START-TO-END SIMULATIONS FOR 10 GeV PAL-FEL PROJECT

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Abstract

We investigate the design of a X-ray free electron laser (FEL) facility for the radiation power of 5 GW in the wavelength of 0.1 nm that is based on a 10 GeV linac. The facility consists of a 135 MeV photoinjector, a 10 GeV linac with two bunch compressors and an undulator of 100 m long to generate intense radiation. In this paper, we present a lattice design of the linac with a beam transport line and tuneable four matching sections, and parameters of two bunch compressors for the 10 GeV X-ray FEL facility. We also show the results of start-to-end beam simulations that include the effects of rf jitters to estimate performances of the designed linac.

INTRODUCTION

In this paper, we present the designed lattice for the 10 GeV linac and the results on the start-to-end simulations in the linac. For the simulations, we utilize injection beam that are similar with LCLS in the energy of 135 MeV, emittance of 0.97 μm rms and bunch length of 870 μm rms and bunch charge of 1 nC[1]. Code ELEGANT[2] was used up to the undulator entrance to estimate the beam performance in the designed linac. Figure 1 shows a designed schematic for a 10 GeV FEL facility.

LATTICE DESIGN FOR PAL-FEL

The designed facility is composed of one X-band section, two bunch compressors, a 10 GeV linac, a beam transport linac, four matching sections and an undulator beam line. Figure 2 shows Twiss parameters for the facility from end of the injector to undulator entrance. The gun and injector linac are excluded in Figure 2. In the following subsections, we will give investigations on design concept, beam and machine parameters in the designed linac.

10 GeV LINAC

Four quadrupole magnets just after the injector are used to match the Twiss parameters into the linac. The 0.6 m long X-band rf section is inserted just prior to the first bunch compressor to obtain the better linearity of the energy-time correlation along the bunch. The X-band section is set to the off-crest phase of 208 degree and the beam energy is reduced by 15.2 MeV in the section, which has the gradient of 31 MV/m. L1 linac in the linac accelerates the beam from 135 MeV to 420 MeV with off-crest angle of 21.2 degree and provides the linear energy-time correlation that is required in the first bunch compressor. L1 linac consists of 4 3-meter S-band rf structures. Because of the large off-crest rf phase angle and relatively long bunch length, the rms energy spread in L1 linac increases from 0.14 % to 1.32 %. L2 linac in the linac accelerates the beam from 420 MeV to 2.84 GeV with off-crest angle of 21 degree and provides the linear energy-time correlation that is also required in the second bunch compressor. L2 linac consists of 28 3-meter S-band rf structures. L3 linac includes 96 3-meter rf structures and it is used for the energy acceleration to 10 GeV. The short bunch length of 78 fs rms in the linac effectively eliminates transverse wakefields as a source of emittance growth and the rms energy spread decreases from 0.53 % down to 0.037 % in the L3 linac. The rf phase angle in the L3 linac is set to 22.2 degree.

Two Bunch Compressors

Figure 3 shows optics of the two bunch compressors. Momentum compaction factors in the first and second bunch compressors are given by R_{56}=64.4 mm and R_{56}=49.5 mm, respectively. X-band rf structure is upstream of the first bunch compressor. The first bunch compressor is designed compress 2.9 ps rms bunch to 0.94 ps rms. The second bunch compressor is designed compress 0.94 ps rms bunch to 0.078 ps rms. The parameters of the bunch compressors are listed in Table I. Beta functions are kept to low values at the exit of the bunch compressors to minimize degradation of emittance due to coherent synchrotron radiation. Twiss parameters of $\alpha_{x,y}$ in the two bunch compressors are also adjusted to reduce the effects of coherent synchrotron radiation.

Matching Sections

Four matching sections are inserted in order to provide adjustable beta-matching in each subsystem of the linac. First matching section is located at the position of between the injector exit and the L1 linac. Second one is inserted to match optics between the BC1 and L2 linac. Third one is inserted to match optics between the BC2 and the L3 linac. Fourth one exists at between the L3 linac and the beam transport line. The optics matching at the undulator entrance is also performed. All matching sections are composed of four quadrupoles.

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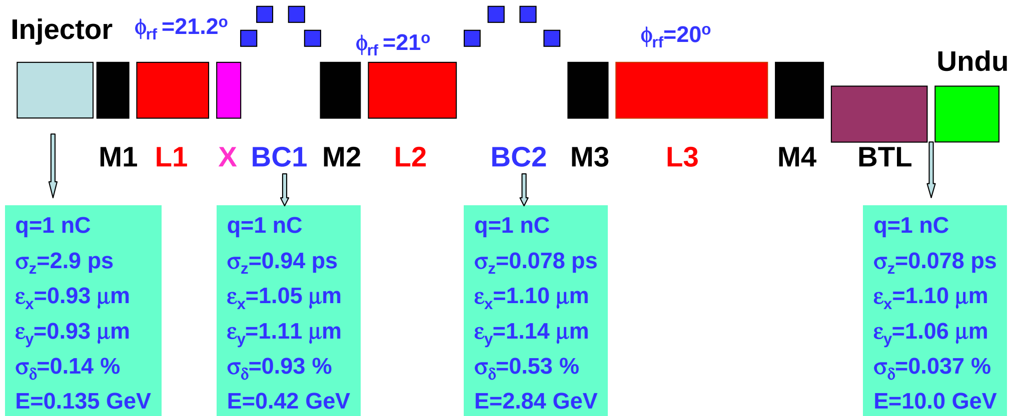

Figure 1: Schematic for a 10.0 GeV FEL facility.

Beam Transport Line

The system with four dipole magnets is used for beam transport between the existing linac and undulator beam line, and a quadrupole triplet exists between dipole magnets. The net R_{56} in the four dipole system is designed to have zero by making the dispersion function to be reverse sign in the center of the four bending magnets. Each bending angle in the bending magnets with 1.9 m long is given by +0.5, +0.5, -0.5, -0.5 degree, respectively.

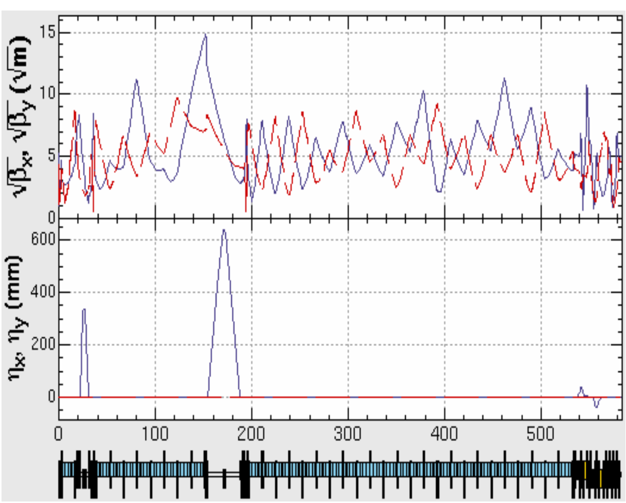

Figure 2: Twiss parameters from injector exit to undulator entrance.

RESULTS ON START-TO-END BEAM SIMULATIONS

A start-to-end simulation has been performed to optimize the beam parameters for the PAL-FEL. Our full simulations use the beam that comes from the LCLS photoinjector which produces the charge of 1 nC, the bunch length of 2.9 ps rms, the relative energy spread of 0.14 % rms and emittance of 0.93 μm rms. L1 linac is used for energy chirp before the beam enters the X-band rf section. A bunch compression factor of 36 and a peak current of 3.5 kA in the bunch length of 78 fs rms were obtained by the simulation. Figure 3 shows the longitudinal beam distributions in the several positions that are obtained by the start-to-end simulation. Figure 4 shows the slice beam distributions in the entrance of the undulator. Figure 5 shows the radiation power as a function of the undulator when we use the beam from the start-to-end simulations. The saturation power shows around 6 GW.

We also estimated the effects of the rf jitters in the linac on the start-to-end simulations. It is shown that rf jitters of 0.5 ps rms timing, 0.1 degree rms phase and 0.05 % rms voltage are acceptable to the performance of the beam in the designed linac. Figure 7 shows the fluctuations of the bunch lengths in successive 30 bunches under the effects of rf jitters.

Table 1: Parameters of first and second bunch compressors.

Parameter	**1st BC**	**2nd BC**
Beam energy	420 MeV	2.84 GeV
Ini. rms bunch length	2.9 ps	0.94 ps
Final rms bunch length	0.94 ps	0.078 ps
Final rms relative energy spread	0.93 %	0.53 %
Final emittance(x/y)(μm)	1.05/1.11	1.10/1.14
Magnetic field	0.68 T	0.91 T
R_{56}	64.4 mm	49.5 mm
Bending angle	0.098 rad	0.039 rad
Maximum dispersion	340 mm	550 mm
Length of bending magnet	20 cm	40 cm

CONCLUSIONS

We have performed the lattice design for the 10 GeV PAL-FEL facility and the alpha Twiss parameters in optics was adjusted to minimize effectively degradation of the emittance and energy spread due to the CSR and wakefields. Start-to-end beam simulations under the effects of rf jitters in the linac were also performed. These designed works have demonstrated the beam parameters and feasibility of 0.1 nm FEL at PAL. The simulation results also show that the beam performance of the designed linac is acceptable the magnitudes of the rf jitters of 0.5 ps rms timing, 0.1 degree phase and 0.05 % voltage.

REFERENCES

[1] LCLS Design Study Report, SLAC-R-521 (1998).

[2] M. Borland, APS LS-287, Sept. 2000.

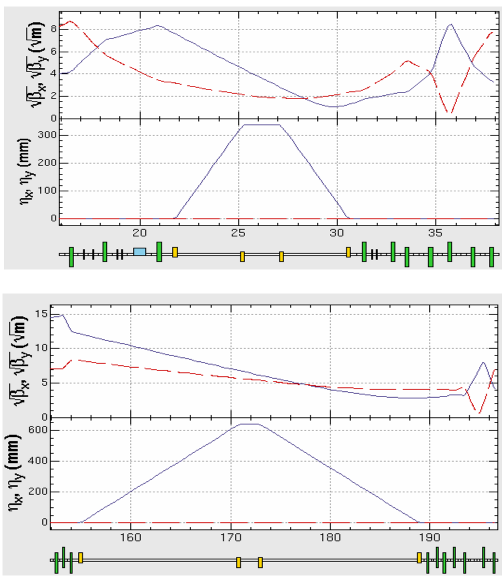

Figure 3: Optics for first (top) bunch compressor and second (bottom) bunch compressor.

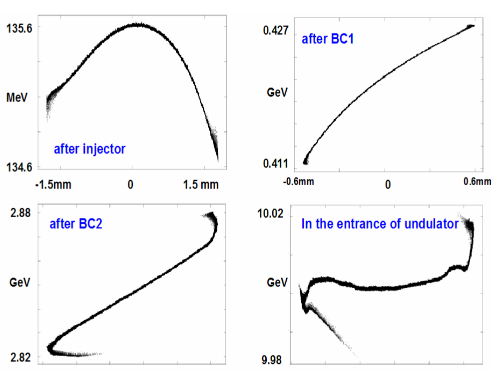

Figure 4: Longitudinal beam distributions from the start-to-end beam simulations.

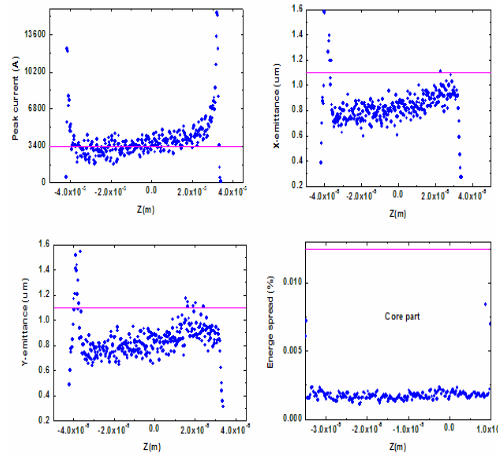

Figure 5: Slice beam distributions in the entrance of the undulator.

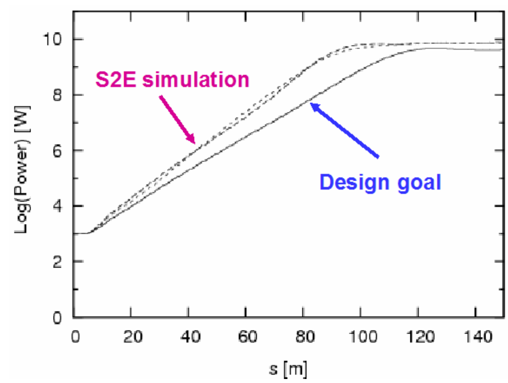

Figure 6: Radiation power as a function of undulator from start-to-end beam simulations.

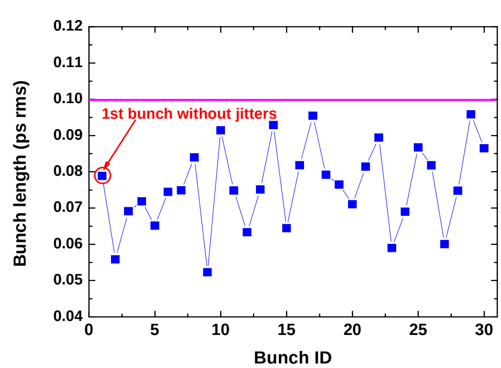

Figure 7: Fluctuation of bunch lengths in the 30 successive bunches under the effects of rf jitters of 0.5 ps rms timing, 0.1 deg. rms phase and 0.05 % rms voltage.