

# COMMISSIONING OF BPM SYSTEM FOR THE TPS PROJECT

P. C. Chiu, K. H. Hu, C. H. Kuo, C. H. Huang, Demi Lee, Y. S. Cheng, K. T. Hsu  
NSRRC, Hsinchu 30076, Taiwan

## Abstract

Taiwan Photon Source (TPS) is a newly constructed 3-GeV synchrotron light source which ground breaking began February 2010. Its Booster beam commissioning and hardware improvement started at August 2014 and ramped to 3 GeV successfully in December 16 2014. Soon the stored beam in the storage ring had achieved 5 mA in December 31[1][2]. The BPM electronics Libera Brilliance+ [3][4] are adopted for booster and storage ring of TPS. The provided BPM data is useful for beam commissioning where it can be used to measure beam position, rough beam intensity along the longitudinal position and also for tune measurement. This report summarizes BPM commissioning and measurement during beam commissioning.

## INTRODUCTION

The TPS is a state-of-the-art synchrotron radiation facility featuring ultra-high photon brightness with extremely low emittance [5]. The TPS accelerator complex consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. The Storage Ring's circumference is 518.4 meters with 24 DBA lattice and 6-fold symmetry; the booster has 6 FODO cells and its circumference is 496.8 meters. The booster and the storage ring share the same tunnel in a concentric fashion. During 4 years of construction period, civil constructions had been completed in early 2013.

At September 2014, booster BPM commissioning had committed with beam commissioning. After some hardware improvement such as power supply tuning, chamber and magnet re-alignment, demagnetization of chamber, kicker and septum improving and etc., booster had achieved beam ramped to 3 GeV at December 16 2014. Later, after improving field leakage of Booster extraction DC septum, we had a 5-mA stored beam on Dec. 31 2014. Diagnostic system played a helpful role to provided beam profile and information to improve or tune subsystem to make progress quickly during beam commissioning. This report will focus on the BPM related environment, functionalities and measurement.

## BPM FUNCTIONALITIES AND COMMISSIONING

The TPS storage ring is divided into 24 cells and there are 7 BPMs per cell; the booster ring has six cells where each cell is equipped with 10 BPMs. Booster button BPM shapes 35x20 mm elliptical and button diameter 10.7 mm.

The calibration factor  $K_x$  and  $K_y$  is 8.25 and 9.66 mm respectively. There are two kinds of BPM for storage ring as Fig. 1 shown: one is standard button BPM shapes 68x30 mm elliptical and diameter 7.4 mm at arc section; the other is primary BPM shapes 64x16 mm racetrack and diameter 7.4 mm at straight line. The calibration factor  $K_x/K_y$  is 13.8/12.73 and 6.58/8.89 mm for standard and primary BPM respectively.

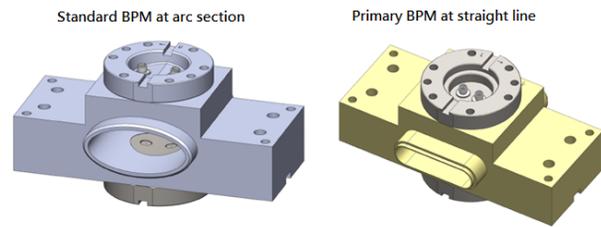


Figure 1: Mechanical drawings of standard type and primary type BPM for TPS storage ring.

The conceptual functional block diagram of the BPM electronics is shown in Fig. 2. It will provide several data type for different application. ADC and TBT data is acquired on demand by trigger; 10 Hz slow data is for DC average orbit and 10 kHz fast data could be applied for booster ramping orbit or fast orbit feedback application. It is also embedded with EPICS IOC for control, monitor and configuration. The timing AMC module would provide functionalities of synchronization, trigger, interlock and post-mortem. To support operation of the BPM electronics, functionalities like cold start, shutdown, housing, control system interface should meet the requirements. The delivered units also had been performed functionality and performance test to ensure compliance with this specification.

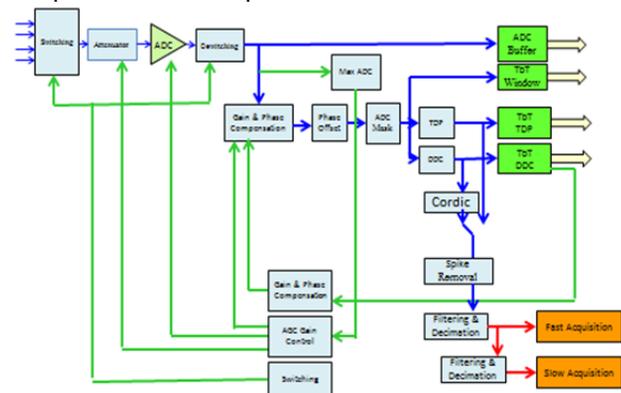


Figure 2: BPM platform functional block diagram.

At September, the first turn of the booster beam had achieved soon after correctors steering. There are only

few buttons of BPM found to have contact problems quickly by observing ADC data with extremely low count compared to other buttons. The real BPM calibration factor was agreed with the designed values by measuring and comparing the optical function of machine model. The first turn and accumulated beam of the storage ring soon obtained without correctors after injection started. It was also found that there are some cabling problems during machine measurement and optimization. Button B and C of two BPMs were cross connected. The cables of BPM 24\_4 and 24\_6 were also in wrong order. Besides, the LOCO fitting for BPM calibration factor showed that there were three primary BPMs which sensitivity  $K_x/K_y$  were almost only the half as shown in Fig 3. It was caused by incorrect settings of sensitivity factor of these three BPMs. Primary BPM are generally installed at straight line for normal ID. However, vertical beam duct height enlarge rather than reduce to transition to large aperture of vacuum duct of SRF modules. Therefore, standard BPMs are installed rather than primary BPMs installed at these sites.

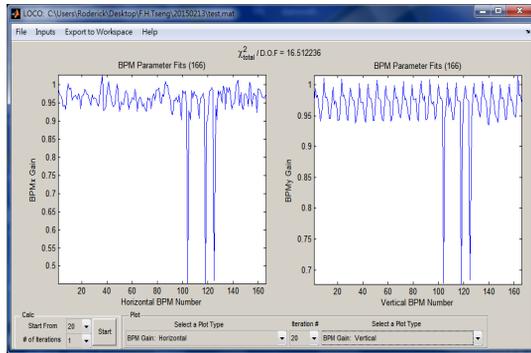


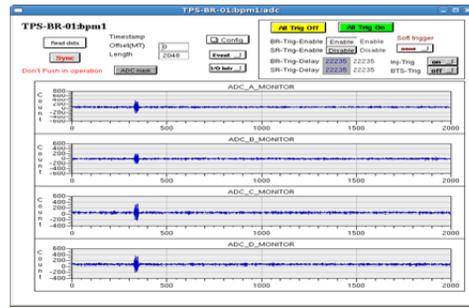
Figure 3: BPM calibration factor fitting results for LOCO. There are three BPM that should be primary BPM but actually standard BPM.

### BOOSTER BPM MEASUREMENT

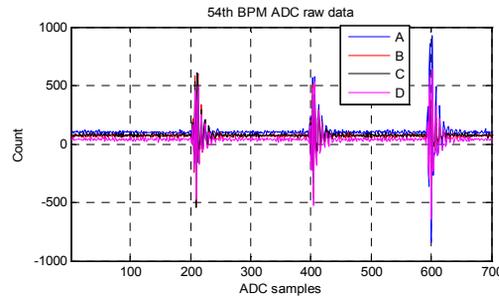
There are 60 sets of phase-trimmed 0.240" form polyethylene coaxial cables connected between the buttons and BPM electronics for booster. The trimmed BPM cables have the phase difference less than  $\pm 3^\circ$  and attenuation difference less than 0.1 dB. Different BPM data flow will be demonstrated for different applications in this section.

#### ADC Raw Data

The ADC raw data is useful for checking the timing of the beam and beam property especially in the first turn. The phase delay due to time difference when beam travel pass the buttons along the ring could align by ADC clock offset. Fig. 4(a) shows that the first beam passing through the injection septum and kicker and arriving the 1<sup>st</sup> BPM of the booster ring when beam first steered pass through; (b) ADC data as the beam had stored in the booster.



(a)



(b)

Figure 4: (a) The ADC data when beam passes through the 1<sup>st</sup> BPM of the booster synchrotron on the first day of Booster commissioning. (b) The ADC data as the beam had stored in the booster.

#### First-turn Application

BPM electronics provides single pass mode for calculating first turn trajectory from ADC data. However, vast beam losses and ADC DC offset up to 100 count will result in worsen signal to noise ratio and position calculation offset error. Therefore, a soft IOC would be applied to acquire more precise first turn trajectory from ADC raw minus DC offset. Fig. 4 shows the first turn orbit trajectory and sum along 60 BPMs. Horizontal trajectory shapes like dispersion function due to energy drift from Linac modulator.

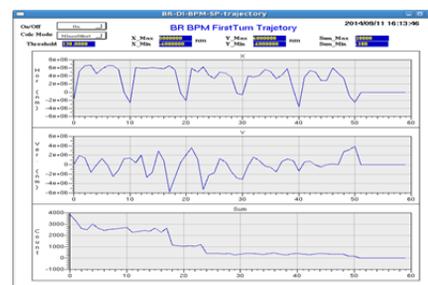


Figure 5: First turn horizontal, vertical trajectory and sum along 60 BPMs of booster.

#### Slow & Fast Orbit Data

The BPM electronics also provide 10 Hz slow and 10 kHz fast position data to measure average stored beam orbit. Figure 6 shows the FA orbit variation for DC and AC mode respectively. At DC mode, 60 Hz orbit

perturbation is clearly observed mainly from quadrupole power supply ripple. Horizontal phase advance between adjacent BPMs is around  $\pi/4$ . Resolution of BPM is gradually deteriorated after 120 msec due to beam loss. At AC mode, close orbit variation during ramping could be around 6 mm in horizontal and 2 mm in vertical. The variations in horizontal during the first thousands of turns are especially large due to the synchrotron motion.

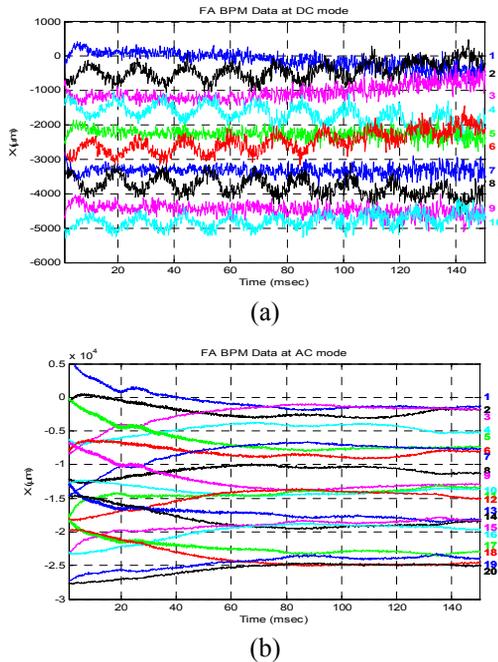


Figure 6: (a) DC mode Orbit. (b) AC mode Orbit.

Turn by Turn Application

DDC (Digital Down Converter) and TDP (Time Domain Processing) Turn-by-turn data are both provided and the resolution could achieve around 150  $\mu\text{m}$  at 0.5 mA. The BPM TBT data could be applied to extract tune as Fig. 7 shown as well as calculate optical function such as beta and dispersion. To use TDP properly, phase offset should be adjusted by beam according ADC data. Compared to DDC, TDP could well resolve tune due to clear and no smear TBT data as Fig. 8 which shows the spectrogram of DDC and TDP data respectively.

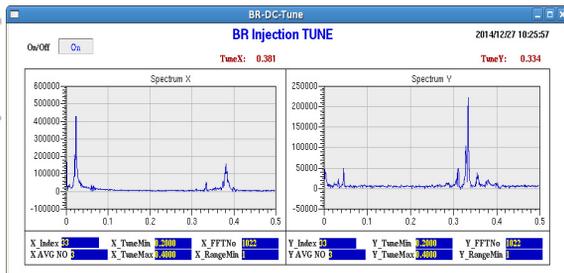


Figure 7: Booster injection tune extracted from BPM TBT data at injection time.

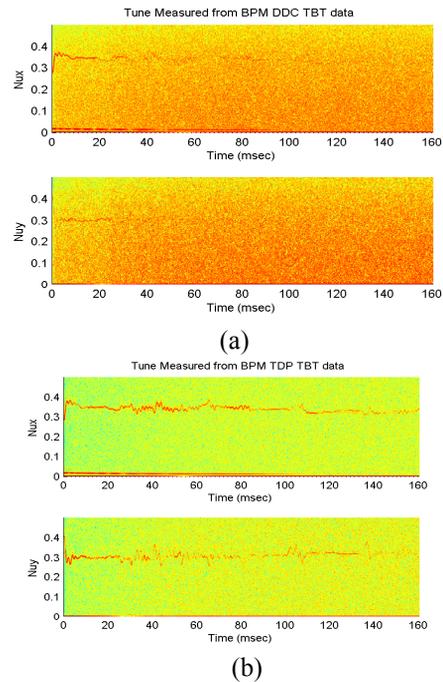


Figure 8: (a) Tune extracted from BPM DDC TBT data during booster ramping (b) Tune extracted from BPM TDP TBT data.

STORAGE RING BPM MEASUREMENT

There are many similar applications and commissioning process with Booster and Storage Ring such as ADC data, first-turn application and tune measurement. The phase offset for each BPM is also set according to ADC data. Turn-by-turn and FA BPM data will be focused in this section.

Turn-by-turn Data

After beam stored, the beam current had achieved 50 mA in March 2015 with vacuum pressure dropped. However, it was hardly continuously accumulated and beam trip happened. It was later verified that synchrotron motion is the major reason due to RF feedback loop resonance. The BPM turn-by-turn data observed that the synchrotron motion make horizontal position vibration at same phase as Fig 9 shown and it became stronger as beam current increased.

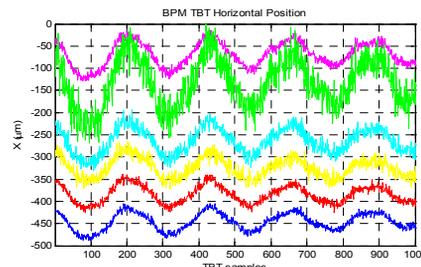


Figure 9: Horizontal TBT data. The synchrotron motion's amplitude for each BPM is proportional to its dispersion.

TBT data is also applied to extract tune in the storage ring. Besides injection kickers, the horizontal and vertical pingers are used to excite beam motion in two planes respectively. Timing for trigger of BPM, kickers and pingers are controlled by event system. Fig. 10 shows the real time tune display page. The chosen BPM, average number, FFT length and etc. could be selected according to different condition and requirement.

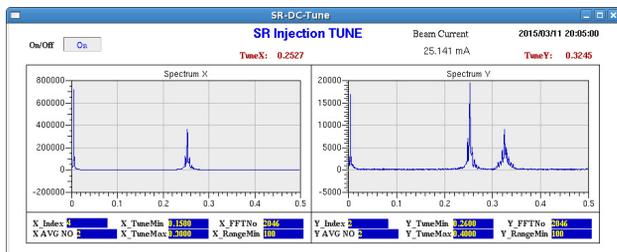


Figure 10: Storage ring tune extracted from BPM TBT data where beam are excited by pingers.

**FA Data**

10 kHz FA data could be provided to analyse transient motion, orbit stability as well as applied for fast orbit feedback. Fig. 11 shows orbit turbulence due to field leakage of septum during injection. The synchrotron motion around 2 kHz could be also observed.

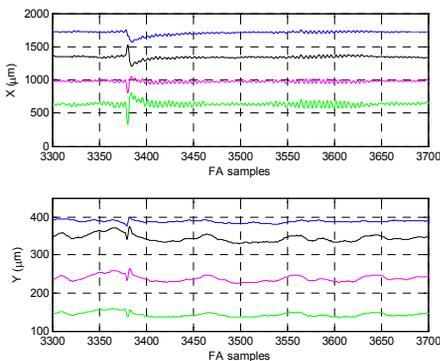


Figure 11: Horizontal & vertical FA position data during injection. The septum filed leakage cause horizontal orbit distortion 100 µm.

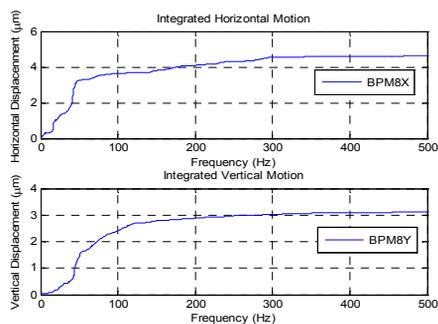


Figure 12: Horizontal and vertical integrated PSD.

According to BPM spectrum from FA data, 29 Hz

noise was found the dominant noise source induced from turbo-pump motor. Booster extraction at 3 Hz repetition rate also makes 3 Hz noise observed. Besides, water flow also causes wide band vibration from 30 to 70 Hz. Fig. 12 shows the integrated PSD for the horizontal and vertical planes. Efforts to eliminate the noise source will be undertaken in the future.

Moreover, BPM FA data of the storage ring are also used for interlock safety for position and angle. BPM electronics itself provide position interlock functionalities. Another dedicated IOC is adopted to calculate all angles between different BPM from streaming in FA data through Gigabit Ethernet and activates interlock. Fig. 13 shows BPM angle interlock display and control page.

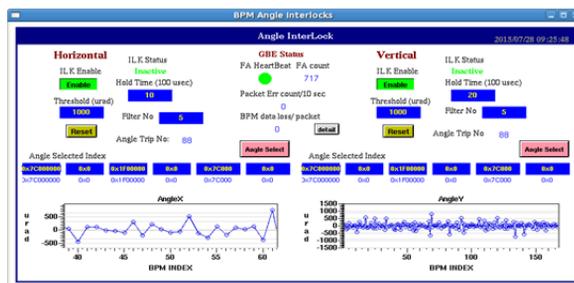


Figure 13: BPM angle interlock display and control page.

**CURRENT STATUS**

Final BPM system test and beam commissioning for TPS had started at the same time in September 2014 and completed at December 31. BPM functionalities and performance for the booster and storage ring have been exercised with beam during last several months. Supporting tools of software have been continuously revised and developed. Now the optimization of injection efficiency is still required further improvement [1]. The diagnostic tools especially BPM system provide quite a lot of information during commissioning as well as future optimization.

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