UPGRADE OF ACCELERATOR COMPLEX AT POHANG LIGHT SOURCE FACILITY (PLS-II)*

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Abstract

In order to meet the domestic Korean synchrotron user's requirements demanding high beam stability and extended photon energies, PLS-II upgrade program has been launched in January 2009 through a 3-year project plan. PLS-II storage ring is newly designed a modified achromatic version of Double Bend Achromat (DBA) to achieve almost twice as many straight sections as the current PLS (TBA) with a design goal of the natural emittance of 5.8 nm·rad, 3.0 GeV beam energy and 400 mA beam current. In the PLS-II, the top-up injection using full energy linac of 3.0 GeV beam energy will be routinely operated for higher stable photon beam as well and therefore the production of hard x-ray undulator radiation of 8 to13 keV is anticipated to allow for more competitive scientific research activities namely x-ray bio-imaging and protein crystallography.

INTRODUCTION

The Pohang Light Source (PLS) located at Pohang Accelerator Laboratory (PAL) in Pohang University of Science and Technology (POSTECH), in Korea is a dedicated synchrotron radiation user facility. This third-generation VUV to X-ray light source has been in routine operation since 1995, delivers 4,680 hours of beam to 30 beamlines simultaneously and 1,240 hours for machine tuning and beam study per year. Based on the 15 year operation of PLS, the PLS-II upgrade has been officially launched with a project period of three years from 2009 to 2011 to improve all areas of the current experimental program at the PLS, identified as the core science fields for the following decade namely protein crystallography, nanotechnology, medical X-ray imaging, time-resolved science, structural and macromolecular biology [1].

The PLS-II will incorporate achromatic version of Double Bend Achromat (DBA) to achieve almost twice as many straight sections as the current PLS with a design goal of the relatively low emittance of 5.8 nm·rad, incorporating the top-up injection using full energy linac, and increasing the stored electron beam current and beam energy. As described, the main goals of PLS-II are the increase of straight sections for more insertion devices, the energy increase from 2.5 GeV to 3.0 GeV, a stored beam current from 200 mA to 400 mA, a relatively low emittance of 5.8 nm·rad, and more stable beam conditions. During the final year of 2011, the current PLS facility will be shutdown and new components be built, and then the first stage commissioning of 100 mA with 3.0 GeV be finalized. New beamlines and experimental stations will be also relocated with newly established insertion devices, while the existing insertion device beamlines may be preserved. The PLS-II is to open for user experiments in 2012 after the international review for assessment of the PLS-II performance and readiness [2].

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LATTICE DESIGN OF PLS-II

The PLS-II storage ring magnet lattice consists of 12 cells with a center-line ring circumference of 281.82 m. Each cell is composed of a double-bend achromatic structure to occupy more insertion device with a short straight section of 3.69 m long. In each cell there are 2 gradient bends, 8 quadrupoles of three different types of magnetic length, and 8 sextupoles of two different types of magnetic length, respectively. In the nominal setting, the lattice functions for one cell are mirror symmetric, as shown in Fig. 1. The typical machine parameters of the PLS-II are also listed Table 1.

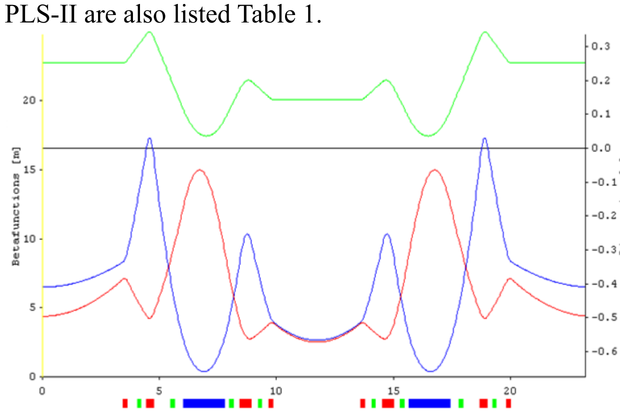

Figure 1: Magnetic lattice and Twiss functions for one cell of the PLS-II

Table 1: PLS-II Typical Machine Parameters

Parameter	Value
Injection	Top-up (full energy injector linac)
SR circumference	281.82 m
Number of cells	12 (DBA)
Beam energy	3.0
Beam current	400 mA
Natural emittance	5.8 nm·rad
Emittance coupling	<1%
Energy spread	0.1%
Tune (h/v)	15.28/9.18
Touschek lifetime	10 hr@400 mA

STORAGE RING COMPONENTS

The PLS-II storage ring upgrade will come as the results of increasing the number of selected insertion device straight sections, increasing the stored electron current and beam energy, operating in a top-up mode and improving degraded components of accelerator system. An important requirement for this upgrade has been derived from the user community, namely the improvement of brilliance by reducing horizontal emittance and maintaining simultaneous storage ring performance in terms of reliability and stability.

The combined function gradient bending magnets is newly designed and fabricated in collaboration with IHEP, Beijing, to meet the lattice structures of the PLS-II. The bending magnets have an effective length of 1.8 m, resulting in a bending radius of 6.87549 m with a central field of 1.4557 Tesla. All magnets are rectangular types with a nominal gradient field of 4.0035 T/m [3]. To significantly reduce the electrical power demand, one might follow other new facilities in choosing a small pole gap of 34 mm compared to that of 56 mm in PLS current magnets. The central field at the magnet arc center has been measured with hall probe and was confirmed with the design value of PLS-II, as shown in Fig. 2.

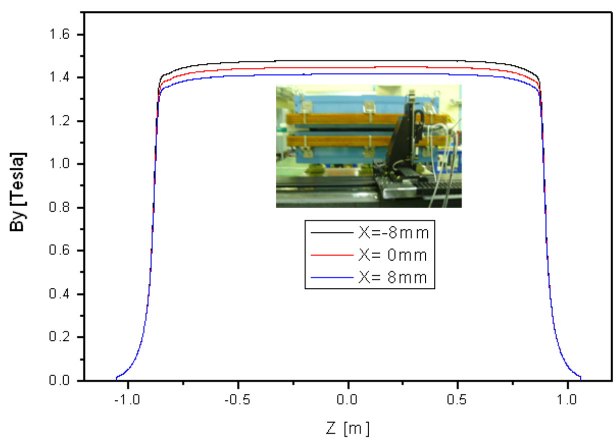

Figure 2: Central field profile of combined function bending magnet for the PLS-II

Based on the DBA lattice solution to reach lower beam emittance, PLS existing quadrupoles and sextupoles can be partly reused up to 3.0 GeV although a set of 24 new 51 cm long quadrupoles is needed to provide additional space for vacuum components. Also, 48 existing sextupoles will be reused, while some 48 new sextupoles should be constructed. The existing bending magnet power supply of 1 kA DC will be well sufficient even at 3.0 GeV. All quadrupoles are expected to be powered in family series from individual power supplies, and independent auxiliary coil power supply is used to allow the adjustment of beam orbit trajectories during the operation. All sextupoles are subdivided into four families each powered by one power supply. In the upgraded storage ring all horizontal and vertical correctors as well as rotated quadrupole fields is incorporated into the sextupole magnets.

Because of these changes in magnets and their positions in the PLS-II storage ring, a new vacuum chamber must be in-house designed and constructed. The replacement of the vacuum chamber, though, allows the significant reduction of the bending magnet aperture and consequent reduction of the electrical excitation power and cost. Since the angle of the dipole section is too large to bend the extruded chamber, the dipole vacuum chambers will be fabricated from machined aluminum of A5083-H321. The dipole chamber is fabricated with lower impedance by reducing the quantity of tapers, flange gaps and pumping slots. The photon absorbers will be located as far from the source as possible to reduce the peak power density. High capacity pumps are also located closed to the photon absorbers. Each vacuum cell has two dipole vacuum chambers, designed to fit the apertures of the adjacent multipole magnets.

The radio frequency (RF) system must be able to sustain an electron beam of up to 400 mA at 3.0 GeV in the presence of many insertion devices (a maximum of 20 IDs) including high field multipole wigglers. In PLS-II new superconducting RF cavities with modern CW power supplies have been selected in order to avoid electron beam coupled bunch instabilities induced from higher-order harmonics during high beam current operation. The energy loss per turn from 24 bending magnets and 20 IDs are 1042 keV and 250 keV, respectively, equivalent to RF power of 517 KW at design beam current of 400 mA. According to beam dynamics design, the energy acceptance ($\Delta E/E$) must be higher than 2.7% to assure high injection efficiency from the full energy linac. A lifetime of more than 10 hours with 400 mA at 3.0 GeV is another requirement from users, because users want very stable radiation all the time. To assure the requirement of beam lifetime, the overvoltage factor is 2.66, which corresponds to RF voltage of 3.3 MV. The CESR-III cryomodules for its proven performance in 500 MHz storage rings has been chosen to the PLS-II. In order to meet the RF voltage and power requirements of the PLS-II, two cryomodules will be installed in one long straight section. During the first commissioning stage of PLS-II, the current normal conducting cavities of a total maximum power of 300 kW using 5 cavities will be used for the low beam current operation of 100 mA.

LINAC AND BEAM TRANSPORT LINE

With existing building structures, the linac upgrade has been conducted with proper linac features such as full energy injector. One set of modulator and klystron in MK12B is newly installed with more tuned energy pulse compressor. The 3 downstream RF stations are separated with one klystron to two-accelerating structures feeding and increasing the klystron power to obtain high accelerating gradient of the structures. So the PLS-II linac will be composed of 16 klystron-modulator modules to obtain a more stable beam in the space and energy of 3.0 GeV. Furthermore, to meet the top-up mode injection there is improvement of beam energy spread and energy stability through the reduction of gun pulse length and energy feedback system adopted. In the beam transport line, the horizontal magnet for the 8.23° bending to meet focal point to the septum has been newly designed and adjusted in the diagnostic instruments.

PHOTON BEAMLINES

The existing PLS beamlines should be relocated with optical device upgrades to accommodate increased power density and stability improvements. All beamline front end components have been also upgraded to provide adequate beam delivery under high heat load condition. The components permitting, existing ID beamlines will be reused with a modification of photon transfer line to follow. The bending magnet beamlines servicing around 20 independent experimental stations will also gain the benefits, coupled with higher current, the increase of critical energy of from 5.46 keV to 8.97 keV and the reduction of source sizes from 133×29 μm^2 and 61×29 μm^2 for PLS and PLS-II, respectively, as depicted in Table 2. The performance of PLS-II ID beamlines will deliver seven to nine times the flux and a hundred times brightness improvement. In order to confine the growth of electron beam emittance due to a finite value of the dispersion function in the straight sections, low field undulators with small gap in-vacuum are mainly installed in the long straight sections. With these IDs, the emittance is actually reduced albeit only barely so. Installation of high field multipole wiggler magnets must be done with a caution. Specifically, to minimize the impact on the beam emittance, the period length should be kept as small as possible. The overall PLS-II ID layout is schematically presented, as shown in Fig. 3.

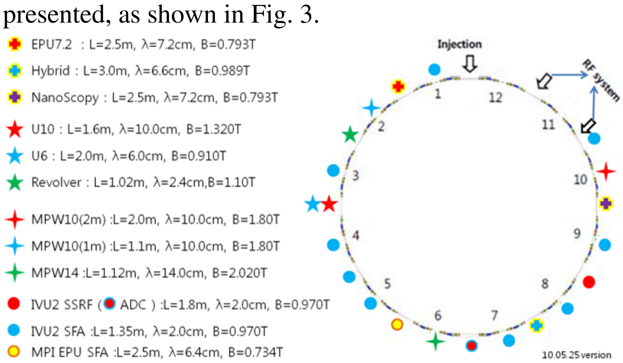

Figure 3: Layout of PLS-II storage ring ID distribution

Table 2: SR Electron Beam Parameters, 1% coupling

Parameter	Value
Dipole section	
Twiss parameters (β_x/ β_x/η_x) (m)	0.38/14.75/0.036
Beam size (σ_x/σ_y) (μm)	61/29
Long straight section	
Number of IDs	10
Length (m)	6.88
Twiss parameters (β_x/ β_x/η_x) (m)	6.5/4.4/0.25
Beam size (σ_x/σ_y) (μm)	332/16
Effective emittance ($\varepsilon_{x,e}$) (nm·rad)	9.5
Short straight section	
Number of IDs	10
Length (m)	3.69
Twiss parameters (β_x/ β_x/η_x) (m)	2.7/2.5/0.15
Beam size (σ_x/σ_y) (μm)	198/12
Effective emittance ($\varepsilon_{x,e}$) (nm·rad)	8.5

ASSEMBLY, INSTALLATION AND COMMISSIONING PLAN

Prior to installation, each component is fully pre-assembled to check the interference and verify the installation sequences, with a separate tunnel evacuation and clearing of infrastructure building floor. In Feb. 2011, the tunnel component installation has been started with shielding modification, water and power cables and alignment monuments. The current PLS-II project is approximately 95% completion of machine fabrication and 30% completion of component installation with a highly coordinated effort. Following 6-month installation by the end of June in 2011, PLS-II commissioning will be performed with three different phases. It will firstly be initiated with current normal conducting cavities and 14 IDs that limited the energy to 3.0 GeV and the current to 100 mA (Phase I), together with the beam clearing of vacuum chamber. After assessment of the PLS-II performance and readiness, the first user operation will be opened in early 2012. And following gradual increase of the beam current to 200 mA, two SC cavities will be installed with a demolition of current NC cavities and then storage ring re-commissioning of 300 mA be made (Phase II) in summer maintenance periods in 2012. Normal user operation will be restarted with more ID installation and a gradual increase of beam current from 300 mA to 400 mA in 2013 (Phase III).

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