DIAGNOSTICS OF THE TPS BOOSTER SYNCHROTRON FOR BEAM COMMISSIONING

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

Abstract

Booster synchrotron for the Taiwan photon source project is in commissioning. Diagnostics which consist of screen monitors, intensity monitors, beam position monitors, tune monitors, visible light synchrotron radiation monitors and radiation-sensing field-effect transistors are integrated with accelerator control system. Integration and functionality check were done recently. Details of these diagnostics and preliminary test results will be summarized in this report.

INTRODUTION

Taiwan Photon Source (TPS) is a low emittance, third-generation light source in NSRRC [1]. It consists of a 150 MeV S-band linac, linac to booster transfer line, 0.15 to 3 GeV booster ring, booster to storage ring transfer line, and 3 GeV storage ring. The booster has 6 FODO cells which include 7 BD dipoles with 1.6 m long and 2 BH dipoles with 0.8 m long in each cell. Its circumference is 496.8 meters and it is concentric with the storage ring in the same tunnel. The radio frequency is 500 MHz with 828 harmonic numbers. The ramping repetition rate is 3 Hz which is locked with the frequency of the power system. Preliminary commissioning of the booster synchrotron is being proceeded and it shares some windows for installation and system-integrated test from mid-August 2014. Diagnostics which equips in booster to help the beam commission will be described in the report, and preliminary results will be summarized as well.

DIAGNOSTIC DEVICES IN THE BOOSTER

There are seven screen monitors in the booster ring to monitor the beam profile and beam position, shown in Fig. 1. The average beam current is measured with a Bergoz's new parametric current transformer (NPCT) and the pulse current is observed by a fast current transformer (FCT). Sixty beam position monitors (BPMs) can be used to measure beam position and rough beam intensity along the longitudinal position. For the tune monitor, the beam is shaken by stripline electrodes or a magnetic shaker using narrow band white noise; the beam motion signal is picked up by BPMs. Two visible light synchrotron radiation monitors (SRMs) are used to measure the synchrotron radiation profile. They are set up in the opposite side of the booster with a camera inside the tunnel and one outside the tunnel. In order to investigate applicable of radiation-sensing field-effect transistors (RadFETs) for measuring the local beam loss, several RadFETs are installed at the injection area of the booster ring.

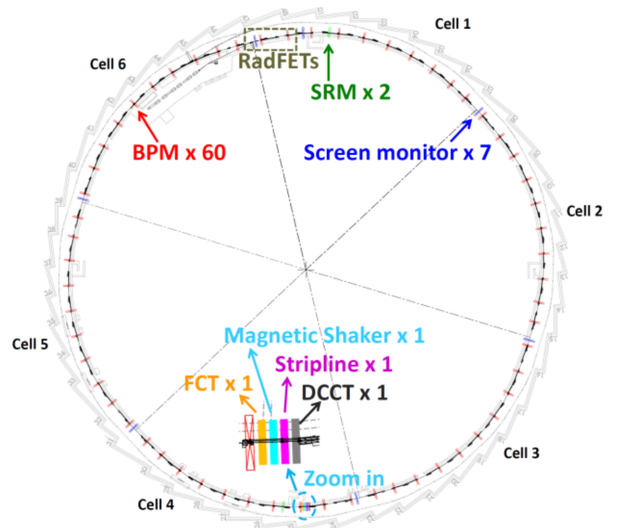


Figure 1: The layout of the diagnostic devices in the booster ring.

SCREEN MONITOR

Seven screen monitors are designed in the beginning of six cells of the booster and behind the 1st DB dipole of the 1st cell for booster commissioning. The screen monitor assembly consists of a hollow tube, a Yag:Ce screen with 25 mm in diameter and 0.5 mm in thickness. The YAG:Ce screen is mounted at 45^{o} angle in one side to intercept the beam. A vacuum-sealed window is in the other end of the tube to extract the light. A CCD camera is mounted at a supporting tube with LEDs installed beside the CCD camera for illumination. A pneumatic device is used to move the whole assembly in or out. All of these devices are controlled remotely including the on/off of the LED. The structure of the screen monitor assembly is shown in Fig. 2. The power over Ethernet (PoE) switches are used to connect the cameras and uplink to the vision system in the input / output controller (IOC) of the experimental physics and industrial control system (EPICS) [2]. The IOC is constructed based on Linux operating system with areaDetector EPICS module and a compiled Matlab analysis program is used as a graphical user interface, shown in Fig. 3. The camera trigger comes from TPS timing system. Exposure time and camera gain are adjustable to meet various beam conditions. This scheme is simpler than the complicated attenuator design.

ISBN 978-3-95450-141-0

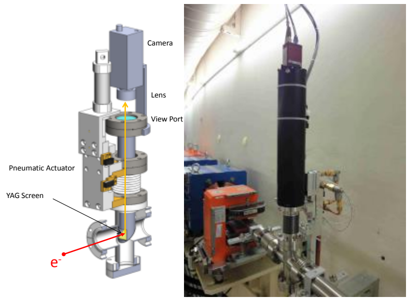


Figure 2: Screen monitor assembly.

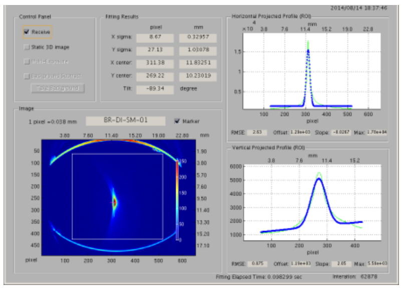
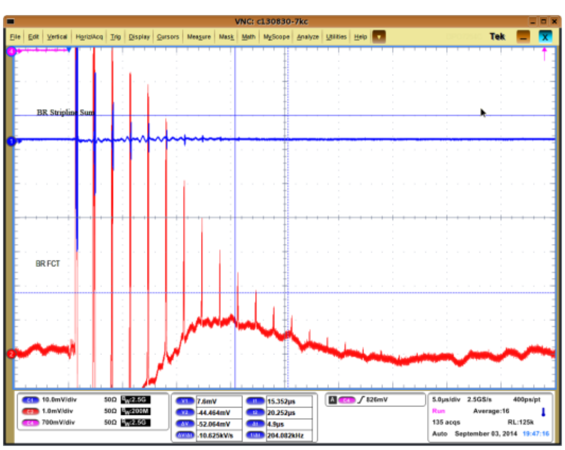


Figure 3: The image profile as the beam passes through the 1st screen of the booster ring.

CURRENT INTENSITY MONITOR

A FCT is used to observe filling pattern via an oscilloscope. Trigger of the oscilloscope is controlled by the timing system which can shift to the timing of any ramping energy. The singles of the FCT and stripline sum are shown in Fig 4. From this figure, it is clear that the electron beam circulates more the ten turns. Average beam current is measured by a NPCT in which current waveform can be obtained using analog-to-digital converters (ADCs) and the averaged beam current can be obtained using digital voltmeters. Beam current data is acquired from an EPICS IOC.



Fiugre 4: Beam singles observed by a fast current transformer (FCT) and stripline .

BEAM POSITION MONITOR

The booster synchrotron equips with 60 button-type BPMs. All BPMs accompany with Libera Brilliance+ electronics [3-4]. There are 60 sets of phase-trimmed 0.240" form polyethylene coaxial cables which connect the button to BPM electronics. The gain variation of BPM electronics is less than 5%. The same attenuation for all BPMs benefits from the equal length of all cable sets. It also makes possible to use the sum signal of a BPM as an intensity indicator. The error would only come from position dependence of the beam. All parameters of BPM electronics are accessible from the EPICS control system.

BPM electronics supports beam position and intensity data for commissioning and routine operation. The raw data of an ADC is useful for checking the timing of the beam and beam property especially in the first turn. The single pass, turn-by-turn, 10 kHz and 10 Hz beam position data will also be deployed and accessed by EPICS process variables (PVs). 10 Hz rate data is only useful for the injection energy at the direct current (DC) operating mode in the booster synchrotron. The BPM data is useful for beam commissioning. To demonstrate usage of the BPM during commissioning, several examples are presented here.

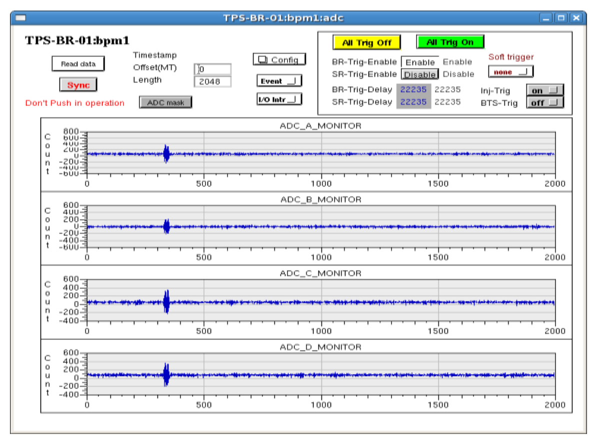


Figure 5: The ADC data when beam passes through the 1st BPM of the booster synchrotron.

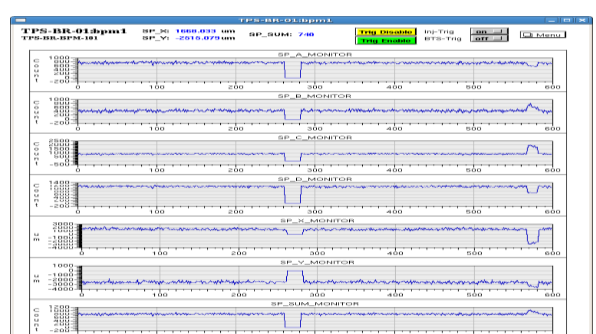


Figure 6: Beam position and intensity trend observed by the 1st BPM of the booster synchrotron. The change of the data is caused by the injection condition.

The first beam which passed through the injection septum and kicker and then arrived the 1st BPM of the booster ring is shown in Fig. 5 and Fig. 6. Beam losses along the longitudinal position can be easy extracted from the ADC data. Figure 7 shows the sums of the ADC count

ISBN 978-3-95450-141-0

of various BPMs as the beam attempts to circulate the first turn.

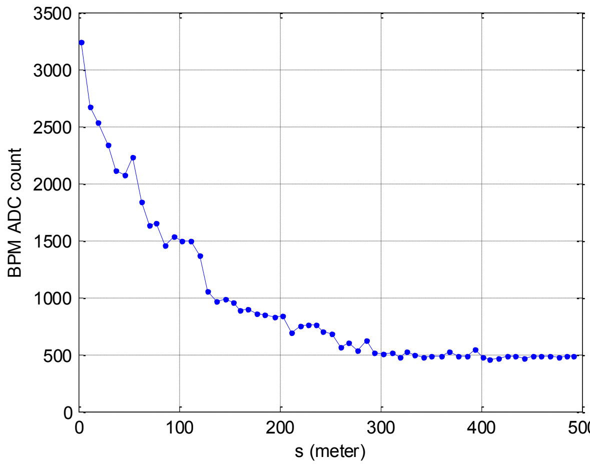


Figure 7: Beam intensity along the booster synchrotron when attempting to circulate the first turn.

After correcting the orbit, the beam, which has completely circulated more than 5 turns, can be clearly observed from the button signals of the BPM ADC raw data in the 1st cell as show in the Fig. 8. The trajectory of the first 3 turns is shown in Fig. 9. It can be identified clearly that particular beam loss happens as the beam passes through the first 3 BPMs of the first turn. A great deal of beam loss at the first cell can be identified by a step change of beam intensity in Fig. 9(c). Large horizontal oscillation is clearly observed at the second turn because the beam sees the injection kicker post-pulse ripple. Horizontal trajectory is large than 5 mm. Vertical oscillation can keep within +/- 2 mm.

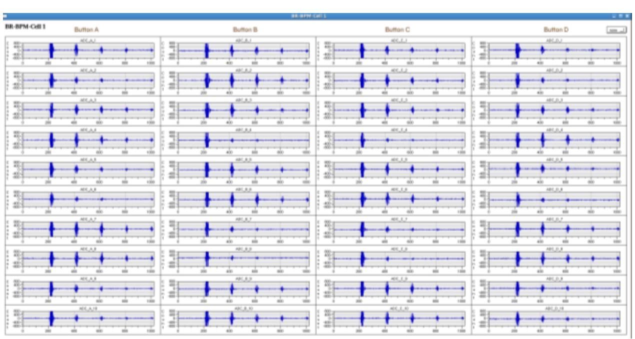


Figure 8: The ADC data as the beam circulates complete 5 turns in the booster.

In order to reduce the beam loss at the first 3 BPM, the chamber is realigned and some further orbit correction has been done. The trajectory variation in the horizontal and vertical plane, shown in Fig. 10, becomes fewer and the beam loss at first turn is around 20%, which is significant improve comparing to previous results. However, the horizontal trajectory in the second turn still remains around +/- 5 mm and the loss between the adjacent turn is still large. To store beam and ramp the energy into 3 GeV are our short-term goals.

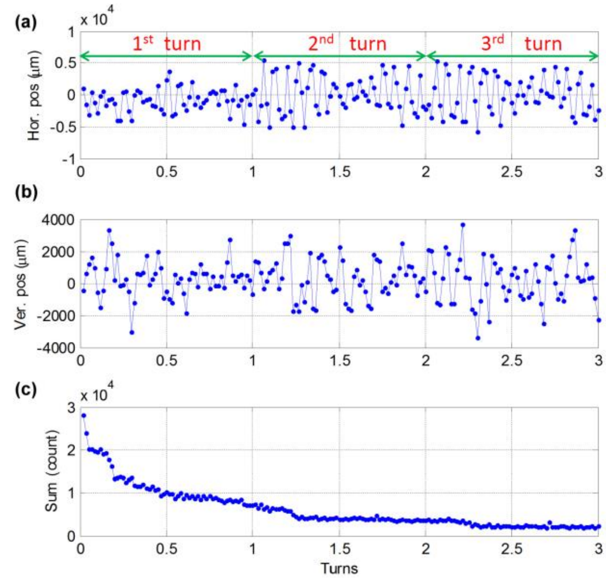


Figure 9: The trajectory in the (a) horizontal plane and (b) vertical plane. (c) Sum of the first three turns.

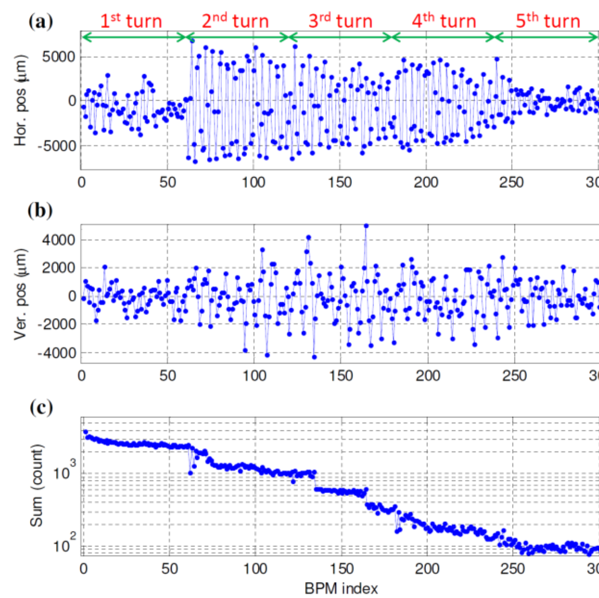


Figure 10: The trajectory in the (a) horizontal plane and (b) vertical plane. (c) Sum signal of the BPMs after aligning the booster chamber and doing the orbit correction.

TUNE MONITOR

Damped oscillation caused by the injection kicker can be used to extract tune information at the injection energy or commission for the DC mode. The injection tune can be extracted from the Fourier analysis of the turn-by-turn data of the selected BPM.

Tune variation during ramping can be measured by a continuing beam excitation and doing spectra analysis of the turn-by-turn data as the energy is ramped up and beam survives. Therefore, when the extraction of booster is not actived, tune measurement during the ramping down

ISBN 978-3-95450-141-0

energy is also available before beam loss. To excite stored beam for tune measurement, a stripline kicker was original proposed to install. However, because it cannot meet commissioning schedule, a magnetic shaker using handy spare parts is installed as Fig. 11 as the current solution. The stripline will be installed later. The magnetic shaker is without bunch-by-bunch capability. It is used to continuously exciting the beam now and is acceptable for tune measurement. The shaker consists of two multi-turn coils mounted on the ceramic chamber in the horizontal and vertical planes of the shaker, which is enclosed by a ferrite box. The kickers with 50 Ω terminated loads have a calibration factor of 3 mG/A. An arbitrary signal, which is provided by a band-limited, amplitude-adjustable signal generator, is amplified by a power amplifier to drive the shaker in each plane. Turn-by-turn beam oscillation data is acquired by the BPM electronics. The functional block diagram of this tune monitor system is shown in Fig. 12.

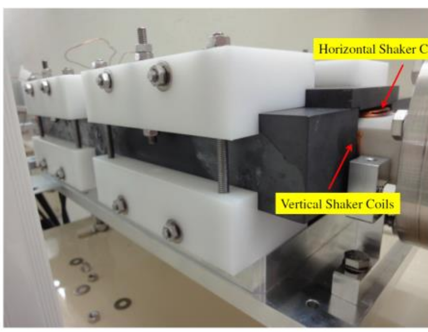


Figure 11: Magnetic shaker.

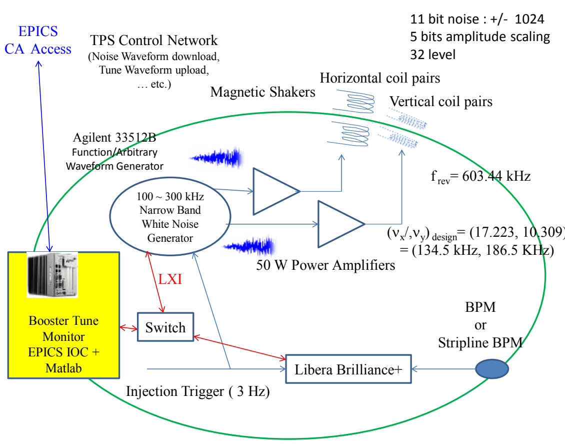


Figure 12: Functional block diagram of the tune monitor.

Preliminary tests in Taiwan Light Source show that the beam can be excited effectively during the whole ramping cycle [5]. The betatron sideband is observed by a BPM with acceptable signal to noise ratio as in Fig. 13. The spectrogram of the horizontal and vertical BPM turn-by-turn data could identify the tune variation clearly. Peak identification from the spectrogram could extract the varying tunes during one ramping cycle.

Tracking of the dipole filed and strength of quadruple families to keep the tune value within the tolerance is important. A large tune shift will degrade the operating performance of the booster synchrotron and even lead to the beam loss. Minimize tune variation can be realized by observing tune variation during energy ramping and be used to correct quadruple settings. The beam currents of the magnets for the TPS booster synchrotron are excited by a 3 Hz sine-like waveform which is in corporation with the radio frequency (RF) system. Tune monitor can provide tune variation during the ramping for tracking compensation.

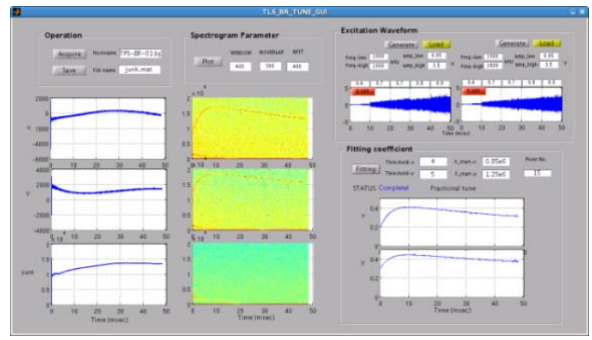


Figure 13: Graphical user interface of the tune monitor.

SYNCHROTRON RADIATION MONITOR

There are two SRMs in the booster synchrotron and their extract ports were installed at the 2nd BD dipole magnet of 1st cell and 4th cell. One port can extract light to the shielding wall for the measurement of a streak camera as shown in Fig. 14. The designed beam emittance at 150 MeV is 0.167 mm-mrad and 0.01 mm-mrad when ramping to 3 GeV. Beam size (σ_x, σ_y) will shrink ten times from (0.7 mm, 1.5 mm) to (0.15 mm, 0.1 mm). To ensure better resolution at small beam size part in 3 GeV, unit conjugate optics for both monitors is adopted. This optic design will ensure that the diffraction is not deleterious to beam size measurement at 100 μm level. The beam size of the booster synchrotron radiation is captured a GigE Vision CCD camera using external trigger which is synchronized with the machine cycle. The PoE switches are also used to connect the cameras and uplink to the vision system EPICS IOC.

Figure 14: The setup of a synchrotron radiation monitor (SRM) after the 2nd BD dipole in the 1st cell.

ISBN 978-3-95450-141-0

REAL-TIME DOSE MONITORING USING RADFETS

A RadFET is a p-channel metal-oxide-semiconductor field-effect transistor with an aluminium gate and thick layer of silicon dioxide as a dosimeter [6-7]. A RadFET changes its electrical characteristics under the influence of ionizing, i.e., removal of electrons and leaving a stationary positive charge in the silicon dioxide layer. The relaxation of the positive charge would be several months, which makes it measure the total dose, not dose rate. The trap charges shift the gate threshold voltage as the reader uses a constant current through the transistor.

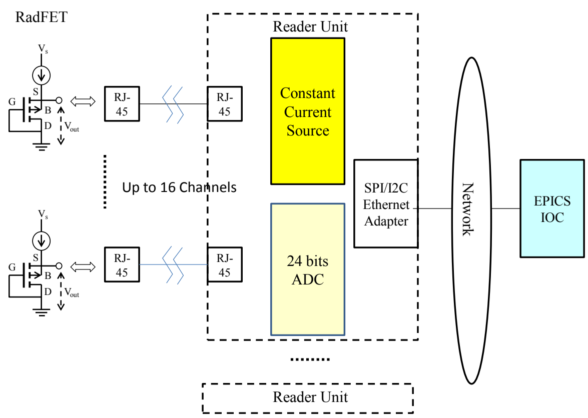


Figure 15: Block diagram of RadFET reader.

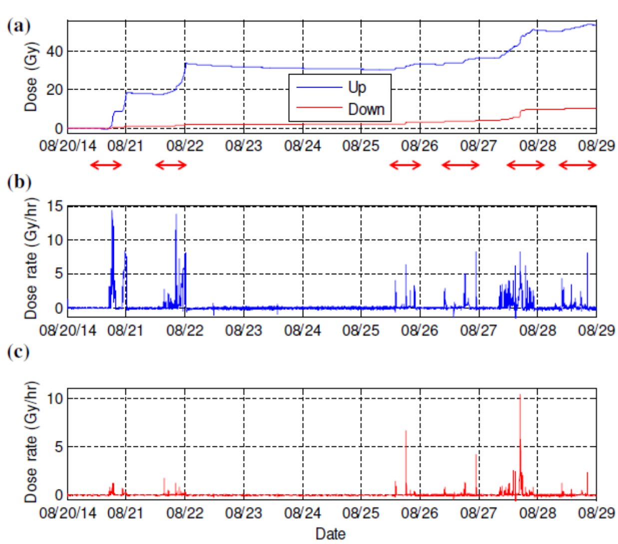


Figure 16: Loss pattern during beam commissioning window from August 20th to 28th, 2014. The RadFETs are installed at the up side and down side of the vacuum chamber after the injection kicker of the booster synchrotron. The red arrow in (a) is the beam commissioning windows.

A prototype RadFET reader which accommodates up to 16 RadFETs has been implemented, shown in Fig. 15. The connection between a RadFET and reader unit is an unshielded-twisted-pair network cable with RJ-45 connectors due to its popularity and easy to handle. Currently reading rate is 60 seconds. The measured doses are published in EPICS PVs format and saved in the archiver for further usage. The dose rate can be easily obtained by taking time derivative of the recoded dose data.

From the radiation dose or dose rate measured by the RadFET installed in the upside and down side of chamber after injection kicker of the booster in Fig. 16, the dose increases at the commissioning windows due to the beam loss during beam test. The dose in the other windows, which is available for continue installation works, is slightly decay due to the annealing effects. The decay rate is around 4% for 24 hours without exposing to the radiation. The position and period of high dose rate which indicates the beam loss may provide some information to the operator to adjust the beam.

CURRENT STATUS

Final system integration test of booster with the installation of the storage ring and preliminary beam commissioning of the booster synchrotron is in progress now. Beam was circulated one turn soon after commissioning work started. To store beam and ramp the energy into 3 GeV are the recent efforts. Diagnostics for the booster synchrotron has been exercised with beam during last several weeks. Functionality and supporting tools of software have been revised. Preliminary results show the diagnostic support fulfills its role.

REFERENCE

[1] TPS Design Handbook, version 16, June 2009.
[2] C. Y. Liao, et. al., "Image profile diagnostics solution for the Taiwan photon source", IBIC 2012, Tsukuba, Japan.
[3] www.i-tech.si
[4] P. C. Chiu, et. al., "TPS BPM electronics Performance measurement and statistics", IBIC 2012, Tsukuba, Japan.
[5] P. C. Chiu, et. al., "New booster tune measurement system for TLS and TPS prototype", IBIC 2013, Oxford, UK.
[6] L. Frohich, et. al., "DOSFET-L02: An advanced online dosimetry system for RadFET sensors", IBIC 2013, Oxford, UK.
[7] L. Frohich, et. al., Nucl. Instr. And Meth. A 703 (2013) 77-79.

ISBN 978-3-95450-141-0