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HARDWARE IMPROVEMENTS AND BEAM COMMISSIONING OF THE BOOSTER RING IN TAIWAN PHOTON SOURCE

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Abstract

Taiwan Photon Source (TPS), a low emittance 3-GeV third-generation synchrotron light source, began its hardware integration testing, safety checkout and beam commissioning on August 12, 2014 [1]. The booster ring and the storage ring share the same tunnel in a concentric fashion; the booster ring has circumference 496.8 m, the largest among light source facilities in operation. A combined-function FODO lattice is adopted for the booster ring with natural emittance 10 nm-rad. After hardware improvements were completed, the commissioning of the beam in the booster ring began on December 12 and attained the 3-GeV design energy on December 16.

INTRODUCTION

Because of constraints at the site, the TPS booster ring shares the same tunnel with the storage ring [2]. The circumference of the booster ring is 498.6 m, the largest booster ring of light source facilities in operation. To reduce the number of magnets, dipole magnets combined quadrupole and sextupole components were adopted, as in SLS and ALBA [3, 4]. The sizes of magnets and vacuum chambers are optimized to save space, construction cost and power consumption. The major parameters of the TPS booster are listed in Table 1. The imperfection issues in hardware integration and commissioning results are reported in this article.

Table 1: Major Parameters of the TPS Booster Ring

Booster parameters	
Circumference	496.8 m
Length of straight section	6.02 m
Harmonic number	828
RF frequency	499.654 MHz
Bending radius, ρ	12.223 m
Betatron tune , ν_x/ν_y	14.380/9.302
Natural chromaticity, $\xi_x/\ \xi_y$	-16.82/-13.24
Momentum compaction	0.0024735
Damping partition, $J_x/J_y/J_e$	1.81/1.00/1.19
Energy spread at 3 GeV	0.095174 %
Natural emittance at 3 GeV	10.32 nm rad
Damping time, $\tau_x/\tau_y/\tau_e$, at 3 GeV	9.4/16.9/14.2 ms
Damping time, $\tau_x/\tau_y/\tau_e$, at 150 MeV	75/136/115 s
Energy loss per turn at 3 GeV	586 keV
Rate of ramping repetition	3 Hz

HARDWARE IMPROVEMENTS

Most installation work in the booster ring was completed by the end of July, 2014. The 150-MeV beam from the Linac to the entrance of the booster ring was available in mid-August; field acceptance tests and tuning of power supplies for the booster magnets were concurrently conducted with beam commissioning due to very tight installation schedule. Beam-based testing of the hardware and improvement of the booster subsystem were in progress. Several hardware glitches were discovered; the solutions were implemented swiftly, for example, the repair of a burned power supply of a booster dipole magnet due to overheating in a protection circuit board while conducting a test with full power rating at high power, the reduction of flat-top field variation of injection kicker from ±2% to ±0.4% and the residual field of post-pulse from +5% to ±0.4% for injection kicker with ferrite load, etc.

At the beginning of September, having the first turn in the booster ring was easily obtained by beam steering; after optimization of transfer efficiency and minimized of the charge loss in the Linac and transfer line, a multi-turn circulating beam was observed; the beam survived up to 35 ms in mid September, but it did not show up capturing and beam storage. We tried to correct the distortions of the beam orbit within 4 mm and to scan the RF frequency, phase and gap voltage but without beam capture phenomena. At the same time, we found that the corrector strengths were about three times the simulated values including the misalignment and tolerance of magnet-field. The vacuum pipe, made of stainless steel (SUS304), has a small elliptic cross section, 35 mm x 20 mm, and thickness 0.7 mm in booster. At the initial stage of beam commissioning, dimension distortions and misalignments of the pipes were critical. More care was taken to realign the chambers' and the magnets' positions. The key setback that stalled the progress of testing the booster hardware was found on November 12. The pipes had a high relatively permeability (ranging from 1.2 to 2.0), which induced from cold-drawn during manufacture [5] without proper annealing process. These unqualified chambers were taken apart and treated in vacuum oven up to 1050 °C, and then re-installed within three weeks. The relative permeability of the pipes, after that treatment, was reduced to be within 1.01 [6].

Several issues were encountered that jeopardized the stability and injection efficiency of the beam; three major problems were encountered, which the booster launching condition deviated 2 mm from optimum because of a leakage field of the DC extraction septum in the horizontal plane, which a random injection kicker strength decreased about -2 % due to misfiring induced on

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excitation of the extraction kicker, and which the reproduction of ramping power-supplies stability was deficient, ±0.5 % at 150 MeV at the beginning but reduced to ±0.2 % with extra effort [7]. All these issues were eventually fixed and improved. So far, the current of the booster beam was 0.23 mA per shot; with DC correctors, the overall efficiency of transmission was about 61 % for extraction at 3 GeV.

COMMISSIONING

After demagnetization of the pipes, the beam survived 50 ms after beam steering on December 11; on December 12, we had a stored beam after the RF system was activated. The beam optics, tunes, chromaticity, tunes and orbit response matrix were measured and corrected in the DC mode during December 12-15. Tests of the energy ramping in the AC mode began on December 15; applied tunes control scheme during ramping, a 3- GeV beam was attained on December 16.

DC Mode (150 MeV)

Figure 1 illustrates the first-turn orbit and corrector strength. The rms values of first-turn orbit are 0.62 and 0.59 mm and strength of correctors are 0.22 and 0.51 mrad in the horizontal and vertical planes, respectively. The 150-MeV Linac was retested with the beam after relocation in August. The measured properties of Linac and the LTB are listed in [8].

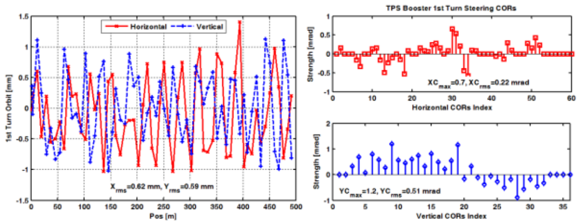


Figure 1: 1^{st} turn steering orbit and corrector strength.

Figure 2 shows the closed-orbit-distortion (COD) corrections of the 150-MeV stored beam. The COD were decreased from 1.3 mm rms to 0.84 mm rms in the horizontal plane and from 0.047 mm rms to 0.031 mm rms in the vertical plane with slight corrector strengths. The integer parts of tunes were identified from the DC orbit response; the fractional parts were measured as shown in Fig. 3. The measured tunes were ν_x=14.381 and ν_y=9.268, agreeing satisfactorily with model values ν_x=14.380 and ν_y= 9.302.

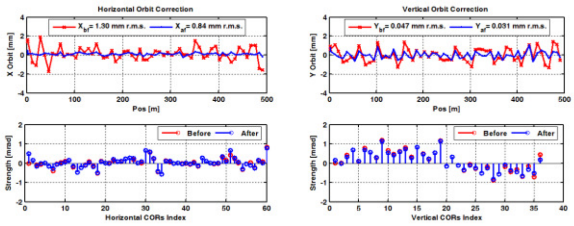
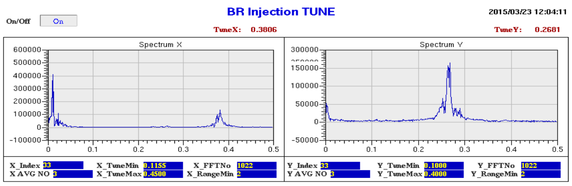


Figure 2: COD orbit correction, red: before, blue: after (left) and corrector strength (right) in both planes.



X_Index 33
X AVG NO 3
X_TuneMin 0.1155
X_TuneMax 0.4500
X_FFTNo 1022
X_RangeMin 2
Y_Index 33
Y AVG NO 3
Y_TuneMin 0.1000
Y_TuneMax 0.4000
Y_FFTNo 1022
Y_RangeMin 2

Figure 3: Fractional part of tune from turn-by-turn BPM data.

The measured optical functions using turn-by-turn BPM data with the ICA (AMUSE) [9] algorithm agreed satisfactorily with bare-lattice model. Figure 4 and 5 show the measured and model optical functions in both planes. Figure 6 depicts the chromaticity measurement. Two families of independent sextupole magnets were powered as defocusing sextupole magnets that might be due to insufficient strength of sextupole components within combined-function dipole magnets. Setting S_1 = -8 m^{-3} and S_2= -4 m^{-3}, we obtained the measured chromaticities 1.21 and 2.06, which closed to the model values 0.93 and 2.06 in the horizontal and vertical planes, respectively.

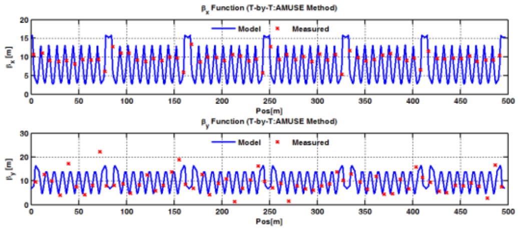


Figure 4: Betatron functions measured (red x) using turn-by-turn BPM data with the ICA algorithm and the bare model (blue line) in both planes.

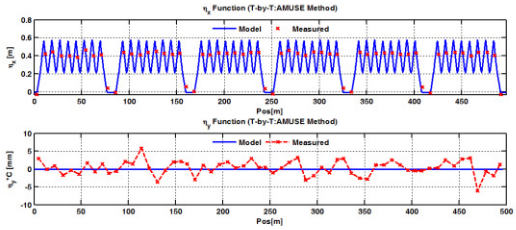


Figure 5: Dispersion functions measured (red x) using turn-by-turn BPM data with the ICA algorithm and the bare model (blue line) in both planes.

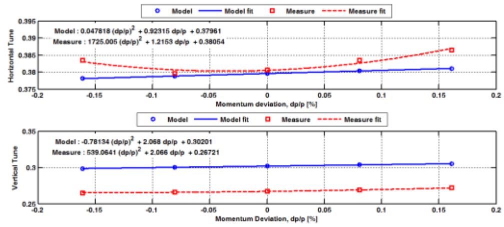


Figure 6: Chromaticity measured (red) and model (blue) in horizontal (above) and vertical (below) planes.

AC Mode (150 MeV~3 GeV)

The 150-MeV injected beam can be ramped up to 3 GeV and down to 1.3 GeV with sinusoidal ramping and a modified tracking waveform in the power supplies of the dipole, quadrupole and sextupole magnets. We used concurrently the family of Q_1 and Q_2 quadrupole magnets

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to control the working tunes by using the measured response matrix during ramping [10]. The tune diagram along the ramping curved shows in Fig. 7; tracking of the tunes were maintained within 0.1. The modified tracking waveform of the quadrupole power supplies is shown in Fig. 8. The amount of variation of the orbit during ramping was kept within 3 mm in the horizontal plane and 1 mm in the vertical plane without ramping waveform applied to correctors, as shown in Fig. 9.

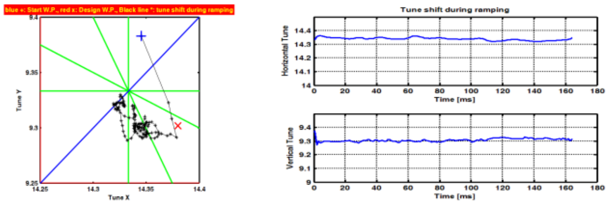

Figure 7: Tune diagram (left) along the ramping curve and tunes tracking maintained within 0.1 in both planes (right).

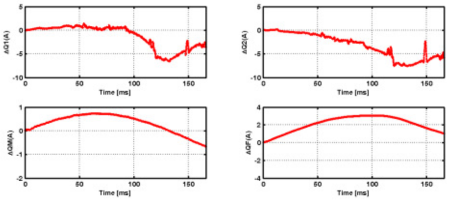

Figure 8: Modified tracking waveform for quadrupole power supplies.

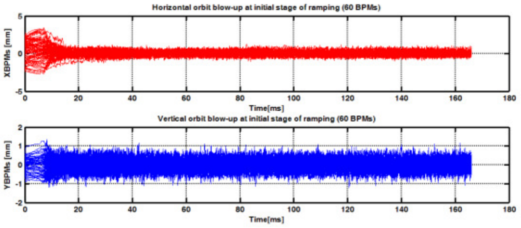

Figure 9: The amount of orbit variation during ramping was kept within 3 mm in the horizontal plane and 1 mm in the vertical plane with no ramping waveform applied to correctors.

Figure 10 shows the beam current in the booster ring during ramping. The maximum beam current is 0.38 mA at 150 MeV without energy slit, 0.26 mA after 1000 turns and 0.23 mA at 3 GeV. The capture efficiency of the booster ring in the first 1000 turns (1.6 ms) is about 68 %. The ramping efficiency is about 89 % without a ramping waveform in the correctors. The measured beam sizes agreed satisfactorily with the model values, as shown in Fig. 11 [11].

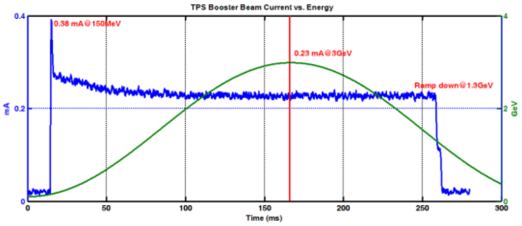

Figure 10: Beam current of the TPS booster ring during ramping. The overall efficiency of booster is about 61 % for extraction at 3 GeV. The beam can be ramped down to 1.3 GeV.

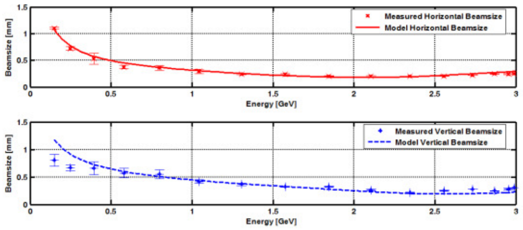

Figure 11: Beam size during ramping with normalized emittance from Linac ε_{nx}=36 / ε_{ny}=30 π mm-mrad and energy spread =0.35 %.

FUTURE CONSIDERATIONS

The optimization of the ramping efficiency requires further control of the orbit in the first 10 ms. Improving the flat-top and tail of injection kicker can diminish injection beam loss. To extend the ramping energy down to 150 MeV, further tuning of the tracking must be conducted. Detailed calibration of the lattice functions using LOCO and ICA in the DC/AC mode will be studied.

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