BEAM DYNAMICS STUDIES FOR COHERENT ELECTRON COOLING EXPERIMENT

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Abstract

Coherent electron Cooling (CeC) is a proposed advanced beam cooling method that has the potential of reducing the ion beam emittance in significantly shorter amount of time compared to existing cooling methods [1]. The newly built linear electron accelerator for the CeC experiment needs to generate electron beam with the required properties in order to maximize the CeC cooling capacity [2][3]. the author studied the beam dynamics of the CeC Linac and simulated the electron beam using beam dynamics tracking code. By utilizing optimization algorithms and beam manipulation techniques, the author has explored the performance of the current CeC Linac. The author ran an end-to-end simulation to model the entire beam line from the generation of electron beam from photocathode to the transport of electron beam to the CeC Free Electron Laser (FEL) section. The results have shown many aspects of the current CeC Linac and would be beneficial to future operation, research and development.

INTROUDCTION

The current CeC beamline (Figure 1) consists of a 112 MHz superconducting radio frequency (srf) gun, a focusing solenoid, two 500 MHz srf cavities, a five solenoids transport channel, a 704 MHz srf accelerating cavity and a dogleg injector to direct the electron beam with energy about 22 MeV to the CeC cooling section. The electron beams with specific requirements are needed in order to fully utilize the CeC cooling capacity [2] [3]. The author examined how to generate electron beam with optimal parameters, and developed strategy and optimization algorithms to optimize this beamline. Through the optimization process, the author used simulation codes by estimating how space charge effect and coherent synchrotron radiation (CSR) effect lead to emittance growth. The goal of this project is to understand and minimize those nonlinear effects and to preserve the electron beam quality needed for cooling.

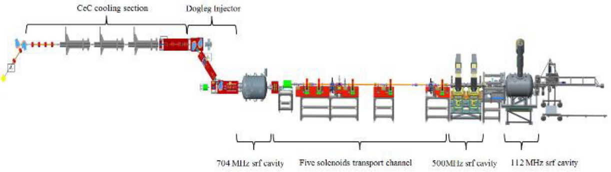

Figure 1: Engineering drawing of CeC beamline (electron beam travels from left to right).

ELECTRON LINAC OPTIMIZATION

In order to maximize the CeC cooling capacity, the electron beam generated from the CeC linac must possess certain properties to fulfill the cooling requirements of CeC. It is important to understand how to generate required electron beam and study the beam dynamics of current electron linac through beam dynamics simulation. The author compared the optimization results generated by two algorithms (Genetic Algorithm and CONDOR algorithm) and presented optimization results of electron beam generated at the entrance of cooling section. The optimization process includes modeling the entire Linac using PARMELA code [4] and following certain optimization strategies. The simulated electron beam and SRF cavity parameters is shown in Table 1 and electron beam initial distribution is shown in Figure 2.

Table 1: Electron beam and SRF cavities parameters used in PARMELA simulation.

Bunch charge	2 nC
Initial Bunch radius at the cathode	2mm
RMS laser pulse length	400 ps
Maximum accelerating gradient of 112 MHz Gun	19 MV/m
Maximum accelerating gradient of the 500 MHz buncher	1.5 MV/m
Maximum accelerating gradient of the 704 MHz Cavity	37 MV/m

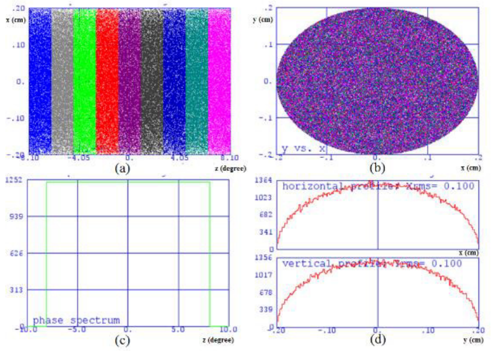

Figure 2: Initial longitudinal cut (a), transverse beam size (b), longitudinal current profile (c), transverse current profile (d) of the electron beam used in PARMELA simulation. Number of macro-particle used in simulation is 200000.

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ELECTRON BEAM OPTIMIZATION FOR LOWEST EMITTANCE

The algorithm was set to optimize for low emittance by changing the magnetic strength of six solenoids along the Lnac. As shown in Figure 3, the individual slices of the electron beam are aligned into the same direction and the overall projected emittance is minimized. the final projected emittance of electron beam is 2.7 mm-mrad and the projected emittance within FWHM is 1.3 mm-mrad. Figure 4 is the simulated electron beam parameters from the 112 MHz srf cavity to the exit of 704 MHz srf cavity.

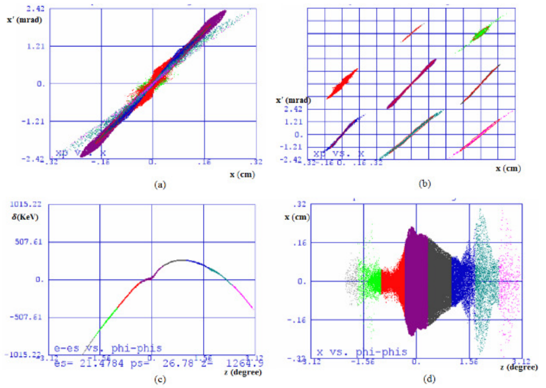

Figure 3: Transverse phase space (a), slice phase space (b), longitudinal phase space (c) and longitudinal cut view (d) of the optimized electron beam with lowest emittance.

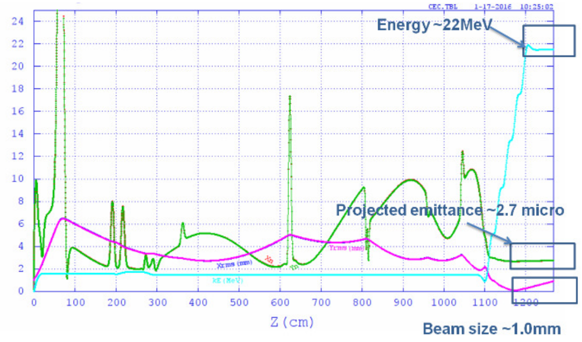

Figure 4: Evolution of energy (turquoise curve), rms beam size (pink curve) and transverse projected emittance (green curve) along the CeC linac from photocathode to the exit of 704MHz cavity. The energy is about 22MeV, the projected transverse emittance is 2.5 mm-mrad and beam size is 1 mm at exist of the 704MHz srf cavity.

LATTICE DESIGN FOR CEC DOGLEG

To design a lattice for the dogleg injector, the designed twiss functions of the lattice need to be matched from the exit of 704MHz cavity to the entrance of the CeC FEL section. The author used the optimization algorithm implemented in Elegant code to optimize the lattice. As shown in Figure 5, two bilateral symmetry (blue and yellow-grey) solutions of betatron function for the three sections of helical undulator allow a minimal betatron oscillation. Figure 6 shows the optimized twiss functions for the dogleg injector. This lattice design allows for minimal betatron oscillation to preserve the electron beam quality.

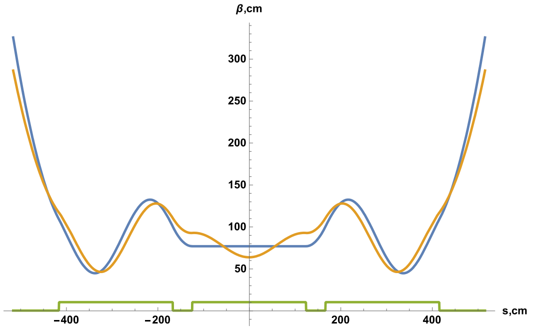

Figure 5: Two bilateral symmetry solution of betatron function with lowest beta-beat calculated in [5].

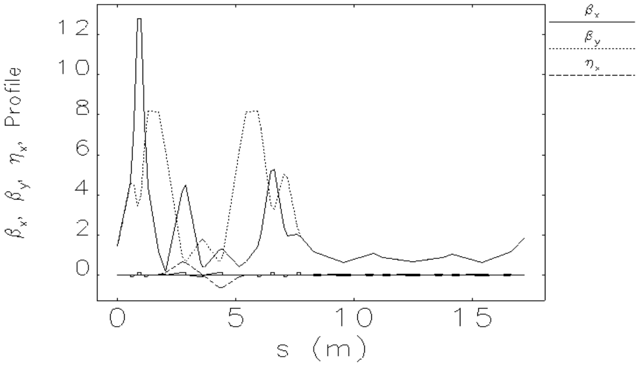

Figure 6: Lattice design to match the betatron function for the CeC FEL section.

COHERENT SYNCHROTRON RADIATION STUDIES AND SIMULATION

As electron beam passing through a dogleg section, two dipoles are used to bend the electron beam at opposite direction. The bended electron beam can emit radiation. The light emitted from electron beam can impact on the electron beam itself and leads to emittance growth. If the electron bunch is relatively short compared to the wavelength of emitted light, the radiated power increases quadratically with beam peak current. The electron beam parameters at the entrance is shown in Figure 7 and Figure 8 is the emittance evolution of electron beam through the dogleg injector.

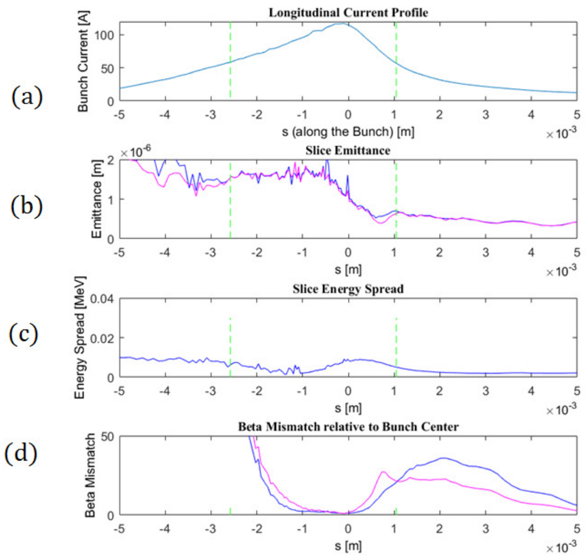

Figure 7: Summary plot of the optimized electron beam after dogleg injector. Longitudinal current profile (a), slice emittance (b), slice energy spread(c) and beta mismatch (d) of the optimized electron beam.

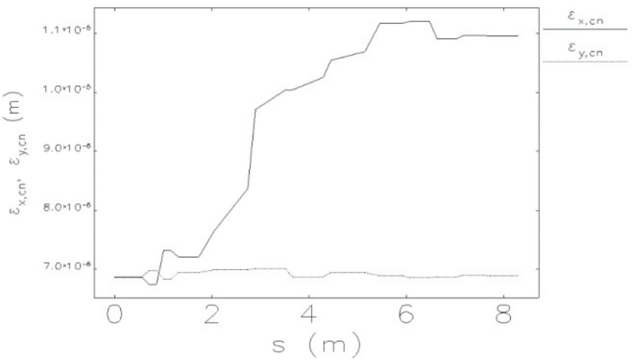

Figure 8: Evolution of emittance growth in the dogleg injector section for the optimized electron beam.

CONCLUSIONS

The simulation results shown here indicate several important aspects of current Linac. Space charge effects prevent us from generating longitudinal flat-top electron beam during the low energy region before the 704MHz SRF cavity. The electron beam's longitudinal phase space after compression is far from ideal because of longitudinal space charge force. Chromatic effect induced emittance growth is large for electron beam with large energy spread. As simulation results indicate, an initial electron beam with bunch length of 400 picoseconds and total charge of 2nC can generate an electron beam which fulfills the CeC requirements. CSR effect induced emittance growth is small and negligible comparing to chromatic effect induced emittance growth.

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