NEW SOFT X-RAY UNDULATOR LINE USING 10 GeV ELECTRON BEAM IN PAL-XFEL

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Abstract

PAL-XFEL is designed to have five undulator lines and only two undulator lines, the HXR undulator line with 10 GeV electron beam and the SXR undulator line with 3.15 GeV electron beam, will be installed during phase I. A photon beam energy from 0.28 to 1.24 keV will be provided at the SXR undulator line and different range from 2 to 20 keV will be supplied at the HXR undulator line. According to existing schedule, however, photon beam energy from 1.24 to 2 keV won't be provided in PAL-XFEL. In this research, new soft X-ray undulator line for PAL-XFEL using 10 GeV electron beam in main linac is proposed to cover the vacant photon energy. Four candidates are evaluated by estimating and comparing FEL performances using Ming Xie's formula.

INTRODUCTION

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) is designed to have three undulator lines at the end of 10 GeV main linac and two undulator lines at the end of 3.15 GeV branch linac as shown in Fig. 1 [1,2]. But only two among five undulator lines will be installed during phase I. One is the hard X-ray (HXR) undulator line with 10 GeV electron beam and the other is the soft X-ray (SXR) undulator line with 3.15 GeV electron beam. Main parameters of PAL-XFEL are listed in Table.1.

A photon beam with energy from 2 to 20 keV will be supplied at the HXR undulator line. Another photon beam with different energy from 0.28 to 1.24 keV will be provided at the SXR undulator line. According to existing schedule, photon beam with energy from 1.24 to 2 keV won't be usable in PAL-XFEL. In this vacant region, however, it is estimated that there are some demands for outstanding experiments [3] and therefore that region has to be covered in the near future. There are two main ways to cover the vacant region: One is extending photon energy supply of existing undulator lines. The other is designing new undulator line using one of three available undulator lines.

In this research, new SXR undulator line for PAL-XFEL using 10 GeV electron beam in main linac is proposed.

Table 1: Main Parameters of Current PAL-XFEL

	Hard X-Ray	**Soft X-Ray**
Location	Main Linac	Branch Linac
Energy	4 – 10 GeV	2.5 – 3.15 GeV
FEL Photon Energy	Und. Gap Change (Max. Energy Fix)	
	12.4 – 20.0 keV (0.1 – 0.06 nm)	0.41 – 1.24 keV (3 – 1 nm)
	Energy Change (Min. Und. Gap Fix)	
	2.0 – 12.4 keV (0.6 – 0.1 nm)	0.28 – 0.41 keV (4.5 – 3 nm)
Und. Period	26 mm	35 mm
Peak Current	3 kA	2 kA
Normalized Slice Emittance	0.4 mm-mrad	0.6 mm-mrad
Slice Energy Spread	1.5 MeV	1.5 MeV
Bunch Length	18 um (60 fs)	27 um (90 fs)

Evaluation is conducted by comparing estimated FEL performances of existing undulator lines and newly designed undulator lines in the vacant region. All estimation of FEL performances are based on Ming Xie's formula [4]. Time-dependent simulation is also performed with selected solution by GENESIS 1.3 using real beam parameter [5].

EXISTING UNDULATOR LINE

There are two undulator lines, the HXR and SXR undulator lines, according to existing schedule in PAL-XFEL, so two specific candidates are also available. Each parameters of two lines are listed in Table 1.

Soft X-Ray (SXR) Undulator Line

In the SXR undulator line, electron beam energy is fixed at maximum values, 3.15 GeV, as shown by blue dashed

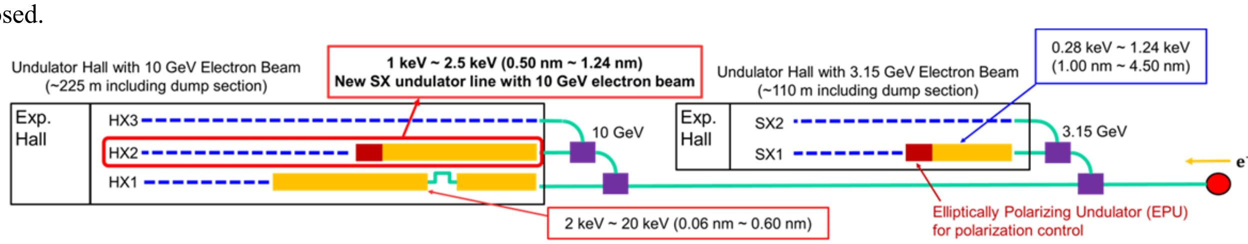

Figure 1: Schematic diagram about undulator lines of PAL-XFEL.

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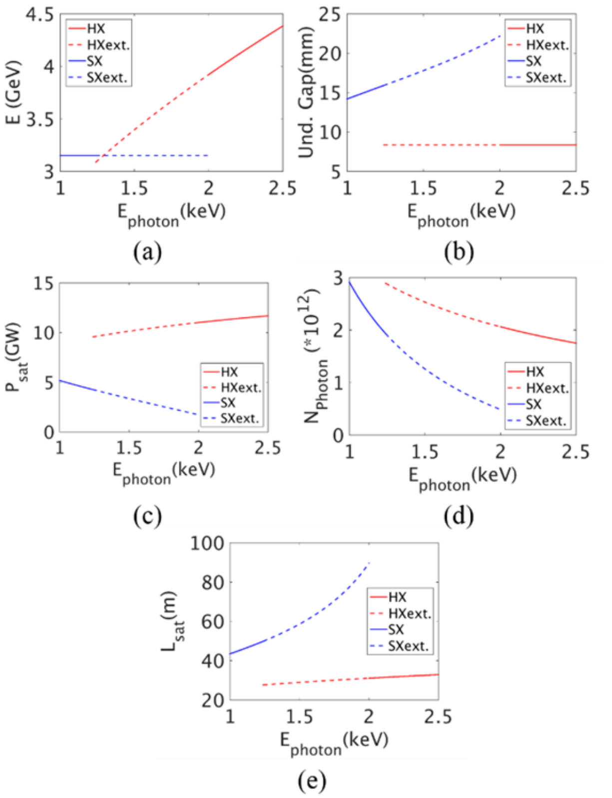

Figure 2: Blue (red) line indicates the existing SXR (HXR) undulator line. Solid (dashed) line means provided (vacant) photon energy region (a) Electron beam energy (b) Undulator gap (c) Saturation power (d) Number of photons (e) Saturation length.

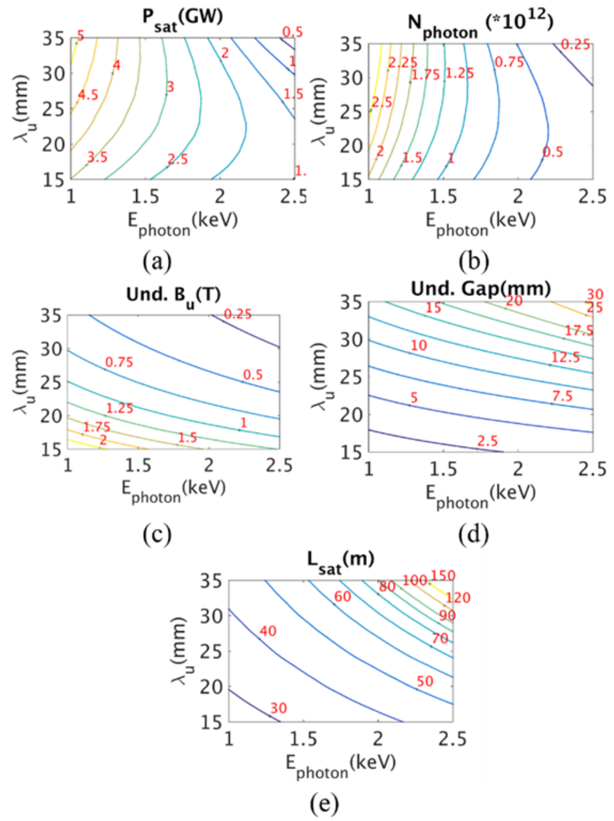

Figure 3: Contour graphs vs. undulator period and resonance photon energy in 3.15 GeV branch linac (a) Saturation power (b) Number of photons (c) Undulator peak magnetic field (d) Undulator gap (e) Saturation length.

line in Fig. 2 (a). Resonance photon energy is adjustable by changing undulator gap and photon energy supply can be extended. The wider undulator gap is opened, the higher photon energy is obtained as plotted by blue dashed line in Fig. 2 (b). Saturation power and number of photons are decreasing as photon energy becomes higher as drawn in Fig. 2 (c) and (d) by blue dashed line. 1×10^{12} is minimum number of photons standard of SXR in PAL-XFEL project and it can't be reached over 1.63 keV as shown in Fig. 2 (d) by blue dashed line. Furthermore, saturation length is increasing rapidly as photon energy becomes higher as shown in Fig. 2 (e). Therefore, it is hard to cover the vacant region at the existing SXR undulator line in PAL-XFEL.

Hard X-Ray (HXR) Undulator Line

In the HXR undulator line, undulator gap is fixed at minimum values, 8.37 mm, as shown in Fig. 2 (b) by red dashed line. Resonance photon energy is adjustable by changing electron beam energy and photon energy supply can be extended. The lower energy electron beam has, the lower photon energy is gained as plotted by red dashed line in Fig. 2 (a). FEL performances such as saturation power, number of photons and saturation length are not bad in vacant region as shown by red dashed line in Fig. 2 (c), (d) and (e). However, required electron beam energy is too low (< 4 GeV) and it can't be realized because of technical limit in accelerator section. Thus, it is also hard to cover the vacant region at the existing HXR undulator line in PAL-XFEL.

NEW SOFT X-RAY UNDULATOR LINE

There are two available locations for new SXR undulator line. One is the end of branch linac with 3.15 GeV electron beam energy and the other is the end of main linac with 10 GeV electron beam energy. Thus, two candidates will be evaluated. Electron beam parameters at each linacs are listed in Table 1.

3.15 GeV Branch Linac

In the new SXR undulator line at the end of branch linac, electron beam energy is fixed at 3.15 GeV over the vacant region. Ordinary saturation power is expected as shown in Fig. 3 (a). Number of photons, however, can't satisfy minimum standard, 1×10^{12}, above 1.5 ~ 1.6 keV photon energy as plotted in Fig. 3 (b). If the undulator period is shorter than 25 mm, requisite peak magnetic field is above 1 T as shown in Fig. 3 (c). It is hard to realize such high field by undulator, so undulator period has to be longer than 25 mm to cover the vacant region. Undulator gap respond to needed peak magnetic field is shown in Fig. 3 (d). Minimum gap is restricted by

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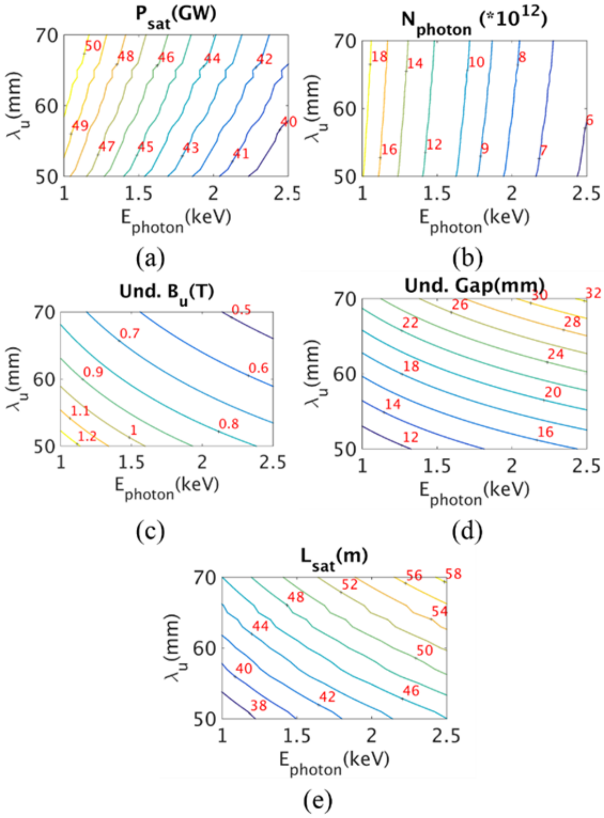

Figure 4: Contour graphs vs. undulator period and resonance photon energy in 10 GeV main linac (a) Saturation power (b) Number of photons (c) Undulator peak magnetic field (d) Undulator gap (e) Saturation length.

diameter of beam tube and mechanical margin. So undulator period has to be longer than 28 mm when same minimum gap of existing undulator line, 8.37 mm, is applied. Furthermore, saturation length is rapidly increasing as photon energy becomes higher when undulator period is longer than 30 mm as shown in Fig. 3 (e). Therefore, new SXR undulator line with any undulator period in 3.15 GeV branch linac is inappropriate to cover the vacant region.

10 GeV Main Linac

In the new SXR undulator line at the end of main linac, electron beam energy is fixed at 10 GeV over the vacant region. Sufficiently high power and number of photons at any photon energy are expected as shown in Fig. 4 (a) and (b). If the undulator period is longer than 60 mm, requisite values of peak magnetic field and undulator gap are enough reasonable as plotted in Fig. 4 (c) and (d). Furthermore, proper saturation length is estimated at any undulator period and photon energy as shown in Fig. 4 (e). So, the new SXR undulator line with 60 mm undulator period in 10 GeV main linac is the best candidate to cover the vacant photon energy region, 1.24 ~ 2 keV.

SIMULATION RESULTS

Time-dependent simulation is conducted about selected candidate. Real beam parameters for 10 GeV main linac with wakefield effect is used in simulation [6].

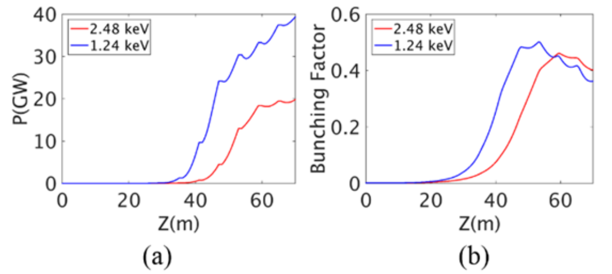

Figure 5: SASE simulation results with non-tapering. Blue (red) line indicates 1.24 (2.48) keV photon energy. (a) Radiation power (b) Bunching factor.

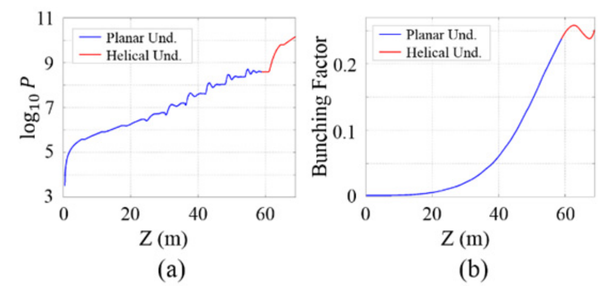

Figure 6: Polarization control with EPU simulation results. Blue (red) line indicates planar (helical) undulator output. (a) Logarithmic radiation power (b) Bunching factor.

SASE simulation

Only 5 m-long planar undulator lattice is used in SASE simulation with non-tapering [6]. Simulations about two different photon energies are carried out. Radiation powers are sufficiently high as shown in Fig. 5 (a). Radiation power at 60 m is 33.28 (18.38) GW when photon energy is 1.24 (2.38) keV as indicated by blue (red) line in Fig. 5 (a). Both saturation points where the bunching factor has the maximum value are occurred within 60 m as plotted in Fig. 5 (b). With proper tapering scheme after saturation, radiation power will grow much higher than this.

Polarization Control with EPU

In the soft X-ray regime, polarization control is essential and it can be realized using additional elliptically polarizing undulator (EPU) with reverse tapering method [7]. Ten 5 m-long planar undulators are used and reverse tapering method is applied to them. Two additional 3.5 m-long EPUs are used for polarization control [6]. Simulation is conducted about 1.24 keV photon beam. Logarithmic power graph is shown in Fig. 6 (a). Linearly polarized radiation power at the end of planar undulators is 0.38 GW. Circularly polarized radiation power at the end of EPUs is 14.06 GW which is 5 times higher than previous results at the existing SXR undulator line by virtue of high electron beam energy [8]. According to definition of degree of polarization [7], it is 98.65% in this case. By optimizing reverse tapering method, higher circularly polarized radiation power and degree of polari-

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zation will be obtained. Bunching factor of this case is shown in Fig. 6 (b).

CONCLUSION

To cover the vacant photon energy region from 1.24 to 2 keV in PAL-XFEL, four candidates are evaluated by estimating and comparing FEL performances using Ming Xie's formula. New soft X-ray undulator line with 60 mm undulator period at the end of 10 GeV main linac is the best solution to cover it. Moreover, FEL performances of overlapped photon energy region such as 1.24 keV is quite improved by virtue of high electron beam energy.

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