SIMULATION RESULTS OF SELF SEEDING SCHEME IN PAL-XFEL

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Abstract

There are two major undulator lines in Pohang Accelerator Laboratory XFEL (PAL XFEL), soft X-ray and hard X-ray. For the hard X-ray undulator line, self-seeding is the most promising approach to supply narrow bandwidth radiation to the users. The electron energy at hard X-ray undulator is 10 GeV and the central wavelength is 0.1 nm. We plan to provide the self-seeding option in the Phase I operation of PAL-XFEL. In this talk, the simulation results for the self-seeding scheme of hard X-ray undulator line in PAL XFEL will be presented.

INTRODUCTION

PAL-XFEL is now under construction in Pohang Accelerator Laboratory (PAL) site [1]. The undulator used in PAL-XFEL hard X-ray undulator hall has 24.4 mm period to make 0.1 nm radiation with 10 GeV electron beam. To supply an X-ray with good longitudinal coherence and high photon flux to users, self-seeding technique will be applied in the hard X-ray undulator line [2]. Using [0 0 4] optical plane of a diamond crystal, we can generate a seed X-ray with 0.15 nm wave length [3]. To meet the resonance condition in the undulator in PAL-XFEL, the electron beam energy will be adjusted as 8.126 GeV in the self-seeding operation. In this study, a preliminary simulation results for the self-seeding scheme for PAL-XFEL are presented with 8.126 GeV electron beam.

BEAM PROPERTIES

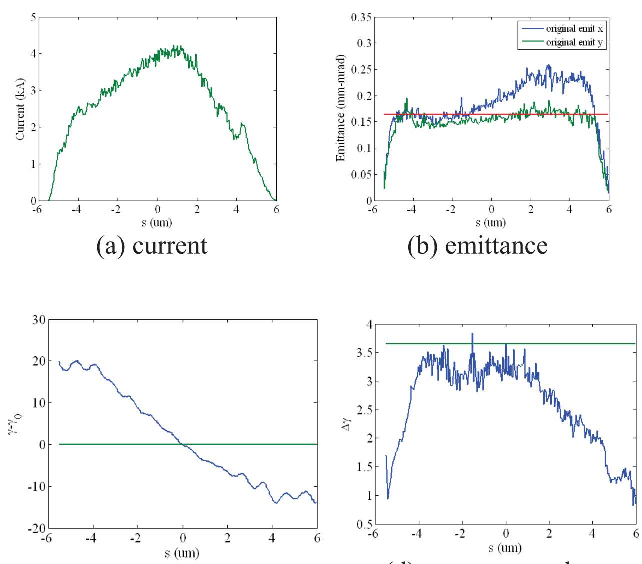
Electron beam properties at the entrance of hard X-ray undulator in PAL-XFEL with self-seeding scheme are listed in Table 1.

Table 1: Electron Beam Properties

Beam energy	8.126 GeV
Total charge	100 pC
Peak current	4 kA
Emittance	0.15 mm mrad
Energy spread	0.022 %

In PAL-XFEL, basic target wavelength in hard X-ray beamline is 0.1 nm with 10 GeV energy electron beam. However, for the self-seeding operation in Phase I, the wave length 0.15 nm is chosen [3], beam energy must be adjusted to 8.126 GeV to meet the resonance condition in the undulator.

The detail slice parameters used in this simulation are presented in Fig. 1. The beam current shown in Fig. 1 (a) has no horns and looks like almost a Gaussian profile with 3 um standard deviation. The horizontal direction (x) emittance values keep almost 0.15 mm mrad level. The vertical direction (y) emittance shows a little higher value than x-emittance, however almost values are lower than 0.25 mm mrad. Beam energy in Fig. 1(c) shows an energy chirp which is not a final optimized result for PAL-XFEL operation. γ_0 in Fig. 3 is 15902 which is the relative factor of 8.126 GeV. Energy spread is lower than 0.022 % in all slices as shown in Fig. 1(d).



(a) current (b) emittance (c) beam energy (d) energy spread

Figure 1: Slice properties of electron beam used in the simulation.

In the first 30 m of undulator line at hard X-ray undulator hall, the electron beam is sent through the undulator to generate 1 GW level radiation as shown in Fig. 2, to make seed radiation using diamond crystal with optical plane [0 0 4] which thickness will be 100 μm. In Fig. 2(a), the steady state simulation result is shown by black line. It reaches 13 GW level at the saturation position. Time dependent simulation result is shown by green line and the current profile is shown by same color line also in Fig. 2(b). Time dependent simulation shows 1 GW radiation power around 30 m position which

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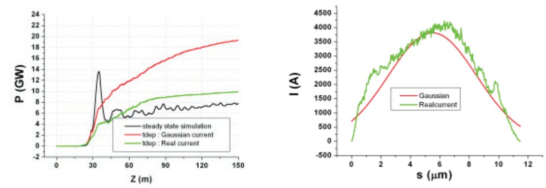
radiation will be send to the diamond crystal to make seeding radiation. For the comparison, a time dependent simulation with a Gaussian current profile also plotted with red line in Fig. 2(a) and the current is shown by same color line in Fig. 2(b).



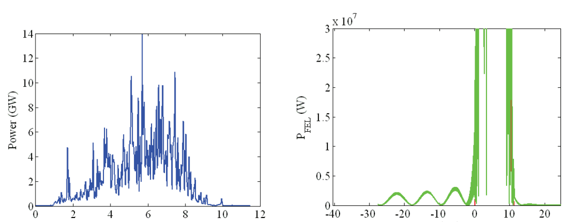
(a) (b)

Figure 2: SASE part simulation: (a) radiation power vs z. (b) Real current profile and a Gaussian one.

The phase and amplitude of SASE radiation at 30 m position are saved to calculate the seed radiation with a diamond crystal, which result will be introduced in next section.

SELF SEEDING SIMULATION

The profile of FEL radiation from the first 30 m of undulator line which is shown in Fig. 3(a) has been changed to another form as shown in Fig. 3(b). It shows a ringing part at the tail part due to the optical reaction of the diamond crystal [4]. The first ringing part which position is -5 um in Fig. 3(b) will be used as seeding radiation in this study.



(a) (b)

Figure 3: FEL radiation (a) before diamond crystal, (b) after diamond crystal with crystal plane [0 0 4].

Undulator for the self-seeding scheme will be tapered as shown in Fig. 4 with stepwise manner because one the frame of undulator module in PAL-XFEL has has no ability for tilt within one module.

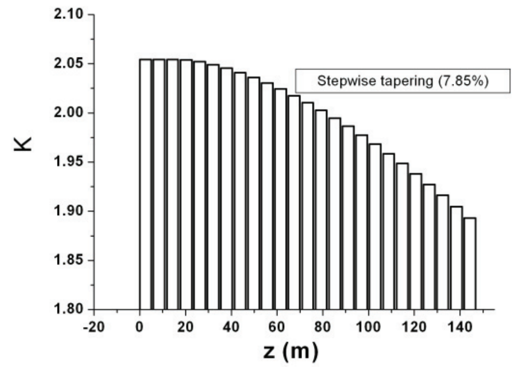


Figure 4: Stepwise tapered module of undulator in PAL-XFEL self-seeding scheme.

The lengths of electron beam and seeding radiation used in this study are compared in Fig. 5. The seeding radiation is the first ringing part in the tail of the radiation shown in Fig. 3 (b). The length of electron beam is larger than the electron beam, which means that some part of electron beam has no supporting from seeding radiation for the generation of an x-ray pulse. The effect of electron bunch length change and arrival timing jitter effect will be studied in near future.

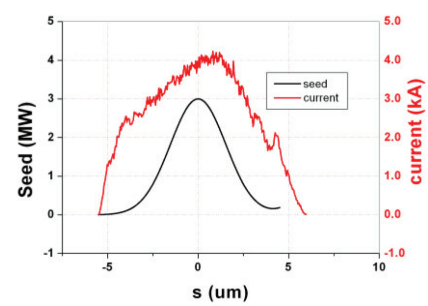


Figure 5: Current and seeding radiation.

Three simulation results are presented in Fig. 6. Black line represents a simulation result with Gaussian current profile beam with an ideal seeding. Ideal seeding means that the length of radiation is infinite with 3 MW power level. All electrons are supported from same power level seeding radiation. Red line in Fig. 6 shows a time dependent simulation result with Gaussian shape current profile of electron beam which is shown by red line in Fig. 2(b) and the real seed profile which is plotted by black line in Fig. 5. The radiation power at 150 m position decreased from 200 GW to 120 GW due to the change of seeding profile. This indicates that the length of seeding radiation is very critical one to make higher X-ray in self-seeding scheme. Green line shows the realizable result in PAL-XFEL with the real current profile and the real seed radiation. It shows 80 GW level radiation power. Note that the green line is not going up from 90 m position. We used a single quadratic function in the tapering of undulator which can be an origin of the behaviour.

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Further study will be conducted to find more optimized tapering in near future.

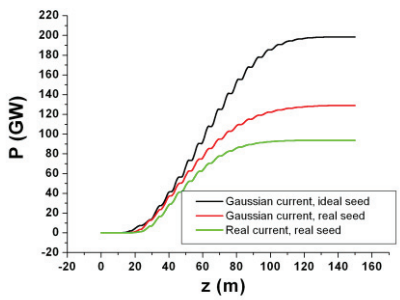

Figure 6: Stepwise tapered undulator in PAL-XFEL self-seeding scheme.

Finally, two kinds of spectrum are shown in Fig. 7. Black line shows the spectrum of the radiation generated with real seeding and stepwise tapered undulator. There is a high peak at 0.14991 nm in the spectrum. For the comparison, the spectrum of SASE radiation without seeding, but same tapered undulator, is shown by red line in Fig. 7. PAL-XEL can supply an X-ray radiation with very short bandwidth with self-seeding technique.

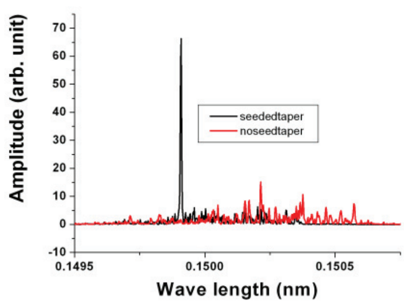

Figure 7: Stepwise tapered undulator in PAL-XFEL self-seeding scheme.

SUMMARY AND DISCUSSION

In PAL-XFEL, we will try to realize a self-seeding scheme with 0.15 nm wave length radiation with 8.126 GeV electron beam. A 80 GW level radiation will be generated with very narrow bandwidth. We need to find a way to search the optimal tapering function in self-seeding scheme. We used a single function to give tapering for undulators. However, it will be better to find each undulator parameter K for one module to find highest radiation power level. We will report soon the comparison results with several algorithms to find best way to give tapering for self-seeding for XFEL.

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