ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEP2PT032

FEASIBILITY STUDY OF HIGH ENERGY X-RAY SOURCE AT PLS-II

Jang-Hui Han†, Jaeyu Lee, Sangbong Lee, Sojeong Lee, Tae-Yeon Lee
Pohang Accelerator Laboratory, Pohang, Korea

Abstract

PLS-II operates for user service with the 34 beamlines since 2012. For engineering applications, especially for thick metal samples, a high energy X-ray beamline is under consideration to cover a photon energy up to 100 keV or beyond. By comparing the radiation spectra from various insertion devices types, superconducting wiggler was found to be a most promising candidate. A feasibility study to install the high field wiggler in the PLS-II ring is presented in this paper. Electron beam dynamics studies for a minimum impact on the electron beam parameters and engineering consideration to add more magnets are carried out.

INTRODUCTION

Pohang Light Source II (PLS-II) operates for user service with synchrotron radiation ranging from IR to hard X-ray [1]. The electron beam energy is 3 GeV. The nominal beam current is 400 mA with top-up operation. The 282 m circumference ring has 12 cells. Each cell has two, 6.88 m long and 3.69 m short, straight sections. The ring have 24 straight sections in total. Twenty out of them are used for insertion devices, and the other straights are used for electron beam injection and RF cavities installation.

The main radiation source of PLS-II is the in-vacuum undulators with a period of 20 mm. The twenty in-vacuum undulators have a maximum magnetic field of 0.97 T when the magnet gap is 5 mm. One in-vacuum revolver undulator with four different periods, three APPLE-II type elliptically polarizing undulators and one out-vacuum undulator are in use. Two multipole wigglers with periods of 100 mm and 140 mm have maximum fields of 1.80 T and 2.02 T, respectively. The wigglers provide radiations up to 40 keV with a flux enough for users.

There is a request from users to provide higher energy X-rays for engineering applications. For instance, a high energy X-ray of 100 keV can be used to investigate a thick metal sample with a thickness of a few millimeters. A new insertion device for this purpose can be installed at the 2C slot which is empty at present. In this paper, we find the best insertion device type to generate a high energy X-ray with the electron beam parameters of PSL-II. We then study the feasibility to install the insertion device into the PLS-II ring with minimum impacts to the performance of the existing radiation sources.

INSERTION DEVICE

Given the electron beam energy, a higher magnetic field generates an X-ray with higher photon energies. The critical energy (ε_c) in keV varies with the magnetic field in T as $\varepsilon_c = 0.67E^2B$, where E is the beam energy in GeV. To provide a sufficient flux at 100 keV, we need a critical energy of about 25 keV, which means a magnetic field of 4.2 T is required at the 3 GeV electron beam energy.

The flux densities from insertion devices under consideration, SCU16 (superconducting undulator with a 16 mm period) and SCW48 (superconducting wiggler with a 48 mm period), in addition to the existing ones, MPW10, MPW14 and IVU20, in PLS-II have been calculated by using the Spectra code [2] as shown in Fig. 1. A superconducting wiggler with a 4.2 T field and a 16 period can produce a flux density of more than one order of magnitude than the existing permanent magnet wigglers at the 100 keV photon energy. The parameters of the insertion devices used for the spectra calculation are summarized in Table 1.

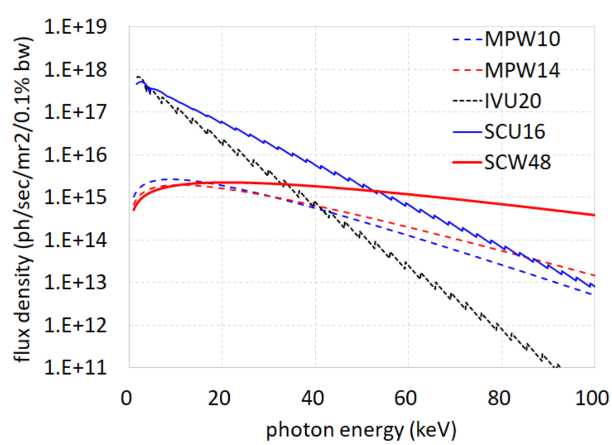

Figure 1: Spectra from insertion devices at PLS-II. At the 100 keV photon energy, a superconducting wiggler (SCW48) can provide a flux with more than an order of magnitude compared with the wigglers (MPW10 or MPW14) installed in the PLS-II ring.

Superconducting wigglers with a 4.2 T magnetic field are used at other synchrotron radiation sources [3]. Because of the available length of the 2C straight section, we consider a short SCW with a magnet length of about 0.8 m. In the 3.69 m long straight, a cryogenic tank to implement the SCW and additional quadrupole magnets for electron beam dynamics adjustment will be installed.

IMPACT TO THE ELECTRON BEAM PARAMETERS

An insertion device with a high magnetic field can generate high flux at high photon energies. However, an insertion device with such a high magnetic field may deteriorate the electron beam emittance if that is placed at a position with

† janghui_han@postech.ac.kr

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEP2PT032

Table 1: Parameters of Selected Insertion Devices at PLS-II

	MPW10	MPW14	IVU20	SCU16	SCW48
Period (mm)	100	140	20	16	48
B_{max} (T)	1.80	2.16	0.97	1.50	4.20
Critical energy (keV)	10.8	12.9	–	–	25.1
K	16.8	28.2	1.81	2.24	18.8
Number of periods	18	12	90	75	16
Magnet length (m)	1.8	1.68	1.8	1.2	0.768
Flux density at 35 keV	7.5×10^{14}	7.2×10^{14}	2.1×10^{15}	9.5×10^{15}	2.15×10^{15}
Flux density at 100 keV	4.8×10^{12}	1.3×10^{13}	3.6×10^{10}	8.1×10^{12}	1.22×10^{15}
Total power (kW)	13.3	20.1	3.9	6.1	30.9

the horizontal dispersion is not zero. Figure 2 shows the Twiss parameters of one cell of the present PLS-II lattice. The Twiss parameters were calculated by using the OPA code [4]. The blue rectangles on the top in the figure indicate the dipoles, the red ones the quadrupoles and the pale green ones the sextupoles. Currently, one short straight section is available for the installation of the superconducting wiggler. The short straight section is located at the center in Fig. 2. The horizontal dispersion at the short straight is 0.144 m and the insertion device at the non-zero dispersive section may lead to an emittance increase.

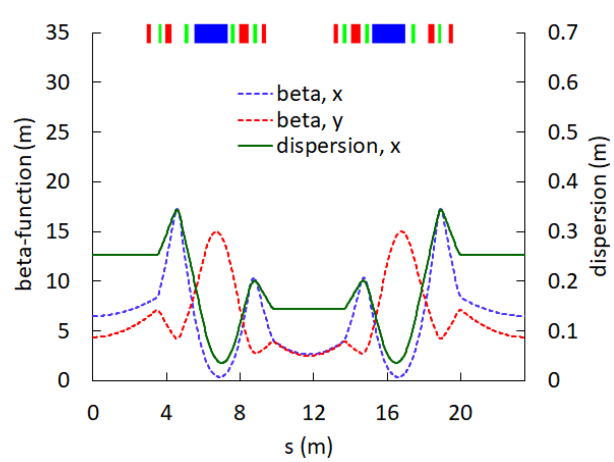

Figure 2: Twiss parameters of the present cell lattice.

The emittance change as a function of the dispersion for the beta-function of 2.7 m is plotted in Fig. 3. When the horizontal beta function is kept as present, the emittance does not increase if the dispersion is 0.058 m or smaller. Note that the emittance dependence on the dispersion changes with the beta function, which is not indicated here. With a higher beta function, the requirement for the dispersion is relaxed.

To minimize the emittance growth caused by the high magnetic field of the superconducting wiggler, we modified the local cell lattice as Fig. 4. Six quadrupoles were added in one cell and the strength of all quadrupoles in the cell were optimized to reduce the dispersion at the straight and to match the Twiss parameters to the neighbor cells. Maintaining the appropriate beta function and tune, we reduced the dispersion at the short straight section to 0.079 m.

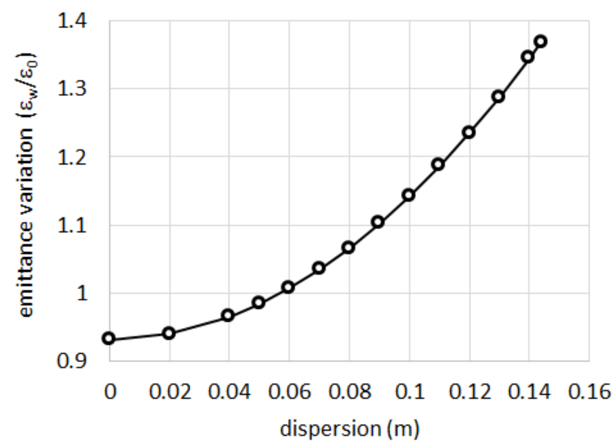

Figure 3: Emittance variation depending on the dispersion.

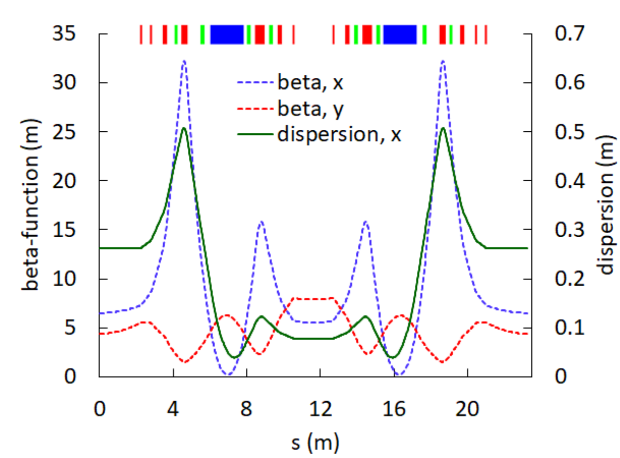

Figure 4: Twiss parameters of the modified cell lattice. The dispersion is reduced to 0.079 m and the horizontal beta function is increased to 6.3 m to suppress the emittance rise.

The new horizontal beta function in the modified PLS-II lattice is presented in Fig. 5. Only the second cell is modified and the other cells are unchanged. The horizontal emittance is changed from 5.8 to 6.3 nm. After the installation of the

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEP2PT032

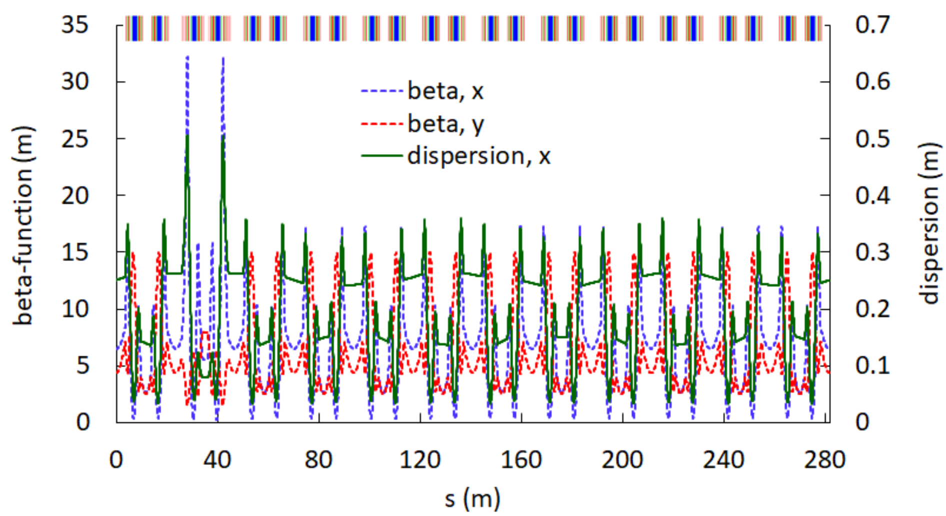

Figure 5: Twiss parameters of the ring lattice including the modified cell. The Twiss parameters are unchanged except for the second cell where a new wiggler is to be installed.

superconducting wiggler, the horizontal emittance is reduced to 6.2 nm and it is an acceptable change.

Figure 6 shows the dynamic aperture of the modified PLS-II ring. It was calculated using the OPA code for 1000 turns. The injection devices were not included in the OPA lattice.

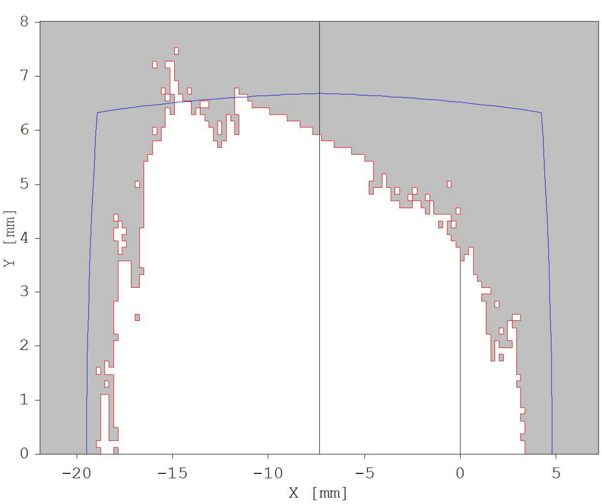

Figure 6: Dynamic aperture of the modified ring. The injection position is −15 mm.

After the cell modification, the dynamic aperture decreased dramatically because of the asymmetry. We optimized the sextupoles to increase the dynamic aperture using OPA. Also the energy offset was set to −3%.

The current injection point is x = −15 mm and y = 0 mm and it will be changed to x = −12 mm and y = 0 mm after the PLS-II injection system upgrade project which is ongoing. The transverse size of the injection bunch is about 1 mm. Therefore, the dynamic aperture of the the modified PLS-II ring is acceptable.

ENGINEERING ISSUES

To implement six additional quadrupoles and a cryotank with the superconducting wiggler, the availability was reviewed. In Fig. 7, the mechanical layout of Cell 2 of the PSL-II ring is presented. An electron beam passes from the left to the right.

The right side in the figure is the 2A slot where the EPU with a 72 mm period and a 2.58 m magnet length is installed. Between the EPU and the first quadrupole in the cell, there is a drift with a length of about 1.5 m. Two corrector magnets and an ion pump are installed in the drift. Two additional quadrupoles can be installed in the drift without a major mechanical modification.

The left side is the 3A slot where the in-vacuum revolver undulator is installed. In the drift between the las quadrupole and the revolver undulator, two additional quadrupoles can be installed without a major mechanical modification as for the 2A slot.

The center straight is the 2C slot where the superconducting wiggler is to be installed with two additional quadrupoles, one upstream and another downstream of the wiggler. A dummy chamber with a length of 2.385 m is installed now. When a wiggler tank length of 1.8 m is assumed, there is space for the quadrupoles and two additional corrector magnets.

CONCLUSION

Following the user's request, we studied the feasibility to install a high energy X-ray source in the PLS-II ring. We first reviewed the spectra from the present insertion devices and possible candidates as a high energy source. We concluded a superconducting wiggler with a magnetic field of 4.2 T can provide an X-ray up to 100 keV with a sufficient flux. Due to the non-zero dispersion in the straight section where a new superconducting wiggler is to be installed, the beam

ISBN: 978-3-95450-206-6 doi:10.18429/JACoW-FLS2018-WEP2PT032

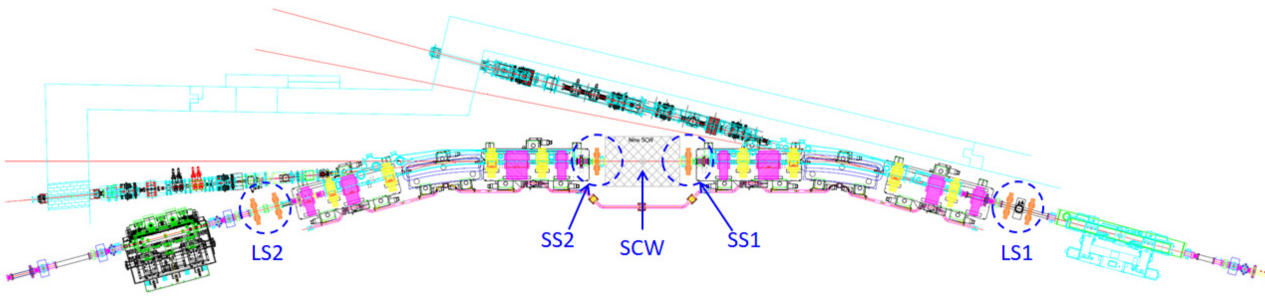

Figure 7: Mechanical layout of Cell 2 with additional six quadrupoles and a superconducting wiggler. The positions for the new quadrupole installation are indicated with blue circles. A new superconducting wiggler is to be installed in the rectangle box in the center.

dynamics was studied to minimize the impact to the performance of the existing insertion devices. We conclude that a new superconducting wiggler can be installed in Cell2 of the PSL-II ring without major issues in the beam dynamics and engineering point of view.

REFERENCES

[1] S., H. Nam, H.-S. Kang, I. S. Ko and M. Cho, "Upgrade of Pohang Light Source (PLS-II) and Challenge to PAL XFEL", *Synchrotron Radiation News* 26:4, 24 (2013).

[2] T. Tanaka and H. Kitamura, "SPECTRA: a synchrotron radiation calculation code", *J. Synchrotron Rad.* 8, 1221 (2001).

[3] N. Mezentsev, " Superconducting Multipole Wigglers for Generation of Synchrotron Radiation", in *Proc. 24th Russian Particle Accelerator Conf. (RuPAC'2014)*, Obninsk, Russia, Oct. 2014, paper THZ01, 296 (2014).

[4] A. Streun, OPA version 3.39, `https://ados.web.psi.ch/opa`