ISSUSE OF ENERGY SPREAD AND TRANSVERSE COHERENCY OF PAL XFEL*

H. S. Kang†, T.Y. Lee, J. Choi
Pohang Accelerator Laboratory, POSTECH, Pohang, Kyungbuk, 790-784 KOREA

Abstract

Pohang Accelerator Laboratory has recently launched a XFEL project called PAL-XFEL. PAL-XFEL will cover from the soft x-ray radiation to the hard x-ray of 0.3 nm with the 3.7 GeV beam and in-vacuum undulator with 4-mm gap. Laser beam heating to reduce the micro-bunching instability induces an increase of the uncorrelated energy spread during the bunching process in bunch compressors. With a relatively small beam energy of 3.7 GeV and a relatively large uncorrelated energy spread, transverse higher modes can have comparatively large growth rates, which may result in poor transverse coherency. Simulation study with Genesis code assuming different beam conditions is presented here.

INTRODUCTION

Pohang Accelerator Laboratory (PAL) is going to build a x-ray FEL called PAL-XFEL based on SASE (self amplified spontaneous emission) scheme. PAL-XFEL will utilize the existing 2.5 GeV electron linac and upgrade its energy and performance. The linac is currently used for the injection to the 2.5 GeV storage ring of Pohang Light Source (PLS). PAL-XFEL will cover from the soft x-ray radiation to the hard x-ray of 0.3 nm by upgrading the linac energy to at least 3.7 GeV. Details of PAL-XFEL project are presented in a separate paper[1].

Fundamental parameters of PAL-XFEL is listed in Table 1. PAL-XFEL is aiming at achieving hard X-ray laser with a relatively low energy electron beam. LCLS (Linac Coherent Light Source) [2] uses 14.45 GeV electron beam to obtain 0.15 nm radiation that is only half of the PAL-XFEL radiation. To obtain 0.3 nm radiation with 3.7 GeV, the undulator period should be small, giving rise to the undulator gap of 4 mm, which is allowed only for in-vacuum undulator. Therefore, PAL-XFEL will adopt in-vacuum undulator. As shown in Table 1, each undulator segment is 4.5 m long. Between segments, a 0.5 m space is reserved for diagnostic equipments and a quadrupole for the beam focusing. The full undulator length would be 80 – 100 m to take care of possible errors.

Transverse overlap between photon beam and electro beam requires higher beam energy. The 3.7 GeV electron beam, relatively low energy, has larger divergence than the 3 $\AA$ radiation beam. Even more, if the uncorrelated energy spread becomes relatively large, the transverse coherence becomes even worse. Laser beam heating to reduce the micro-bunching instability induces an increase of the uncorrelated energy spread during the bunching process in bunch compressors. With a relatively small beam energy of 3.7 GeV and a relatively large uncorrelated energy spread, transverse higher modes can have comparatively large growth rates, which may result in poor transverse coherency. The computer simulation with GENESIS code [3] has been done to see whether the transverse coherence is still preserved or not in SASE process with the low energy electron beam.

Table 1: Parameters of PAL-XFEL

Beam Parameters	**Value**	**Unit**
Electron energy	3.7	GeV
Peak current	3	kA
Normalized slice emittance	1	mm mrad
RMS slice energy spread	0.01 %	
Full bunch length	270	fs
Undulator Parameters		
Undulator period	1.5	cm
Segment length	4.5	m
Full undulator length	80 - 100	m
Undulator parameter, K	1.49	
Undulator gap	4	mm
FEL Parameters		
Radiation wavelength	3	Å
FEL parameter, ρ	5.7×10^{-4}	
Peak brightness	5×10^{31}	*
Peak coherent power	1	GW
Pules repetition rate (Max.)	60	Hz
1D gain length	1.2	m
Saturation length, L_{sat}	60	m

* photon/(sec mm^2 mrad^2 0.1%BW)

ENERGY SPREAD

Small density modulations from the photocathode RF-gun can be significantly amplified by the coherent synchrotron radiation (CSR) in bunch compressors, which results in a micro-bunching instability. The CSR instability is easy to develop for very cold beams [4, 5, 6]. However, the growth rate of the micro-bunching instability can be remarkably reduced by increasing the uncorrelated energy spread [7].

Linac has two sets of bunch compressors (BC1 and BC2) and a laser heater just after the 135 MeV injector (see Fig. 1). In the current design, the 1st bunch compressor (BC1)

* Work supported by Korean Ministry of Science and Technology
† hskang@postech.ac.kr

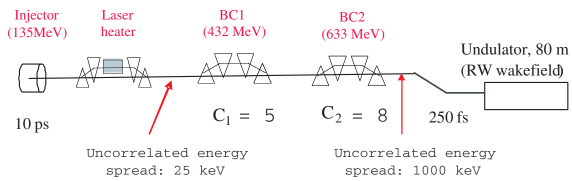


Figure 1: Layout of bunch compressors of PAL-XFEL.

is located at the point of 430 MeV and the 2nd one (BC2) is located at 630 MeV. BC1 compresses the 10 ps injector output to around 200 μm and BC2 compresses it further to 80 μm. Total compression ratio $C = C_1 \times C_2$ is about 40. If the uncorrelated energy spread of 25 keV is added by a laser heater, the uncorrelated energy spread grows to 1 MeV at the undulator entrance.

Figure 2 shows the saturation length as a function of the uncorrelated energy spread using Ming Xie's fitting formula[8]. In general, the uncorrelated energy spread should be smaller than the FEL parameter (5.7×10^{-4}). Allowing a 15% increase of the saturation length, the tolerable uncorrelated energy spread at the undulator entrance is about 2.7×10^{-4} in Fig. 2, which corresponds to 1.0 MeV. Figure 3 shows the radiation power of PAL-XFEL calculated with GENESIS code assuming the uncorrelated energy spread of 1 MeV and 2 MeV, respectively. In case of 1 MeV the saturation length is around 60 m, including the diagnostic space. If the uncorrelated energy spread is increased to 2 MeV, the radiation power does not saturate as shown in Fig. 3(b). Figure 4 shows the radiation power when the beam energy is lowered to 3 GeV. The uncorrelated energy spread is assumed to be 1 MeV and 1.375 MeV, respectively. With the uncorrelated energy spread of 1.375 MeV the radiation power does not saturate as shown in Fig. 4(b).

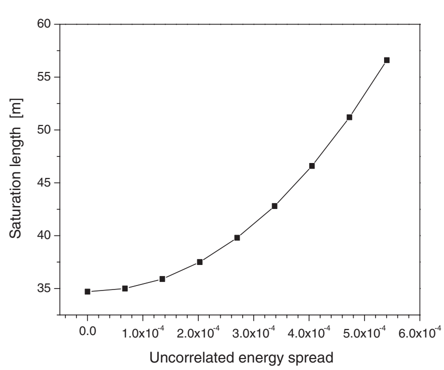


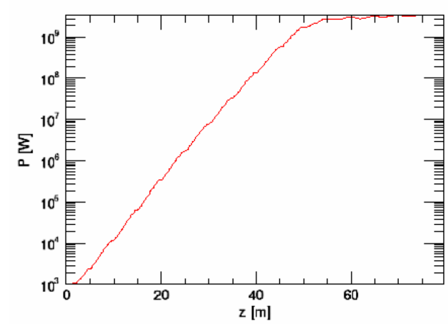
Figure 2: Saturation length as a function of the uncorrelated energy spread at the undulator entrance.

TRANSVERSE COHERENCE

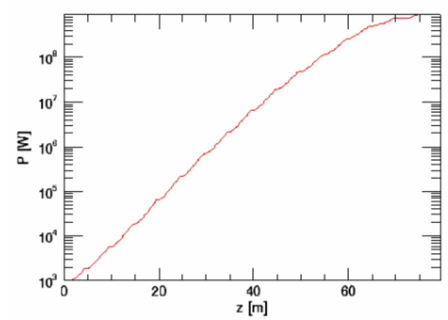
Full transverse coherence in SASE process requires the dominance of the fundamental mode (E_{00}). The numerical simulation study confirmed that the transverse coherence of SASE FEL reaches over 90% [9]. The fundamental mode should be most enhanced before the saturation while the higher order modes(E_{01}, E_{10}) should die out. The growth rate of E_{01} and E_{10} mode should be much smaller than that of E_{00}, which depends on undulator and electron beam parameters [10]. However, if the uncorrelated energy spread is increased in order to reduce the micro-bunching instability, the saturation length increases (see Fig. 2) as well as the growth rate of transverse higher order mode could be relatively high, which degrades the transverse coherency. In this case, transverse higher order modes do not vanish.

In case of full transverse coherence, the radiation beam has a profile of pure gaussian. The radiation beam profile at 80 m of the undulator with the 3.7 GeV beam is shown in Fig. 5 and Fig. 6. The uncorrelated energy spread is assumed 1 MeV and 2 MeV, respectively. In case of 1 MeV the transverse coherence looks good while in the 2 MeV case it looks poor.

Figure 7 shows the radiation beam profile with the 3 GeV beam and the uncorrelated energy spread of 1.5 MeV. The transverse coherence looks very bad. The 3.0 GeV beam gives rise to bad transverse coherence even with a smaller uncorrelated energy spread of 1.5 MeV than 2 MeV of the 3.7 GeV beam case as shown in Fig. 6. It means that the lower energy of electron beam, the smaller tolerance of uncorrelated energy spread to get full transverse coherence. This is contradictory to the energy spread requirement of

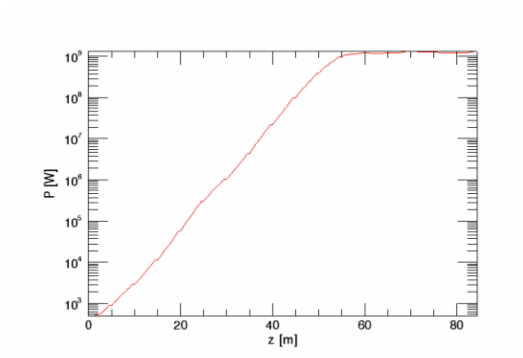


(a)

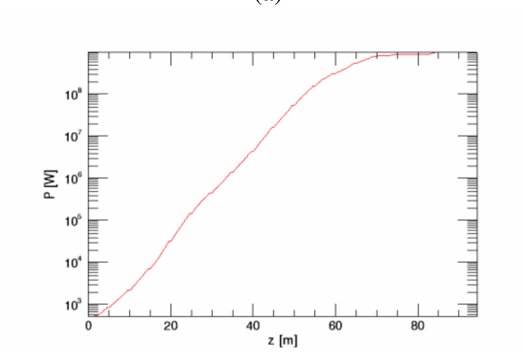


(b)

Figure 3: Power gain of PAL-XFEL with 3.7-GeV beam. The uncorrelated energy spread is 1 MeV (a) and 2 MeV(b).



(a)



(b)

Figure 4: Power gain of PAL-XFEL with 3.0-GeV beam. The uncorrelated energy spread is 1 MeV (a) and 1.375 MeV(b).

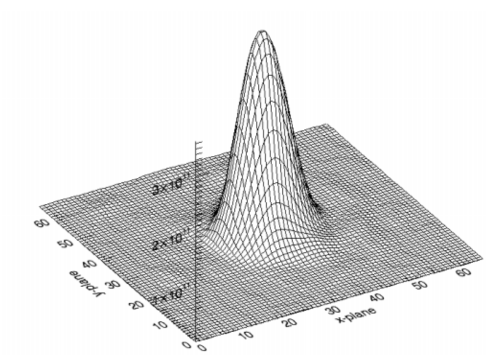


Figure 5: Radiation profile at z=80 m. The uncorrelated energy spread is 1 MeV.

micro-bunching instability. However, the 3.7 GeV case has a allowable span of uncorrelated energy spread of 1.5 MeV. Considering the increase of saturation length as shown in Fig. 2, the uncorrelated energy spread should kept below 1 MeV.

SUMMARY

PAL-XFEL is aiming at generating the hard x-ray radiation of 0.3 nm with the 3.7 GeV beam and in-vacuum undulator with 4-mm gap. Transverse coherence of 0.3 nm radiation was studied with GENESIS code changing the uncorrelated energy spread which is necessary to reduce the micro-bunching instability. With the uncorrelated energy spread of 1 MeV both the transverse coherence and the saturation length are satisfactory. With the lower beam energy of 3 GeV the transverse coherence looks bad compared to the 3.7 GeV case and the uncorrelated energy spread must be smaller than 1 MeV, which may limit the tolerance of energy spread for reducing the micro-bunching instability.

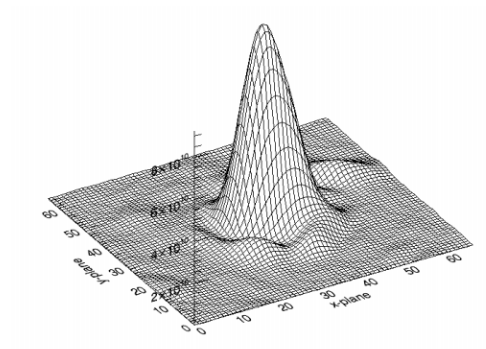


Figure 6: Radiation profile at z=80 m. The uncorrelated energy spread is 2 MeV.

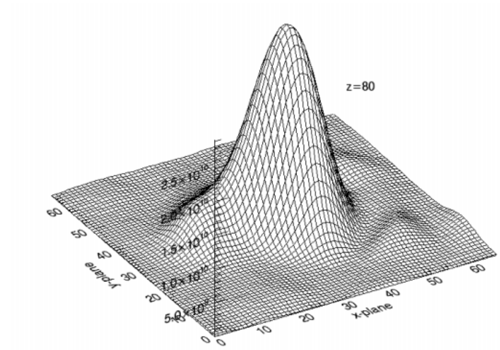


Figure 7: Radiation profile at z=80 m. The electron beam energy is 3 GeV and the uncorrelated energy spread is 1.5 MeV.

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