ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO068

COMMISSIONING OF THE 2.4 T MULTIPOLE WIGGLER AND THE 6.5 T SUPERCONDUCTING WAVELENGTH SHIFTER AT SIAM PHOTON SOURCE

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Abstract

A 2.4 T hybrid multipole wiggler (MPW) and a 6.5 T superconducting wavelength shifter (SWLS) have been successfully installed and commissioned at Siam Photon Source (SPS). The influences of the two insertion devices on the electron beam dynamics at different operating points have been studied in order to determine the optimal lattice configuration for operation. In this paper, the compensation of the linear optics will be presented, and the commissioning scheme will also be described. In addition, the investigation of the difference between the model and the actual observed machine parameters will be reported in details.

INTRODUCTION

The Siam Photon Source is a 1.2 GeV synchrotron radiation source in Thailand. Due to its relatively low electron energy, the light source has thus far been able to provide the users with synchrotron light limited in the VUV and soft X-ray regions (1.4 keV critical energy from 1.44 T bending magnet). In order to address the user demand for higher energy X-rays, installation of high field magnets to extend the available spectral region and to increase the photon flux was planned. Two insertion devices, namely, a 2.4 T MPW, which is on loan from AsTEC, UK, and a 6.5 T SWLS, which is provided by NSRRC, Taiwan, have been installed in the SPS storage ring to achieve these goals.

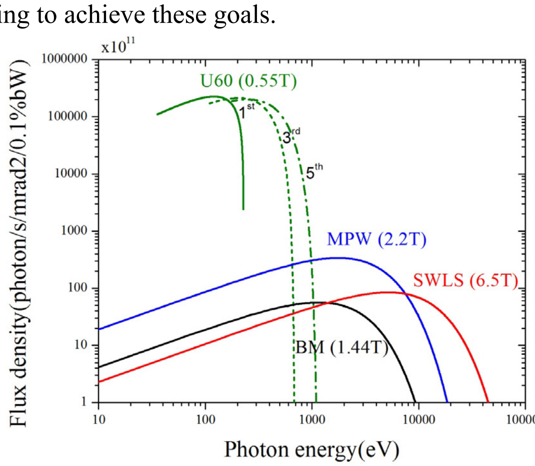

Figure 1: Comparison of the generated spectrum from various sources at SPS. (U60 is the SPS Halbach-type planar undulator already installed.)

The resulting 5-20 keV photons generated by the MPW will be utilized by a hard x-ray beamline comprises of 3 branches. One is for X-ray scattering (SAXS and WAXS) experiments. Another one is for X-ray microtomography, and the third and final branch will be optimized for X-ray absorption spectroscopy (XAS). As for the SWLS, the produced photons will be used by a protein crystallography beamline. Figure 1 shows the SPS spectral flux densities.

MAGNET SPECIFICATIONS AND INSTALLATION

The lattice of the SPS storage ring is a double bend achromatic (DBA) lattice with four superperiods and four 6.8 m straight sections. Three straight sections are currently in use for injection, a RF cavity, and a permanent magnet planar undulator (U60). The remaining straight section was designated for the SWLS. The MPW was to be installed in the injection section close to the septum magnet. Due to the limited space, the magnet cannot be placed at the center of the straight section. Main parameters of the two IDs are listed in Tables 1, 2.

Table 1: MPW Specifications

Peak field	2.4 T
Period length	220 mm
Number of full strength poles	9
End pole field	1.9 T
Number of end poles	2
Minimum magnetic gap	20 mm

Table 2: SWLS Specifications

Number of poles	3
Physical length	0.85 m
Peak field	6.5 T
LHe consumption rate	< 2 L/hr
Beam duct aperture	100 x 20 mm
Beam duct temperature	300 K

Before the magnets were installed, the magnetic field, as well as the first and second field integrals, were measured. For the MPW, shimming had to be performed to correct the sextupole component of the field integral. While the MPW is capable of achieving the maximum field of 2.4 T, we decided to increase the vertical size of the beam chamber to ensure efficient injection and good beam lifetime. This increases the minimum gap of the MPW from 20 mm to 23.5 mm, corresponding to 2.2 T magnetic field. The heat load from the two magnets and the subsequent thermal deformation of the vacuum

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chambers were analyzed [1]. Additional power supplies for matching quadrupoles were installed to correct the optics distortion. Vertical and horizontal corrector magnets were also added upstream and downstream of both IDs for orbit correction.

EFFECTS ON THE STORAGE RING OPTICS

The SPS storage ring can be operated in 3 different modes as shown in Table 3. Originally the ring was designed to operate in zero dispersion mode, with 107 nm-rad beam emittance [2]. The emittance can be reduced to 61 nm-rad and 41 nm-rad by relaxing the restriction placed on the dispersion. We opted to employ the 41 nm-rad low emittance mode for normal operation in order to obtain higher photon flux density. However, the 61 nm-rad distributed dispersion mode provides the smallest vertical betatron function at the straight section center.

In order to determine the optimal operation mode with the 2 IDs, the linear and nonlinear effects including betatron tune shift, beta beating, increased energy loss per turn, change of emittance, change of energy spread, closed orbit distortion, and dynamic aperture reduction were studied for each mode of operation.

Table 3: Comparison of Optics Parameters in Each Mode

Parameters	Zero dispersion mode	Distributed dispersion mode	Low emittance mode
Natural emittance, ε_0 (nm)	107	61	41
Hor. tune, ν_x	4.750	4.768	4.749
Ver. tune, ν_y	2.820	2.813	2.823
Hor. chromaticity, ξ_x	-8.170	-8.475	-9.231
Ver. chromaticity, ξ_y	-6.386	-6.669	-6.515
Betatron at straight center			
Hor. betatron, β_x (m)	13.253	14.538	17.119
Ver. betatron, β_y (m)	3.857	2.979	3.208
Hor. dispersion at straight center η_x (m)	0	0.410	0.807

Linear Effects

Piecewise hard-edge model was constructed to estimate the linear effects [3]. The sinusoidal magnetic field was represented by an array of rectangular dipoles. Each dipole was evenly divided into five smaller pieces. Smaller dipole magnets were added in the model to obtain more precise vertical focusing.

Figures 2 and 3 show that changes in the vertical tune and emittance are different for each operation mode. As expected, the betatron tune shift as well as the beta beating are smallest in the distributed dispersion mode, due to its smallest value of β_y. The horizontal beam emittance is decreased in zero dispersion mode because radiation damping and quantum excitation are minimized when MPW and SWLS are installed in zero dispersion region.

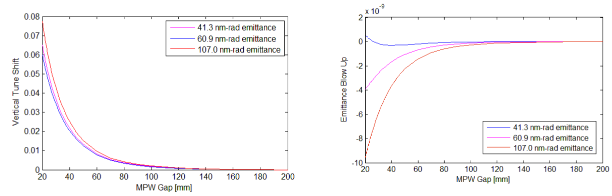

Figure 2: Vertical tune shift (left) and emittance change (right) as a function of MPW gap.

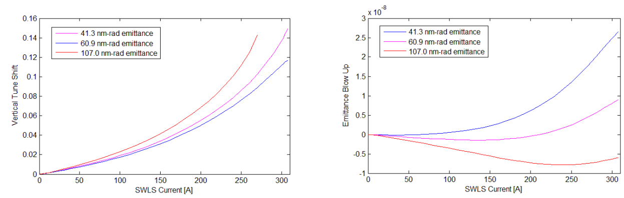

Figure 3: Vertical tune shift (left) and emittance change (right) as a function of SWLS excitation current.

Dynamic Aperture

Natural chromaticities as listed in Table 3 are corrected to +2 with two families of sextupole magnets. The dynamic aperture was calculated using TRACY-III code. In Fig. 4, the left figure shows the comparison of the dynamic aperture without the 2 IDs between each mode. Installation of the 2 IDs in distributed dispersion mode reduces the dynamic aperture by roughly 74%, as shown in the right figure of Fig. 4.

To compromise between the increase in the vertical tune, the reduction of the dynamic aperture, and the change of the beam emittance, the distributed dispersion mode was chosen for the operation with the 2 IDs.

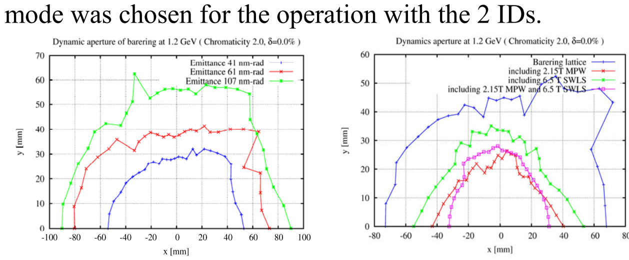

Figure 4: Dynamic aperture without IDs in each operation mode (left), and with the 2 IDs installed in the case of distributed dispersion mode.

COMPENSATION OF LINEAR OPTICS

To minimize the effects introduced by the 2 IDs on the storage ring optics, as described in the previous section, countermeasures were taken as followed. Quadrupole magnets in the matching cell near the MPW and SWLS are used to match the betatron function to the original unperturbed value. The betatron tune was restored to the designed value by two families of quadrupole magnet. Since the MPW was not installed in the middle of the straight section, the matched optics would be asymmetrical, that is, six independent quadrupole magnets are required in the case of the MPW, while only two pairs of quadrupole magnet are sufficient for the SWLS. Figure 5 shows the SPS storage ring optics with

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the 2 IDs before and after compensation. All optics calculations and optical matching were performed using the MAD-X code.

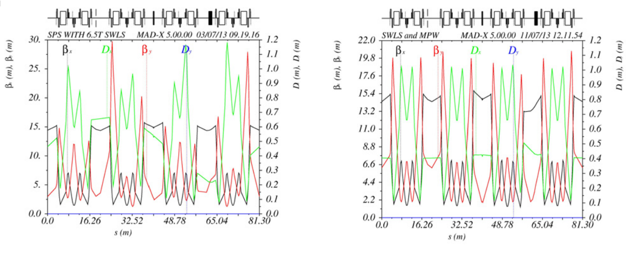

Figure 5: SPS storage ring optics with the MPW and SWLS, before (left) and after (right) correction.

COMMISSIONING RESULTS

Commissioning of the 2 IDs was first performed at 0.98 GeV beam energy. After the magnetic field reaches the peak value, the beam energy is ramped up to 1.2 GeV. This was done successfully without any difficulty for the SWLS, but in the case of the MPW, the injection rate became insufficiently small. This led us to leave the MPW gap opened during beam injection and the subsequent energy ramping, and close the MPW gap after the two processes are completed. The compensation table for both the quadrupoles and the correctors corresponding to the change in the MPW gap were generated. These values are automatically sent to the power supplies by a Programmable Logic Controller (PLC) when the MPW gap is adjusted during operation. (Fig. 6)

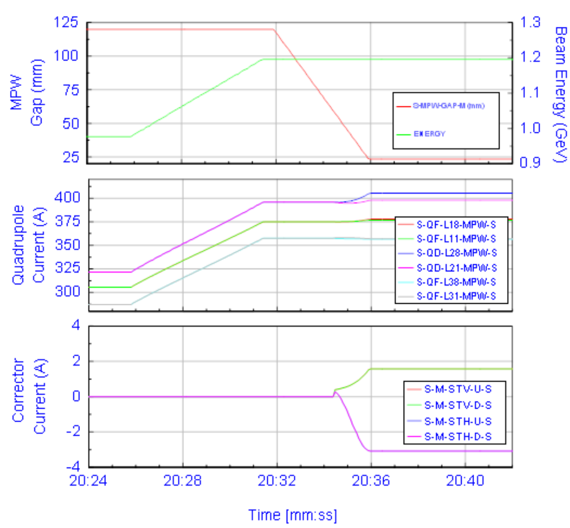

Figure 6: Quadrupole and corrector excitation currents during beam energy ramping and subsequent closing of the MPW gap.

Tune shifts in both directions were measured as the magnetic field is increased step by step (Fig. 7). It was found that the vertical tune shift is in good agreement with the value predicted by the simulation. However, considerable horizontal tune shift is also found. This is most likely due to the imperfection in the alignment. The measured parameters such as the tunes, beam sizes, and beam lifetime with the 2 IDs after correction are listed in Table 4. Values for the bare ring are also included for comparison.

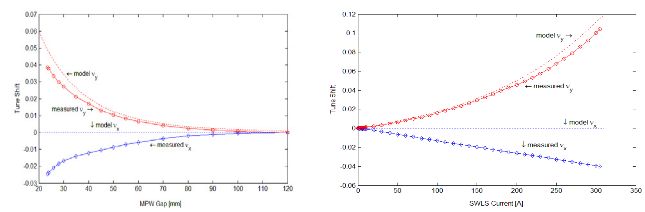

Figure 7: Tune shifts as a function of MPW gap (left) and SWLS excitation current (right).

Table 4: Measured Parameters of the SPS Storage Ring with MPW and SWLS After Correction

Measured parameters	Bare ring	With 2.2 T MPW	With 6.5 T SWLS
Vertical tune	2.817	2.830	2.847
Horizontal tune	4.760	4.738	4.761
Vertical beam size (mm)	0.188	0.258	0.191
Horizontal beam size (mm)	0.593	0.522	0.617
Current-lifetime product (mA.min)	78,000	72,000	56,000

CONCLUSION

The installation and commissioning of the MPW and SWLS in the SPS storage ring were successfully carried out. The optimal lattice was determined by opting for the lowest betatron function at the center of the straight section. The difference between the model prediction and the actual measurement was investigated. It was found that the measured vertical tune shift at peak field is higher than the calculated values for both IDs. After correction, the vertical betatron tune was corrected to the original design value with an error of 0.5% and 1.0% for the MPW and the SWLS, respectively.

ACKNOWLEDGMENT

The authors would like to thank Prof. Jim Clarke of ASTeC for his support on the MPW, and C.S. Hwang of NSRRC for his assistance on the SWLS. The authors would also like to express their gratitude to H.P. Chang of NSRRC for invaluable suggestions for this commissioning.

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