02} and ϕ_{SCA03} are the RF phases, which are defined as the difference from the phase of on-crest acceleration, $K_{1,QMA01}$, $K_{1,QMA02}$, $K_{1,QMA03}$, $K_{1,QMA04}$ and $K_{1,QMA05}$ are the normalized quadrupole fields, and z_{SLA01}. z_{SLA02} and z_{BCA01} are the longitudinal positions of the solenoids and the buncher cavity, respectively.

The optimization results with -80 pC/bunch and 5 k macro particles for the two beamlines in Fig. 1 is shown in Fig. 3. It shows that the rectangular type gives smaller emittance than the sector type. It seems that stronger longitudinal space charge dispersion in the sector type causes the difference of emittance, because the bending angle of the bending magnet in the sector type (19° or 22°) are larger than one in the rectangular type (16°) as shown in Fig. 1.

Effect of number of particles

In order to investigate the effect of the number of particles in simulation, the emittances at the end of beamline for the rectangular type were calculated varying them from 1 k to 500 k particles. Beamline parameters, which gave the rms bunch length of 0.6 mm at the end of beamline in the results of the optimization in Fig. 3, was selected for the calculations. The result and the beamline parameters are shown in Fig. 4 and Table 1, respectively. It shows that at least larger number of particles than 200 k particles is required to calculate emittance accurately. It seems that the effect relates to the number of meshes in the space charge calculation. For the default setting of the space charge calculation in GPT, the number of meshes for each axis, N_{mesh}, in the bounding box to calculate space charge field is given by

$$N_{mesh} = N_p^{1/3}, \tag{1}$$

where N_p is the number of macro particles in the simulation. Thus, for larger number of particles, the mesh size becomes fine and the space charge calculation includes fine structure in the particle distribution.

Table 1: Optimum beamline parameters

Parameter	Value	Parameter	Value
σ_{x0}	0.34 (mm)	ϕ_{SCA03}	10.0°
σ_{t0}	17.6 (ps)	$K_{1,QMA01}$	−27.4 (m^{-2})
B_{SLA01}	0.037 (T)	$K_{1,QMA02}$	−4.6 (m^{-2})
B_{SLA02}	0.024 (T)	$K_{1,QMA03}$	29.8 (m^{-2})
V_{BCA01}	96.0 (kV)	$K_{1,QMA04}$	−2.7 (m^{-2})
$E_{acc,SCA01}$	7.6 (MV/m)	$K_{1,QMA05}$	−24.3 (m^{-2})
$E_{acc,SCA02}$	13.1 (MV/m)	z_{SLA01}	0.38 (m)
$E_{acc,SCA03}$	15.0 (MV/m)	z_{SLA02}	0.71 (m)
ϕ_{SCA01}	−20.9°	z_{BCA01}	1.14 (m)
ϕ_{SCA02}	−20.8°		

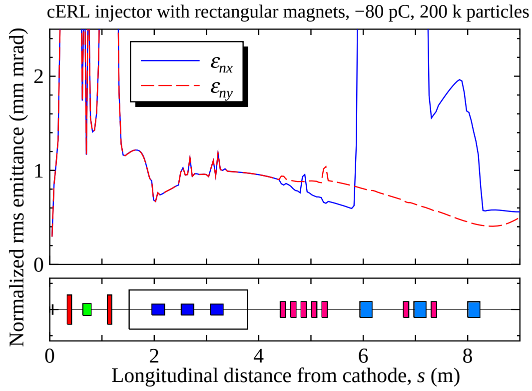

Figure 5: Horizontal and vertical normalized rms emittances for the injector with rectangular type magnets.

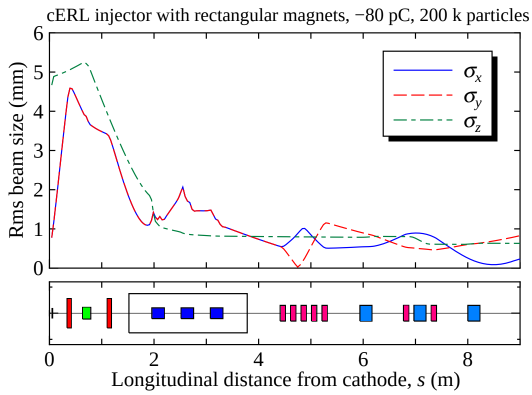

Figure 6: Horizontal, vertical and longitudinal rms beam sizes for the injector with rectangular type magnets.

Evolutions of emittance, beam size and energy

The time evolutions of emittance, beam size, energy and energy spread were calculated with same beamline parameters in Fig. 4 for 200 k particles. Fig. 5 shows the horizontal and the vertical normalized rms emittances. Both the emittances are smaller than 0.6 mm·mrad at the end of beamline. In this case, emittance growth caused by longitudinal space charge dispersion in the merger section was compensated by the optics matching by the five quadrupoles before the entrance of merger. The horizontal and the vertical rms beam sizes and the rms bunch length are shown in Fig. 6. When the emittance compensation was succeeded in the merger section, the horizontal beam size increased after the exit of merger same as the longitudinal space charge dispersion [3]. Fig. 7 shows the kinetic energy and the energy spread. After the three super conducting cavities, the kinetic energy is 8 MeV. The horizontal phase space distribution is shown in Fig. 8. The emittance is 0.58 mm·mrad at the end of beam line. Fig. 8 (e) corresponds to the phase space at the entrance of merger, and Fig. 8 (e) corresponds to one at the exit of merger. It shows that the phase space area is conserved in the merger section.

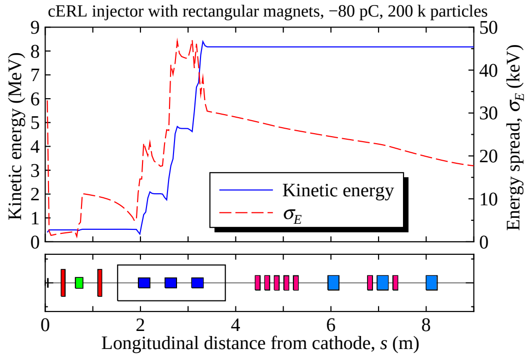

Figure 7: Kinetic energy and energy spread for the injector with rectangular type magnets.

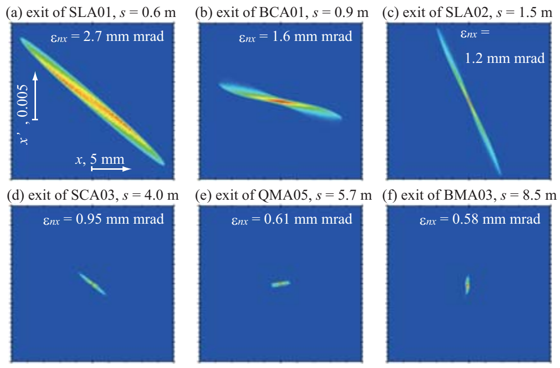

Figure 8: x-x' phase space distribution with -80 pC and 200 k macro particles.

SUMMARY

We have designed the injector for the cERL and carried out beam dynamics simulation using the particle tracking code with space charge effect. Two different types of merger, which have same injection angle and different bending angles of each magnet, were investigated. It found that the rectangular type, which have smaller bending angles, have advantage to compensate emittance compared with the sector type. At the end of injector, we have obtained the emittance of 0.58 mm·mrad with the bunch length of 0.6 mm.

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