OPERATIONAL EXPERIENCE OF THE INSERTION DEVICES AND EXPECTATION OF THE FUTURE SUPERCONDUCTING WIGGLERS AT NSRRC

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Abstract

Since 1995, we have continuously installed five insertion devices (IDs) in the 1.5 GeV storage ring TLS at NSRRC. They include three undulators (U5, U9 and EPU5.6), one 1.8 Tesla wiggler (W20) and one 6 Tesla superconducting wavelength shifter (SWLS). All these five IDs are located in the long straight sections. The real time orbit correction and betatron tune compensation routine have been successfully operated. With these IDs, the machine emittance reduces substantially. We plan to install four more superconducting multi-pole wigglers (SMPWs), one in the long straight and three in the archromat sections. These devices therefore can offer more beam time for the hard X-ray community. The impacts of these IDs on the beam dynamics effects are reported in this paper.

INTRODUCTION

The TLS has six long straight sections, each 6 meters long for the installation of insertion devices, injection elements and RF cavities. Each of IDs, W20, U5, U9 and EPU5.6 occupies one long straight. With the limited space, we squeeze SWLS in the injection section and also plan to install one SMPW besides the RF cavities in this year. Three SMPWs will be put near second bending magnet of the triple bend achromat section [1]. SWLS and SMPWs will serve more X-ray beam time for the increasing X-ray community. Table 1 describes the insertion devices in the TLS storage ring. Figure 1 shows the photon flux vs. the photon energy of bending magnets and IDs at TLS. Two Taiwan beamlines, SP8-BM and SP8-U3.2, at Spring 8 are also depicted.

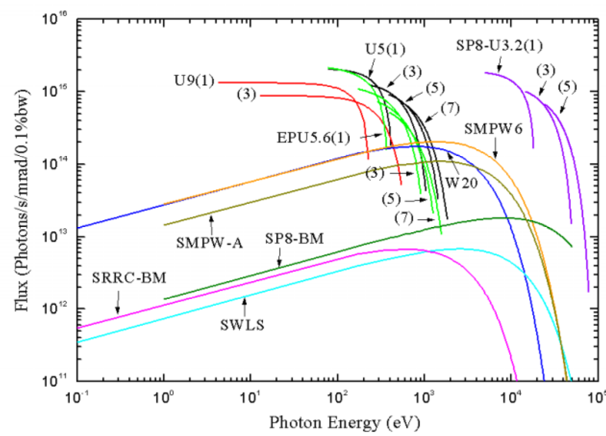

Figure 1: The photon flux vs. photon energy of bending magnets and IDs at TLS. Two Taiwan beamlines, SP8-BM and SP8-U3.2, at Spring 8 are also depicted.

Table 1: Insertion Devices in the TLS storage ring of NSRRC.

Insertion Device		SWLS	EPU5.6	U5	SMPW6	W20	U9	SMPW-A
Location Section		S1/Injection	S2	S3	S4/RF	S5	S6	Arc 2,4,6
Type		Supercon.	Pure	Hybrid	Supercon.	Hybrid	Hybrid	Supercon.
Magnet Length (M)		0.835	3.9	3.9	1.404	3.0	4.5	0.85
Period Length λ (cm)		25	5.6	5	6	20	9	6
(Min.) Gap (mm)		55	18	18	18	22	18	18.5
Number of Periods		1.5	66	76	16	13	48	7.5
Maximum By (Bx) Field (Tesla)		6	0.67 (0.45)	0.64	3.2	1.8	1.25	3.5
Photon Energy (eV) [Used Range]	**Min.**	4000	80	60	5000	800	5	5000
	Max.	38000	1400	1500	14000	15000	100	14000
Defection Parameter Ky (Kx)		190.5	3.52(2.37)	2.99	17.9	33	10.46	19.6
Vertical Tune Shift $\Delta\nu$ (Horizontal Tune Shift)		0.0504 (-0.014)	0.011 (-0.012)	0.008	0.036	0.036	0.033	0.05
Installation Date		Apr.2002	Sep.1999	Mar.1997	Dec.2003	Dec.1994	Apr.1999	2005

INJECTION AND ORBIT STABILITY

With the insertion devices in the beam line, we need to study the beam dynamics effects, such as the lattice optics perturbations, the emittance change, the impact on the dynamic aperture, the orbit stability, lifetime, size reduction of the beam duck and increase of the vacuum reading, etc. It is also important to know if the injection can be seriously jeopardized with any setting of the ID's gap and phase at this 1.5 GeV low energy storage ring.

More cares should be taken in the construction of these IDs and it is necessary to meet the specifications to ensure the minimum impact on the beam dynamics.

It is concluded that for W20 wiggler and SWLS the magnetic field strength are almost set at its maximum operational values even during injection. Therefore it is less complicated to operate such devices in terms of the field scan. However, during the commissioning period, the orbit drift, tune shift and path-length while field is ramped should be carefully compensated for and a correction table thus was established.

Undulator, U5 and U9, EPU5.6, are allowed to be capable of field scan during users shifts. To this end, in addition to a fast global orbit feedback system, we need to apply look-up tables to reduce the orbit fluctuation and tune shift when the gap or phase of these IDs are changed.

Emittance and Dynamic Aperture

The integration of the six IDs in the dispersion-free long straight sections will bring the natural emittance from 25.6 nm-rad of the bare lattice to 21.0 nm-rad. Adding three more superconducting multipole wigglers in the achromats, however, will increase the emittance to 32.0 nm-rad due to large dispersion in these SMPWs locations. The synchrotron loss is increased from 128 keV/turn of the bare lattice without insertion devices to 202 keV/turn with all 9 IDs. The required RF power at 400 mA stored beam should be enough after installing a superconducting RF cavity in the near future. Initial stored current of present routine operation is 200 mA.

Simulation of the dynamic aperture with these IDs has been carried out and including all field errors in all magnets (measured or specified), we obtain an acceptable reduction of the dynamic aperture from PATPET as shown in Fig. 2. Similar results are also from other codes such as MAD.

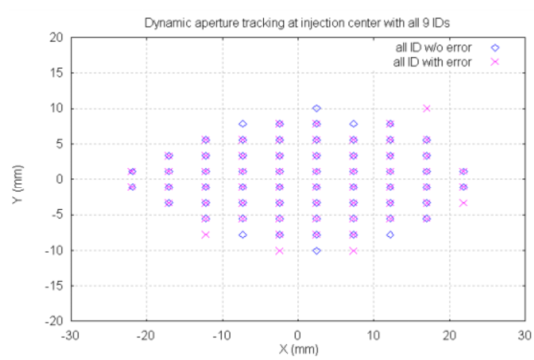

Figure 2: Dynamic aperture simulated from PATPET with field errors and all insertion devices.

Gap and Tune Scan

The EPU5.6 is an elliptical polarization ID and is more complicated than the other IDs, U5 and U9. For U5, U9, and EPU5.6, linear effects such as tune shift and orbit change by the non-zero first- and second- integral field strengths are studied in detail in references [2,3].

Horizontal closed orbit distortion (COD) of those IDs at TLS is about 0.2 to 0.3 mm without correction. It shows the main vertical field errors are almost in the same level. The orbit distortion in vertical plan of an ID may indicate the ID's horizontal field error and the vertical beta-function variation caused by the ID. The observed peak values are 0.2 mm for U5, 0.3 mm for U9, and 1.5 mm for EPU5.6.

In establishing a follow-gap look-up table for orbit correction of each ID, we found that the rms closed orbit distortion can be reduced within a few microns if only one ID gap varies at one time.

The corrector strengths beside the EPU5.6 in the look-up table are both functions of the gap and phase. However it was found that the orbit distortion by varying the phase of EPU5.6 is so small that the phase parameter has been ignored.

The peak of real-time orbit distortion is large than 10 microns when this look-up table method was applied for ID's field scan. In addition, with the help of a fast digital orbit feedback system, the peak of orbit variation thus can be maintained within a few microns (see Fig. 3).

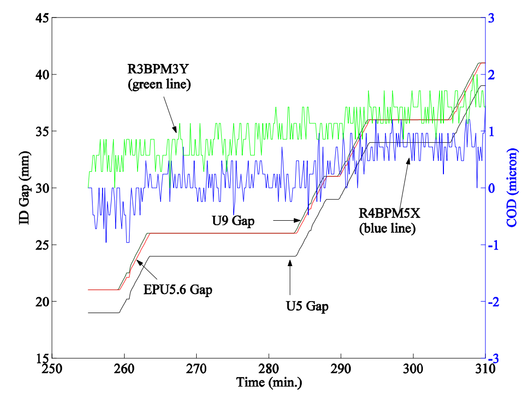

Figure 3: With the follow-gap look-up table and global orbit feedback system, the orbit drift of the field scan of U5, U9 and EPU5.6 can be reduced from a few hundred microns to a few microns. When the gaps of U5, U9 and EPU5.6 are scanned from 19, 21, and 21 mm to 39, 41, and 41 mm, the closed orbit distortions indicated by the R4BPM5X (blue) and R3BPM3Y (green), those are used in the faster orbit feedback system, are within 2 microns in both horizontal and vertical planes.

As shown in Table 1, with the EPU5.6's gap fixed at 20 mm, the observed horizontal tune shift is –0.012 when its phase is tuned from 0 to 180 degree (the encoder is from 0 to 28 mm). There is no horizontal tune shift effect for U5 and U9. The range of total vertical tune shift of these tuneable undulators is about 0.052, which may cross some resonance lines if no tune compensation is followed when ID's gaps are changed. We found the tune shift crossing some of the 5^{th} order resonance lines caused the photon beam instability. The photocurrent drops, when the tune crosses $5V_y = 21$ and $V_x+4V_y = 24$ resonance lines.

We added a follow-gap tune compensation mechanism in the look-up correction table of U9 to avoid the resonance problem. The tune compensation mechanism may use two Q1 and Q2 families or two Q1 and Q2 pairs beside the U9. The Q1 and Q2 families are finally adopted since the optics perturbation is less than the local quadrupole pairs.

Commissioning of the 6 Tesla SWLS

In April 2002, a 6 Tesla, 3-pole cryogenic-free SWLS was installed between two injection kickers in the injection straight section [4,5]. In May, we started charging the SWLS and tests with beam. First stored beam with SWLS at 6 Tesla was observed on May 21. Injection with SWLS fully charged was of no any difficulty. Compensation of the orbit excursion and tune shift while increasing the magnetic field was conducted and as a result there are no major impacts on the beam dynamics effects. It is found that the measured tune shifts, path-length compensation (RF increase by 1.7 kHz at 6 Tesla), etc., are in consistent with the model predicted values (see Fig. 4). Vacuum cleaning with synchrotron light is needed to obtain an acceptable lifetime and beam stability. In August 2002, we found there was a crack in the ceramic chamber of the downstream kicker magnet because of the insufficient shielding against the powerful synchrotron radiation from the high field SWLS. The shielding was reinforced and replaced in October. In reality, the routine operations of SWLS are now at 5.3 Tesla such that the system is cryogenic-free. This field strength is acceptable for the hard X-ray users. As of April 2003, the beam current lifetime at 200 mA of the stable beam is about 8 hours. The commissioning of the associated photon beam line is currently underway.

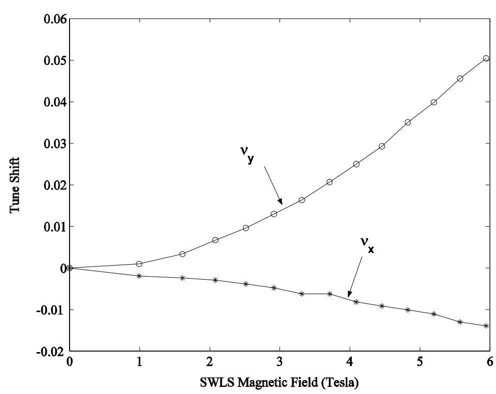

Figure 4: The measured tune shifts of SWLS.

Top-up Injection Mode

Top-up injection scheme is an attractive operation mode demonstrated by the APS and SLS, and NSRRC plans to adopt this operation mode in the near future. Major benefits with top-up mode are less thermal gradient in the accelerator components and photon beam line mirrors, more reduction of the insertion magnetic gap, and allowing smaller emittance lattice operations, etc. Lifetime issue will be of less concern after all. We have proved that the top-up injection is executable with the field scans of insertion devices while keeping the orbit locked with the orbit feedback system (see Figure 5). Major concern of the top-up mode is the injection loss budget, i.e., the control of the radiation dosage level with the heavy-metal shutter opened in the photon beam lines. Studies of the injector reliability and injection efficiency are ongoing.

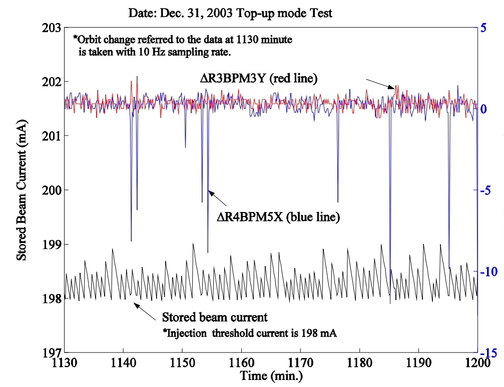

Figure 5: Top-up mode test with SWLS.

A photon beam stability indicator in one of the diagnosis beam line LSGM branch is used to study the beam stability during gap and phase scans. ΔI/I is a number of photocurrent change ratio of a wire in 256 seconds [6]. Beam current decay ratio is subtracted off. Cases with and without turning on SWLS are shown in Table 2.

Table 2: Beam quality of the lattice with and w/o SWLS for top-up mode operation.

ID Gap (Unit: mm)		**ΔI/I % (LSGM)**	
Status	**U5/U9/EPU5.6**	**w/o SWLS**	**SWLS**
Fixed Gaps	20/20/20	0.064	0.071
U5 Scan	(20 − 40)/20/20	0.075	0.076
U9 Scan	20/(20 − 40)/20	0.162	0.165
EPU5.6 Scan	20/20/(20 − 40)	0.653	2.207

CONCLUSION

Five insertion devices have been successfully installed in the 1.5 GeV storage ring TLS at NSRRC and provide versatile light sources for the users. Routine operations with top-up injection mode, in which ID field can be scanned during injection, have been successfully tested. The beam orbit is kept within micron level and photon beam stability is excellent during ID field scan. Four superconducting multipole wigglers are planned to put into the TLS and the beam dynamics effects are studied.

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