LINAC LATTICE AND BEAM DYNAMICS FOR X-RAY FEL AT PAL

E.-S. Kim*, M. Yoon, D.-E. Kim and S.-J. Park
Pohang Accelerator Lab., POSTECH, Pohang, KyungBuk, 790-784 KOREA

Abstract

The PAL-XFEL is a fourth generation light source project to produce soft and hard X-rays which is based on the self-amplified spontaneous emission (SASE) free-electron laser. The XFEL facility consists of a new photoinjector, a 1 GeV new linac, a 2.0 GeV existing linac, with two bunch compressors and long undulators to generate intense radiation. In this paper, we present lattice design of the linacs, bunch compressors, beam transport line, tuneable matching sections for the 3 GeV soft X-ray FEL facility and show results of start-to-end beam simulations that have performed to estimate FEL performance in the designed lattice.

INTRODUCTION

A 2.0 GeV linac in PLS had been used as an injector for 2.5 GeV PLS storage ring which is a third generation light source since 1994. Furthermore from September 2002, the linac has being used for full energy injection of the 2.5 GeV storage ring[1]. For this purpose operating time of the linac is less than 10 %. With the requirement for next generation light sources, the linac is being intensively considered as a facility for soft[3] and hard X-ray FEL, which will include the extension of the linac to achieve the energy of 3.0 GeV.

In this paper, we present concept of designed lattice and show the results on the first start-to-end simulations for an option of the soft X-ray FEL. For this simulation, injection beam in LCLS with energy of 135 MeV, emittance of 0.97 μm rms and bunch length of 870 μm rms and bunch charge of 1 nC was utilized for the particle tracking[2]. Code ELEGANT[4,5,6,7] was used up to 3.0 GeV at undulator entrance to estimate the FEL performance in the designed FEL lattice. Figure 1 shows a designed schematic for 3 GeV soft X-ray FEL in PAL.

LATTICE DESIGN

The designed PAL-XFEL facilities are composed of a 1 GeV new linac that will be constructed, one X-band section, two bunch compressors, a 2GeV existing linac, a beam transport linac, four matching sections and undulator beam lines. The Figure 2 shows Twiss parameters for the PAL-XFEL 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, and beam and machine parameters in the designed lattice.

* eskim1@postech.ac.kr

1 GeV new linac

Six quadrupole magnets just after the injector are used to match the beta functions into the new 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 -175 degree and the beam energy is reduced by 19 MeV from 370 MeV to 351 MeV in the section, which has the gradient of 31 MV/m. L1 linac in the new linac accelerates the beam from 135 MeV to 350 MeV with off-crest angle of -25 degree and provides the linear energy-time correlation that is required in the first bunch compressor. The 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 0.19 % to 1.41 %. L2 linac in the new linac accelerates the beam from 350 MeV to 1.05 GeV with off-crest angle of -25 degree and provides the linear energy-time correlation that is also required in the second bunch compressor. The L2 linac consists of 16 3-meter S-band rf structures and the rms energy spread in L2 linac decreases from 1.5 % to 0.74 %.

Two bunch compressors

Figure 3 shows the bunch compressors which exist in the 1 GeV new linac. Dispersion and beta functions around the first bunch compressor with R_{56}=16.3 mm are shown in Figure 4.

X-band rf structure is upstream of the first bunch compressor. The first bunch compressor is designed compress a 870μm rms bunch to 198 μm rms. Results of longitudinal beam simulations were used to set the bunch length of 198 μm rms in incoming second bunch compressor. Dispersion and beta functions through second bunch compressor with R_{56}=22.4 mm are shown in Figure 5.

The second bunch compressor is designed compress a 198 μm rms bunch to 35 μm rms. The parameters of the first and second bunch compressors are listed in Table 1. The bunch length after second bunch compressor can be varied by controlling parameters of R_{56} in second bunch compressor. Accordingly, the R_{56} of the second bunch compressor is adjustable to satisfy requirements of the different bunch lengths for the option of the soft and hard X-ray. Beta functions are kept to low values at the exit of the bunch compressors to minimize degradation of emittance due to coherent synchrotron radiation. Each bunch compressor has also a short length of about 6 m to reduce the effects of coherent synchrotron radiation.

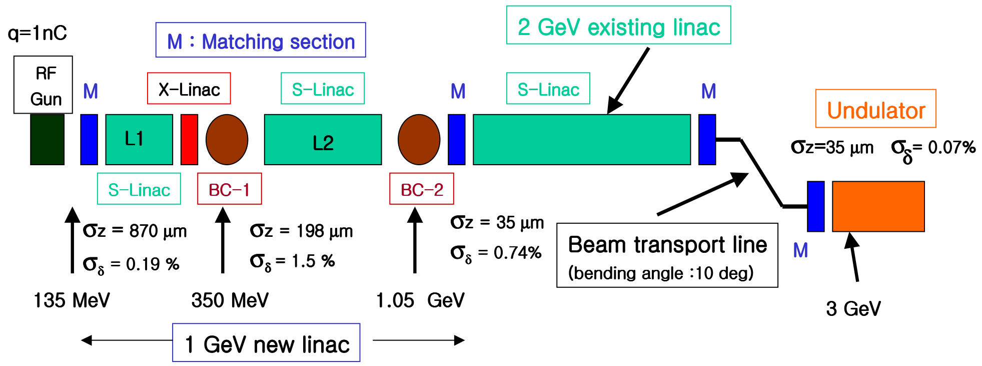

Figure 1: Schematic for a 3.0 GeV soft X-ray FEL in PAL.

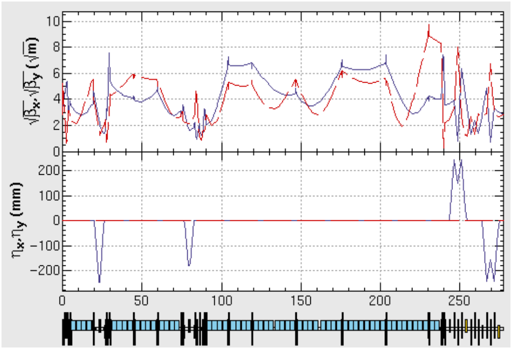

Figure 2: Twiss parameters for PAL soft X-ray FEL from injector exit to undulator entrance.

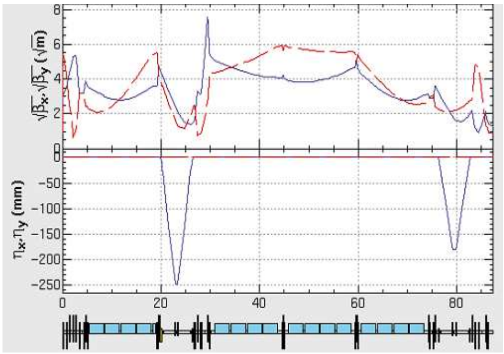

Figure 3: Twiss parameters for the 1 GeV new linac. It includes two bunch compressors, 16 accelerating structures and two matching sections. Matching sections are inserted for matching of optics between injector and L1 linac, and between second bunch compressor and the existing linac. Injector is excluded in this figure.

Existing linac

The existing linac begins at 90 m and ends at 235 m. It includes 42 3-meter rf structures and they will be used for the energy acceleration of 2 GeV for FEL facility. Newly designed lattice for the existing linac is shown in Figure 6. The short bunch of 35 μm rms in the linac effectively eliminates transverse wakefields as a source of emittance growth and the rms energy spread decreases from 0.74 % down to 0.07 % in the linac. The rf phase angle in the linac is set to -10 degree to improve energy stability.

Matching sections

Four matching sections are inserted in order to provide adjustable beta-matching in each system of the designed lattice. First matching section is located at the position between injector exit and L1 linac. Second one is inserted to match optics between the 1 GeV new linac and the existing linac. Third one is inserted to match optics between the existing linac and the beam transport line. The optics matching at the undulator entrance is performed by fourth one to obtain average beta funtions of $\sim$10-meter in the undulator. All matching sections are composed of six quadrupoles. Figure 7 shows the beta functions in the matching section between the new linac and the existing linac.

Beam transport line

Figure 8 shows dispersion and beta functions along 3 GeV 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 almost 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 m long is given by +5, +5, -5, -5 degree, respectively.

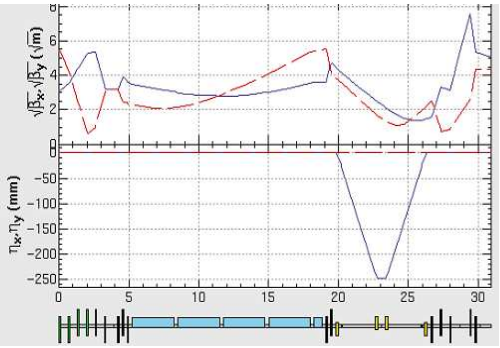

Figure 4: Beta function and dispersion functions around first bunch compressor. A X-band rf is located at upstream of first bunch compressor. 12 S-band rf structures with off-crest phase of -25 degree are located at upstream of the X-band rf section.

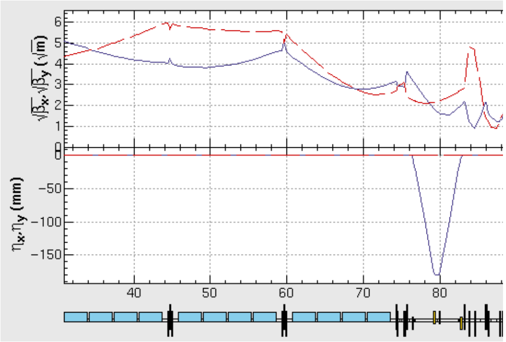

Figure 5: Beta function and dispersion functions around second bunch compressor. 12 S-band rf structures with off-crest angle of -25 degree are located at upstream of the second bunch compressor.

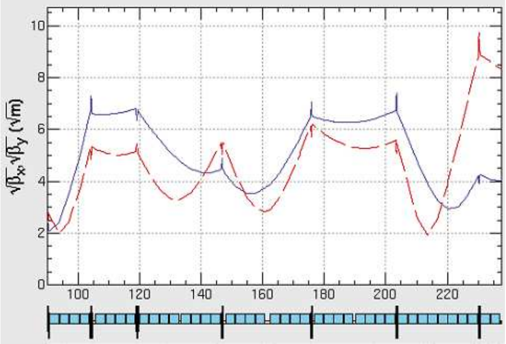

Figure 6: Newly designed beta functions along the existing linac. RF phase angle and energy acceleration for the FEL schematic are set to 10 degree and 2 GeV, respectively.

RESULTS ON START-TO-END BEAM SIMULATION

A start-to-end simulation using the code ELEGANT has been performed to optimize beam parameters for soft X-ray

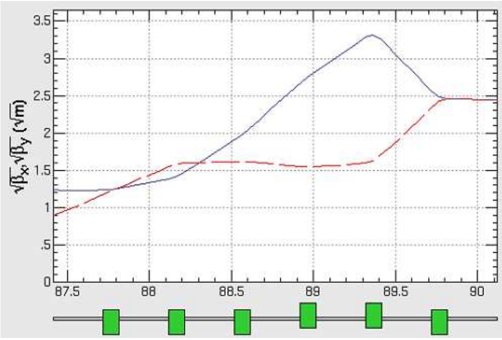

Figure 7: Beta functions in the tuneable matching section between second bunch compressor in the new linac and the existing linac.

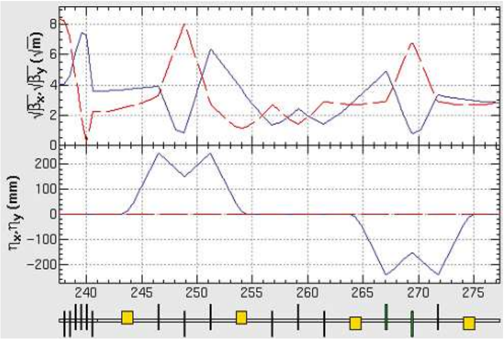

Figure 8: Beta and dispersion functions in the beam transport line with four bending magnets. Each bending angle in the bending magnets is +5, +5, -5, -5 degree, respectively. First bending magnet corresponds to BAS2.

FEL. Our full simulation uses the beam that comes from the LCLS photoinjector which produces charge of 1 nC, bunch length of 2.9 ps rms, relative energy spread of 0.19 % rms and emittance of 0.97 μm rms. The L1 linac is used for energy chirp before the beam enters the X-band rf section. A bunch compression factor of 23.7 and a peak current of 10 KA in the bunch length of 105 fs rms were obtained by the simulation. The bunch compression occurs at beam energy of 350 MeV and 1.05 GeV. Voltage and phase downstream the bunch compressor were also optimized to reduce the energy spread. Table 2 shows the beam parameters at the undulator entrance in the beam energy of 3 GeV.

CONCLUSIONS

We have performed lattice design for the 3 GeV PAL-XFEL project and optics was designed to minimize degradation of the emittance and energy spread due to the CSR and wakefields. Start-to-end beam simulations based on the parameters for soft X-ray FEL were also performed. These designed works have demonstrated the beam param-

Table 1: Parameters of first and second bunch compressors.

Parameter	1st BC	2nd BC
Beam energy	350 MeV	1.05 GeV
Ini. rms bunch length	870 μm	198 μm
Final rms bunch length	198 mm	35 μm
Ini. rms relative energy spread	1.41 %	0.74 %
Final rms relative energy spread	1.5 %	0.74 %
Magnetic field	0.5 T	0.36 T
R_{56}	16.3 mm	22.4 mm
T_{566}	-9.4 mm	-33.8 mm
Bending angle	5.04^o	3.66^o
Maximum dispersion	-250 mm	-180 mm
Length of bending magnet	203 mm	203 mm

Table 2: Beam parameters in the entrance of the undulator.

Parameter	Units	Values
Beam energy	GeV	3
RMS bunch length	μm	35
RMS relative energy spread	%	0.07
Norm. trans. emittance(H/V)	μm	1.2/1.3
Bunch charge	nC	1

eters and feasibility of soft X-ray FEL with wavelength of around 30 Angstron in PAL.

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