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Feasibility Study of Upgrades to the PLS-II Storage Ring

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The PLS-II is a third-generation light source; it has been operating since 2011. It has a double-bend structure with non-zero dispersion along the straight section. Here, we assess three proposed upgrades to the PLS-II. First, we evaluate use of a canted insertion device beamline to increase the number of beamlines. Second, we evaluate the consequences of upgrading the bending magnet to a superbend magnet; the change doubles the strength of the bending field and increases the critical energy from 8.7 keV to 17 keV. Finally, a short-bunch mode for time-resolved experiments is studied; the goal is to achieve a bunch length of 5 ps rms by using a low-alpha mode and increasing the RF gap voltage.

Keywords: Storage ring, Canted ID, Superbend, Low alpha
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I. INTRODUCTION

The Pohang Light Source II (PLS-II) [1] is a third-generation storage ring that works with an electron beam that has 3 GeV energy, 400 mA current, and 5.8 nm emittance. PLS-II has been operated since March 2012. In 2019, it was operating close to its full capacity. A 400-mA top-up mode was achieved [2,3], and a feedback control has been used to increase the stabilities of electron beams and photon beams [4, 5]. More than 7000 users have conducted experiments at 32 beamlines (13 bending beamlines and 19 insertion device (ID) beamlines) and have presented high-quality papers. Every straight section is now fully filled with IDs, and competition for beam time is increasing. Under these circumstances, we have kept working to upgrade the capacity and the operating parameters of PLS-II. This paper reports on an evaluation of three proposed upgrades of PLS-II. Section II describes the 'canted ID' scheme that accommodates two IDs in one long straight section to increase the number of beamlines. Section III introduces the 'superbend', which replaces the bending radiation source to increase the brightness in the high X-ray region. Section IV describes a study to achieve a short-bunch operation mode. Section V summarizes the results.

II. CANTED ID

Many storage rings accommodate two IDs in one long straight section as a way to increase the number of beamlines [6]; this is called the 'canted ID' scheme. Three small bending magnets bump the orbit to tilt the radiations from the two IDs so that they have sufficient angle to be distinguished at the beamline hutch [7].

The long straight section of PLS-II is 6.5 m long, and its in-vacuum undulator (IVU) is about 2 m long. Therefore, we put three steering bending magnets and two IVUs in one long straight section (Fig. 1). The angle between the radiations from the two IDs is 11 mrad, which yields a separation of 190 mm at the end of the front-end. This insertion of three extra steering dipoles breaks the 12-fold symmetry of the storage ring lattice. Consequently, its dynamic aperture and lifetime may decrease. The long straight section of the PLS-II is not dispersion-free, so emittance also increases. As a result of a lattice study, we calculated that the canted ID lattice increases the emittance from 5.8 nm to 6.1 nm. The dynamic aperture decreases, but this change is negligible considering

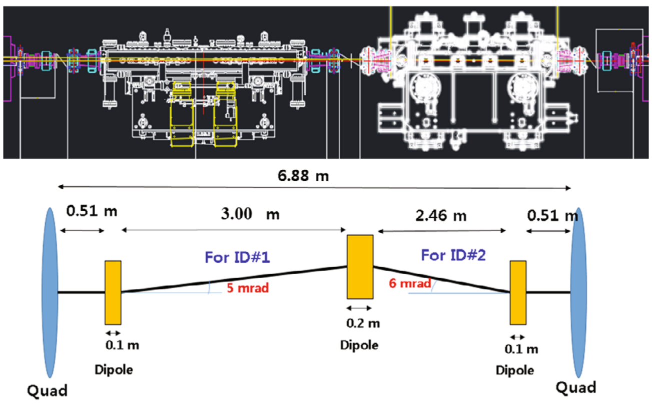

Fig. 1. Drawing of canted ID configuration. Beam propagates from left to right.

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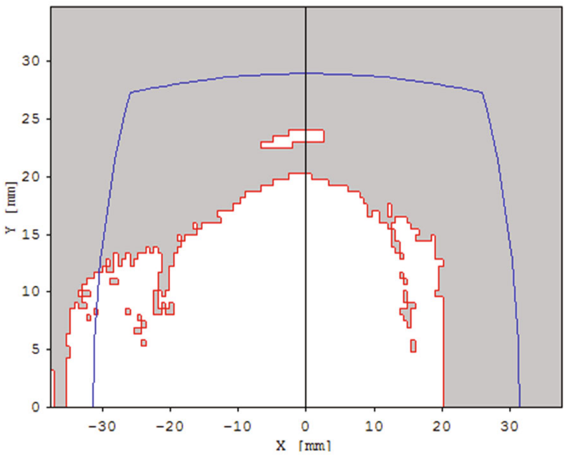

Fig. 2. Dynamic aperture of the canted ID configuration. Injection point is $x = -14$ mm, $y = 0$ mm.

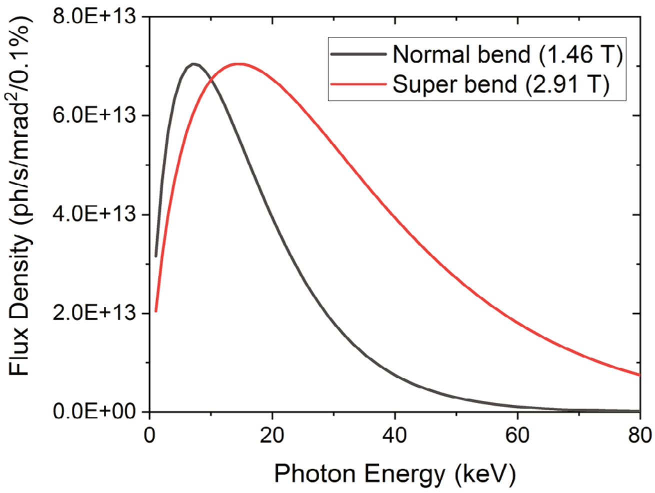

Fig. 3. Flux comparison between normal bend and superbend amgnets.

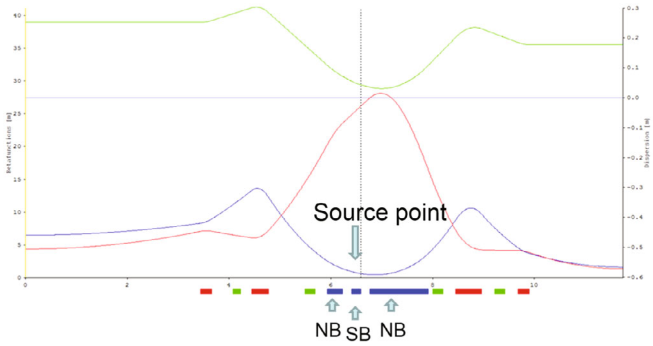

Fig. 4. Half-cell lattice with the superbend (SB). One normal bend (NB) is replaced by two normal bends and one superbend.

that the injection point is at $x = -14$ mm (Fig. 2).

Generally, the beta function of the straight section is designed to be minimized at its center, which will be the radiation source point. For optimization of the beta function of the canted ID configuration, a double-low beta is desirable at the source points of the two IDs [8]. However, that lattice change requires additional quadrupoles, which break the lattice symmetry further. Therefore, we decided to maintain the current beta function of the straight section.

III. SUPERBEND

An arc section of the PLS-II has two 1.8-m long, 1.455-T bending magnets. Each bends the electron beam by 15°, so a total of 24 bending magnets will rotate the beam completely. Of the 24 bending magnets, 13 are radiation sources for the bending beamline; its critical energy E_C is 8.7 keV. Typically, we call an X-ray 'hard' when its photon energy is greater than ∼10 keV. Therefore, the bending radiation source of the PLS-II is relatively weak in the hard X-ray region. To increase the E_C of the radiation emitted from bending magnet, we are considering inserting a strong bending magnet, called a 'superbend'. It uses superconducting coils to achieve a magnetic field > 2 T. Many accelerators use superbends to provide hard X-rays [9]. When the bending field is increased from 1.46 T to 2.91 T, E_C increases from 8.7 keV to 17.4 keV. The flux difference between a normal bend and a superbend increases as the photon energy increases (Fig. 3). The radiation from the superbend is brighter than the radiation from the normal bend, especially in the hard-X-ray region. In the 40-keV region, the flux from the superbend is five times larger than the flux from the normal bend. At ∼50 keV, the flux from the normal bend is negligible compared to the flux from the superbend.

When we change a normal bend to a superbend, we will replace a 1.8-m-long normal bend with two normal bends (1.02 m and 0.42 m long) and one superbend (0.18 m long) to minimize the change in beam characteristics caused by replacing bending magnets. The original normal bend is a combined magnet with quadrupole fields, but the superbend is not. In the designed half-cell lattice (Fig. 4), each cell has a mirror-symmetric structure. The emittance increases from 5.8 nm to 5.9 nm, and the dynamic aperture is acceptable.

IV. SHORT-BUNCH MODE

The storage ring is a powerful light source that provides synchrotron radiation at a repetition rate of a few megahertz. Recently, the demands for synchrotron radiation experiments that exploit the timing characteristics of the storage ring have been increasing. Beamline users who conduct a timing experiment require a low repetition rate and short radiation bunches. The low repetition

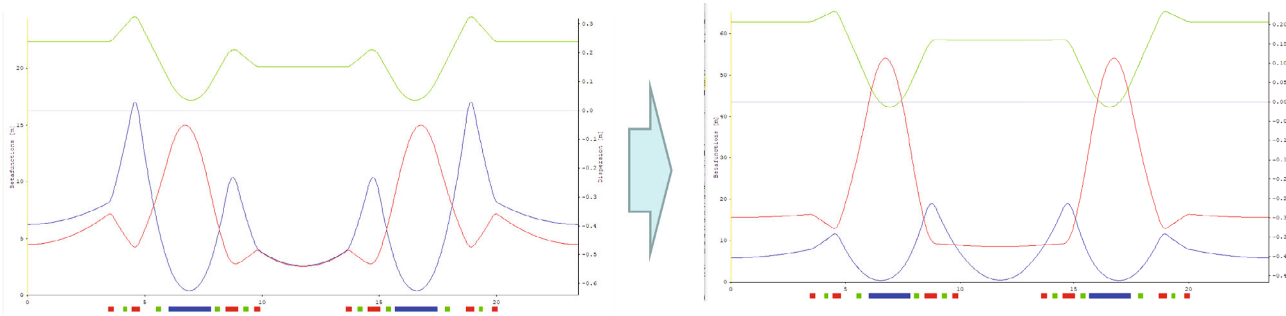

Fig. 5. Optical function change from the normal lattice (left) to the low alpha mode lattice (right). Integral of the dispersion function (green) at the dipole is reduced to 1/10. Large changes are induced in the horizontal (red) and vertical (blue) beta functions.

rate can be achieved by using the hybrid fill operation, but PLS-II does not provide short-bunch-mode operation. This operation mode has been enabled by changing the momentum compaction factor α [10]. Therefore, the short-bunch mode is generally called the low-alpha mode. This mode is provided with very low current because the bunch length also depends on the bunch current. The bunch length at the normal bunch current is independent of the momentum compaction factor [11].

The change in beam characteristics for the low-alpha mode is usually large. The emittance and the dynamic aperture are drastically degraded when α is decreased. Some lattices fail the matching process because of the limited degrees of freedom. The PLS-II lattice has many quadrupoles, so it also has a low degrees of freedom. Therefore, we aimed to achieve a relatively high α for the low-alpha mode. Our goal is reduce α to 1/10 of the original value. To further reduce the bunch length, we can change the RF gap voltage. As a result, we can decrease the rms bunch length from 20 ps to 5 ps. In each cell, the optical functions change, and the emittance increases from 5.8 nm to 18 nm (Fig. 5). The changes cause a decrease in the dynamic aperture; this is an undesirable change. A non-linear optimization should be conducted to minimize this decrease in the dynamic aperture decrease. If that is not sufficient, we should find an alternative approach to achieve the short-bunch mode [12].

V. CONCLUSION

We investigated the possible upgrades of the PLS-II to meet the demands of users. The canted ID scheme will increase the number of IDs. Insertion of a superbend will increase the usage of bending radiation in the hard X-ray region. The lattice change for the low-alpha mode is difficult because of the lack of degrees of freedom, but methods to achieve short-bunch mode operation will be pursued.

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REFERENCES

[1] S. Shin *et al.*, J. Instrum. **8**, P01019 (2013).
[2] I. Hwang *et al.*, Rev. Sci. Instrum. **85**, 055113 (2014).
[3] Y. Sohn *et al.*, J. Korean Phys. Soc. **73**, 1147 (2018).
[4] J. Lee *et al.*, J. Instrum. **11**, T12003 (2016).
[5] J. Ko *et al.*, AIP Conf. Proc. **1741**, 020020 (2016).
[6] D. Shu and M. Ramanathan, Rev. Sci. Instrum. **73**, 1580 (2002).
[7] G. Le Bec and J. Chavanne, Nucl. Instrum. Methods Phys. Res. A **664**, 214 (2012).
[8] A. Loulergue *et al.*, in *Proceedings of IPAC'10* (Kyoto, Japan, 2010), WEPEA011.
[9] D. Robin *et al.*, Nucl. Instrum. Methods Phys. Res. A **538**, 65 (2005).
[10] D. Robin, E. Forest, C. Pellegrini and A. Amiry, Phys. Rev. E **48**, 2149 (1993).
[11] I. P. S. Martin, G. Rehm, C. Thomas and R. Bartolini, Phys. Rev. ST Accel. Beams **14**, 040705 (2011).
[12] M. Carlà, G. Benedetti, Z. Martí and F. Perez, in *Proceedings of IPAC'14* (Dresden, Germany, 2014), MOPRO089.