THE COMMISSIONING OF PHASE-I INSERTION DEVICES IN TPS

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Abstract

The Taiwan Photon Source (TPS) is a low-emittance 3-GeV light source at Natioal Synchrotron Radiation Research Center, next to the Taiwan Light source (1.5 GeV). On March 26, 2015, the TPS storage ring with two 5-cell PETRA cavities has successfully operated in 100 mA in top-up mode without the installation of insertion devices (IDs). To reach the design goal of 500 mA, the machine was shut down for 5 months to replace PETRA cavitites with superconducting RF (SRF) cavities and to install 10 IDs: 7 in-vacuum undulators (IU) and 3 elliptically polarized undulators (EPU). The commissioning of TPS storage ring with SRF cavities and IDs began in Sep. 2015. In this paper, we present our results and proceedures of ID commissioning.

INTRODUCTION

TPS [1] commissioning is divided into two stages. The stage-I commissioning [2] without the installation of insertion devices (IDs) was finished by the end of March, 2015. The storage ring has successfully stored up to 100 mA in top-up mode. The phse-I IDs [3] commissioning is scheduled in the stage II. In the long shutdown period of 5 months after the stage-I commissioning, we replace PETRA cavities of stoage ring with SRF cavities, install phase-I IDs, 9 quadrupoles, 6 correctors, 6 BPMs , 3 phase shifters for double mini-βy lattice [4], and 96 fast correctors (48 located at the upstreams of 48 bending magnets, another 48 located at both ends of 24 straight sections respectively) for fast orbit correction. The dummy chambers located at 3 EPUs are also replaced with racetrack EPU chambers (+/- 34 mm (X), +/- 4 mm (Y), design value). Machine was restarted in Sep. 2015 to launch stage-II comissioning.

TPS storage ring has 24 DBA cells, 18 short straight sections (7m) and 6 long straight sections (12m). Three long straight sections are symmetrically configured as double mini-βy lattice in which three sets of quadrupole triplet are installed in the centers of three long straight sections respectively to accommodate double undulators. The phase-I IDs, 7 in-vacuum undulators (IU) and 3 elliptically polarized undulators (EPU), are installed in the TPS storage ringe to deliver 7 beamlines in which three beamlines are designed for double undulators. The main parameters of phase-I IDs are listed in Table 1. Figure 1 shows the locations of 2 SRFs ,10 IDs and 7 beamlines. The beamline port number 9, 25, 41 are for double undulators.

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The main tasks of ID commissioning are to construct COD feed-forward table, tune feed-forward table, and coupling feed-forward table. The results and procedures are described in the following sections. We use bare lattice in stage-I commissioning to check the machine status. After few weeks, we succeeded in recovering the machine status before long shutdown [5].

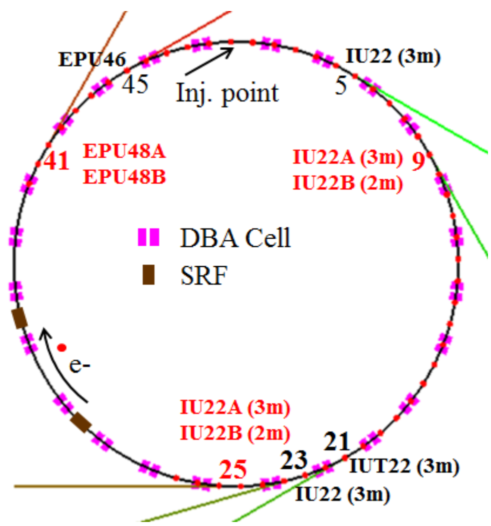

Figure 1: TPS storage ring and 7 beamlines.

Table 1: TPS Phase-I ID Parameters

	IU22	IU22	EPU46	EPU48
Photon Energy	1.25-20	1.25-20	0.28-2.0 0.42-2.0	0.22-2.0 0.34-2.0
λu [mm]	22	22	46	48
Nperiod	95	140	82	67
By [T]	0.74	0.76	0.78	0.83
Bx [T]			0.52	0.55
K_{ymax}	1.52	1.56	3.35	3.72
K_{xmax}			2.23	2.47
L [m]	2.58	3.57	3.89	3.436
Gap [mm]	7	7	14	13

DOUBLE MINI-βY LATTICE COMMISSIONING

In October, 2015, the storage ring lattice was switched to double mini-βy lattice from bare lattice. All IDs' gaps are open. By adjusting the injection septums, kickers and the downstream correctors of BTS transfer line, the electron beam was quickly stored. The closed orbit distortion (COD) is large. Firstly, we used orbit correction application program of MATLAB middle layer (MML) to reduce COD and then apply BBA to measure the offsets of 172 BPMs [6] with rspect to the field center of nearest quadrupoles, the COD are further reduced to within +/- 0.2 mm (X) and +/- 0.1 mm (Y) respectively [5]. Next, LOCO are applied to correct the lattice function by 249 quadrupoles with independent power supplys. After three times of LOCO, the beta-beating were further reduced to 1.2% from 12.9% in horizontal direction, and 0.5% from 7.3% in vertical direction [5].

ID COMMISSIONING

After COD and optics function of double mini-βy lattice of storage ring were corrected and calibrated, ID commissioning was launched in 12, October. Due to the residue field integral of ID imperfect feature from manufacturing, the ID gap/phase moving will result in closed orbit distortion, optics ditortion, tune shift, and the betatron coupling for EPU only. Hence, the major tasks of ID commissioning are to construct COD feed-forward table for each ID, tune feed-forward table for EPU, and coupling feed-forward table for EPU to compensate the adverse effects [7-8].

In the beginning, we need to check the ID alignment. Hence, we close the ID gap slowly at beam current of 0.1 mA. In the meanwhile a YAG screen monitor in the frontend is used to check whether the synchrotron radiation from the ID and its upstream and downstream bending magnets are the same height and coplanar or not. Figure 2 shows the synchrotron radiation from IU22 (port 5) and upstram and downstream bending magnets.

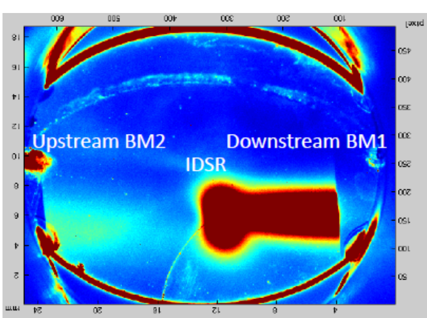

Figure 2 : Synchrotron radiation image from IU22 (port 5) and bending magnets.

COD FEED-FORWARD TABLE

Each ID is equipped with 4 correctors (2 horizontal and 2 vertical respectively) located at both ends of ID. We use these 4 correctors to kick electron beam and 172 BPMs to measure the orbit response matrix at some specified gap/phase.The MML command "measbpmresp" is employed to conduct response matrix measurement. SVD is applied to decompose the orbit response matrix and calculate the desired corrector current to compensate the COD at some specified gap/phase. After the COD feed-forward tables of phase-I IDs are all finished, they are transformed to a waveform associated with 5 EPICS process variables (PVs) (gap and 4 correctors) for each IU and 6 PVs (gap, phase, and 4 correctors) for each EPU. The cPCI EPICS IOC of ID can update the corrector current at a rate of 200 Hz with interpolation [9] according to the COD feed-forward table.

The COD feed-forward table was measured at beam curent of 30 mA, and the reference orbit was taken at gap of 40 mm and 45 mm for 7 IU and 3 EPU respectively. The performance of ID feed-forward table is summarized in Table 2. BC : before correction. AC : after correction. Cor. : corrector. Ref.: reference or open.

Table 2 : Performance of ID COD Feed-Forward Table

	Gap [mm]		COD(X/Y) [μm]		Cor. [A]
	Ref.	Min	BC	AC	Max
IU22-05	40	5.6	39/6	0.5/0.1	0.33
IUT22-21	40	5.5	10/4	0.4/0.3	0.2
IU22-23	40	5.5	41/15	0.4/0.2	0.43
IU22A-09	40	5.5	75/6	0.5/1.5	0.6
IU22B-09	40	7	16/5	0.3/0.2	0.15
IU22A-25	40	5.5	41/7	0.5/0.4	0.27
IU22B-25	40	7	18/5	0.3/0.2	0.13
EPU48A-41	45	13	70/24	6.0/1.5	0.7
EPU48B-41	45	13	137/29	4.5/1.3	1.6
EPU46-45	45	14	65/72	3.0/1.0	1.5

TUNE FEED-FORWARD TABLE

The tune shift of each EPU is compensated by its nearest 4 or 6 quadrupole magnets. Firstly, we recorded the tune shift at some specified gap/phase as a table shown in Fig. 3-4 while COD feed-forward table enable. Secondly, we changed the current of these 4 or 6 quadrupole magnets to measure tune response. The MML command "meastuneresp" is employed to measure the tune response matrix. SVD is applied to calculate the desired current to compensate tune shift. Combined tune response and tune shift table, tune feed-forward table is established.

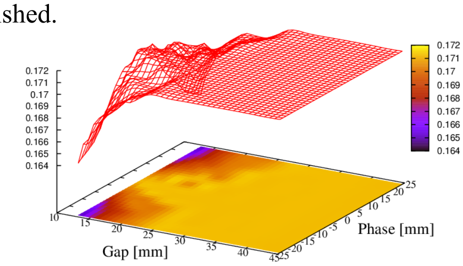

Figure 3: Horizontal tune shift table of EPU48A.

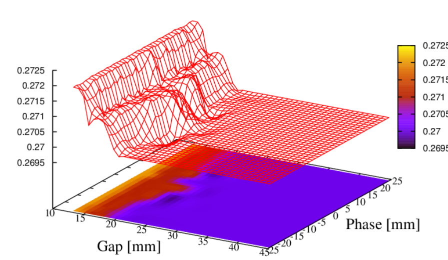

Figure 4: Vertical tune shift table of EPU48A.

Tune compensation is executed by a MATLAB endless while loop in which bi-linear interpolation is invoked to calculate the desired quadrupole currents according to the tune feed-forward table.

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COUPLING FEED-FORWARD TABLE

Each EPU is equipped with a pair of long coil hanged on both sides of EPU magnet array along the electron beam direction to correct the betatron coupling. The betatron coupling correction of EPU is conducted when COD feed-forward table enable. Procedures for coupling correction are described as following.

1. Choose an EPU and enable its COD feed-forwared table.
2. Record the vertical reference orbit as Y0 at reference gap.
3. Change gap/phase.
4. Disable COD feed-forward table when gap/phase ready .
5. Record vertical orbit as Y1 when long coil is off.
6. Record vertical orbit as Y2 when long coil is fed with current of 5A.
7. Calculate the orbit response of coupling for long coil : R=(Y2-Y1)/5.
8. Calculate the long coil current I = (Y1-Y0)/R.
9. Enable COD feed-forward table.
10. Repeat step 3~10 till minimum gap is reached.

The long coil current of EPU48A at each gap and phase for coupling correction is shown in Fig. 5.

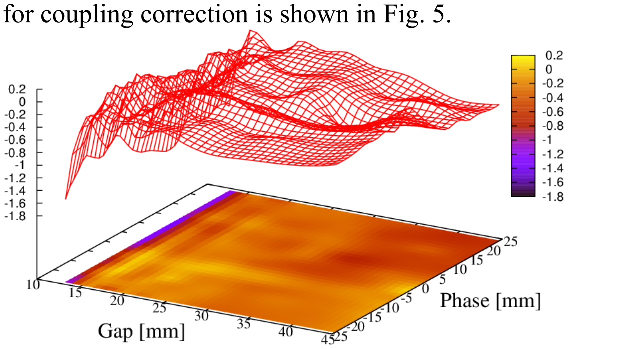

Figure 5: Long coil current of EPU48A for coupling correction.

ORBIT INTERLOCK

The TPS is designed for 500 mA. The synchrotron radiation (SR) from mis-steered electron beam at such high beam cuerrent will damage machine components, such as vacuum chamber, the Cu-Ni foil covered on the surface of magnet block of in-vacuum undulator and so on. To protect machine element from damage, an orbit interlock system is a must [10-11]. The orbit interlock of the TPS is monitored by 34 BPMs. 20 are loacted at the upstream and downstream of each ID. Another 14 are located at both sides of 7 bending magnets in the upstream of the 7 beamlines. If the vertical orbit at the center of ID is deviated from the condition in Fig. 6, the electron beam is tripped.

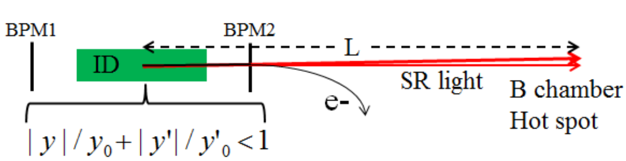

Figure 6: Orbit interlock condition.

We used SPECTRA and other codes to calculate the size of radiation spot at B1 chamber. Combined the distance L between source point and hot spot, plus a safety factor, we derived the orbit interlock conditions in Table3. The unit of y0 and y0' are mm and mrad respectively.

Table 3: Orbit Interlock Table.

	IU22	IU22A	IU22B	EPU48A	EPU48B
Port	5	9		41	
L [m]	7.239	13.360	6.610	13.360	6.610
y	1.573	0.620	1.671	2.382	0.186
y0'	0.169	0.036	0.197	0.139	0.022
	IU22	IU22A	IU22B	IUT22	EPU46
Port	23	25		21	45
L [m]	7.239	13.360	6.610	7.239	7.239
y0	1.573	0.620	1.671	1.573	0.203
y0'	0.169	0.036	0.197	0.169	0.022

SUMMARY

The major tasks of ID commissioning are to build COD feed-forward table, tune feed-forward table, and coupling feed-forward table. With these tables and control cystems, the light source performance can be well-controled.

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