DIAGNOSTICS UPDATE OF THE TAIWAN PHOTON SOURCE

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Abstract

Taiwan Photon Source (TPS) is a 3 GeV synchrotron light source which is being construction at campus of NSRRC. Various diagnostics are in implementation and will deploy to satisfy stringent requirements of TPS for commissioning, top-up injection, and operation. These diagnostics include destructive monitors, beam intensity observation, trajectory and beam positions measurement, synchrotron radiation monitors, beam loss monitors, orbit and bunch-by-bunch feedbacks, filling pattern and miscellaneous devices. Current status will summarize in this report.

INTRODUCTION

The TPS is a latest generation of synchrotron light source featuring high brightness with extremely low emittance [1]. Civil construction and installation will be finished in 2013. Machine commissioning is scheduled in 2014. The accelerator system 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 diagnostics will help TPS to achieve its design goals. Major diagnostics related parameters for the booster synchrotron and the storage ring are summarized in Table 1. Beam size and divergence angle is summary in Table 2.

Diagnostics for the TPS accelerator system were summary in reference [2]. Diagnostics of linear accelerator and transfer lines will help to generate and delivery high quality electron beam to booster and storage ring. Booster diagnostics will provide beam parameters include orbit, working tunes, circulating current, filling pattern, beam size, bunch length, emittance, and derived parameters. The diagnostics are designed to provide a complete characterization stored beam in the storage ring, including averaged beam current, fill pattern, beam lifetime, closed orbit, working tunes, chromaticity, beam size, beam loss pattern, beam density distribution, emittance, bunch length, and etc. To utilize the benefits of the high brightness and small beam sizes of TPS sources, photon beams must be extreme stable both in position and angle to the level of better than 10% of beam sizes and divergence. Table 2 provides the electron beam sizes and angular divergences for the selected TPS sources. The most stringent beam measurement and stability requirement will be for the vertical position at the 7 m straight for ID source (σ_y = 5.11 μm); this will require special consideration for measuring both electron and photon beams.

Table 1: Major Parameters of the Booster Synchrotron and the Storage Ring

	Booster Synchrotron	Storage Ring
Circumference (m)	496.8	518.4
Energy (GeV)	150 MeV – 3 GeV	3.0
Natural emittance (nm-rad)	10.32 @ 3 GeV	1.6
Revolution period (ns)	1656	1729.2
Revolution frequency (kHz)	603.865	578.30
Radiofrequency (MHz)	499.654	499.654
Harmonic number	828	864
SR loss/turn, dipole (MeV)	0.586 @ 3 GeV	0.85269
Betatron tune ν_x/ν_y	14.369/9.405	26.18 /13.28
Synchrotron tune νs	-	0.00611
Momentum compaction (α_1, α_2)	-	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread	9.553×10^{-4}	8.86×10^{-4}
Damping partition $J_x/J_y/J_s$	1.82/1.00/1.18	0.9977/1.0/ 2.0023
Damping time $\tau_x/\tau_y/\tau_s$ (ms)	9.34/ 16.96 / 14.32	12.20/ 12.17 / 6.08
Natural chromaticity ξ_x/ξ_y	-16.86/-13.29	-75 / -26
Dipole bending radius ρ (m)	17.1887	8.40338
Repetition rate (Hz)	3	-

Table 2: The Electron Beam Sizes and Divergence

Source point	σ_x (μm)	σ_x' (μrad)	σ_y (μm)	σ_y' (μrad)
12 m straight center	165.10	12.49	9.85	1.63
7 m straight center	120.81	17.26	5.11	3.14
Dipole (1° source point)	39.73	76.11	15.81	1.11

BEAM INTENSITY MONITORING

The TPS 150 MeV linac system was contracted to the RI Research Instruments GmbH [3]. The schedule for delivery and commissioning is in early of 2011 at test site. The linac will move to the TPS building in late 2012 after TPS building available. Beam instrumentation comprises five YAG:Ce screen monitors for beam position and profile observation, two fast current transformers (FCT) to monitor the distribution of charge and one integrating current transformer (ICT) for monitoring total bunch train charge. Wall current monitors (WCM), which is formed by equally spaced broadband ceramic resistors, mounted on a flexible circuit board and wrapped around a short ceramic break, will give information on beam charge as well as longitudinal profiles of electron bunches. All of mentioned diagnostics were provided by the vendor except the profile measurement data acquisition and analysis [4].

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Integrating current transformer will provide information of beam charge pass LTB and BTS and hence on the beam losses during the injection cycle.

At booster synchrotron, circulating current will be measured with Bergoz's NPCT, while bunch pattern will be monitored with a fast current transformer.

A high precision averaged current measurement at the storage ring will be performed by Bergoz's NPCT. The NPCT device provides a resolution of better than 1 $\mu A/Hz^{1/2}$ and has large dynamic range and bandwidth to make itself a versatile device for measuring lifetime and injection efficiency.

All sensors were acquired form Bergoz [5]. Final design and implementation for all vacuum chambers to host various current transformers are in proceeding.

Two approaches will be used to measure individual bunch current or filling pattern. Fill pattern of the storage ring observed from the sum signal of BPM buttons by wide bandwidth oscilloscope or fast digitizer sampling at RF or a multiple of RF frequency will enable measurement of the bunch current to better than 0.5% accuracy. This information is sufficient for filling pattern control or feedback applications for top-up operation and various studies. The other method is used time correlated single photon counting (TCSPC) for high dynamic population measurement. Avalanche photodiode detector (APD) is used to detect scattered X-ray photon or visible light and count by the HydraHarp 400 TCSPC system [6]. More than six order of dynamic range (10^6) can be achieved easily.

DESTRUCTIVE PROFILE MEASUREMENT

The YAG:Ce fluorescence screens will provide information on beam position and profile for the LTB amd BTS. The OTR screens are also considered to be used for high precision of beam emittance and energy spread measurement at the diagnostic branch of the LTB and at the selected position of the BTS to avoid saturation of YAG:Ce screens. There are six cells of booster synchrotron. Each cell will install a YAG:Ce screens. Fluorescent screens will be installed at injection and extraction section and at the other lattice cells to facilitate booster commissioning, troubleshooting and psychology needing – to see is to believe. The screen material will be YAG:Ce, which has good resolution of the beam image and exhibits high sensitivity and high radiation hardness. There are screen monitor at just after the injection septum of the storage ring for injection condition adjustment. Design and implementation of the screen monitor assembly is in proceeding. Data acquisition and analysis solution is developing [7].

BEAM POSITION MONITORING

The beam trajectory for the LTB/BTS will be monitored with button type beam position monitors equipped with Libera Brilliance Single-Pass [8], its functionality is similar with the BPM electronics for the booster and the storage ring but equipped with high gain analogue board to improve its performance for single pass measurement. Preliminary beam measurement was done at TPS linac test transport line. Better than 50 μm resolution can be achieved for a bunch train with total charge of 0.5 nC [4].

Booster orbit will be monitored with 60 BPMs with turn-by-turn capability. The BPM electronics will be the same as those in the storage ring. The sum signal from the receivers can be used to monitor fast history of the beam current. Booster BPM block is shown in the upper left corner of Fig. 1. All BPM blocks were received. Integrated with vacuum chamber is in proceeding.

The storage ring has 24 DBA lattices cells with 6-fold symmetry configuration [1]. Each cell will have five standard RF BPMs mounted on elliptical chambers, two primary RF BPMs located in the ID straight section mounted on racetrack chambers. To achieve the highest level of orbit measurement resolution, the optimization of the button geometry to obtain a high resolution for both standard and primary BPMs is in progress. Prototype BPM equipped with 7.4 mm button diameter and 17.7 mm separations on the 60x30 mm elliptical chamber has been implemented. The BPM constant is around 13 mm in both planes were achieved with adequate linearity. The primary BPM will install in 20 mm height racetrack chamber with monitor constants around 9 mm, both side have bellows to ensure stability of the BPM. BPM block for the storage ring arc is shown in upper right corner in Fig. 1, while the BPM block of straight is shown in the lower left corner. Photo of the arc BPM flange is shown in the lower right corner.

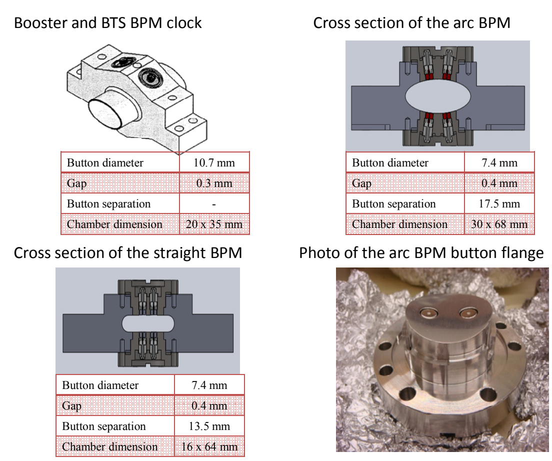

Figure 1: BPM block for the TPS project.

BPM electronics was award to Instrumentation Technologies in 2011 to delivery Libera Brilliance+ [8] for TPS project. The BPM electronics platform is in microTCA form factor. The crate can host up to four BPM modules in AMC form factor. The new BPM

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platform enhanced functionality and performance. All BPM platforms are received in 2012. Acceptance test of functionalities and performance are summary in the reference [9]. Installation for acceptance is shown in Fig. 2.

Up to two X-ray photon BPMs (XBPM) will be installed at each beamline. The electronics consists functionalities such as current to voltage conversion, range selection, bias, ADC, local signal processing, embedded EPICS IOC, delivery slow data (~ 10 Hz rate) for control system access and fast data (~ 10 kHz rate) for feedback purpose. The fast data is compatible with orbit feedback infrastructure. It can seamlessly be integrated with the orbit acquisition system and feedbacks. The BPM electronics will be embedded with EPICS IOC for slow access form the machine control system side and beamline control system side. Commercial products like Libera Photon [8] or its successor will be used.

Figure 2: Acceptance test for the BPM electronics.

TUNE MEASUREMENT

Tune measurement at the booster synchrotron, the electron beam will be excited with narrow bandwidth white noise using striplines. The beam response will be observed with a to the dedicated BPM buttons with the front-end amplifier. Turn-by-turn data acquired by BPM electrons can also use as input for Fourier analysis. Real-time spectrum analyzer is an alternative solution. There will be an extra set of striplines for a bunch cleaning system and for users who need a specific filling pattern in the storage ring. Prototype test at the TLS booster synchrotron is described in reference [10].

There are several methods available for tune measurement at the storage ring. In the instance of injection kicker(s) fire, turn-by-turn data from BPM electronics can be further processing to get tune easily. In the stored beam case, if the beam is unstable, tune by-turn data from the BPM can be used to extract tune. If the beam is stable, shaker by transverse kicker by white noise is needed. Another using the notch in the averaged spectrum of selected bunch or all bunch bunch-by-bunch data can also be used as tune monitor.

BEAM LOSS MONITORING

TPS storage ring plans to adopt coincidence type PIN diodes beam loss monitor (BLM) for loss pattern measurement. Revised version of Bergoz's PIN BLM [5] will be adopted to improve its connectivity. Cat 5/5e twisted cable will be used to connect of BLM to data acquisition electronics and EPICS IOC. The twisted pair cables provide power to the BLM module and send back signal from the BLM. It plans to install 6 PIN BLM per cell and total number is 144 on the TPS storage ring. New design simply the cabling and installation. At the control rack side, an in-house made adapter will equip with power supplies and receiver to convert the count signal into TTL pulse. Several scintillator and photomultiplier combine detectors will also be used for high counting rate applications, such as loss mechanism selective experiments. Both the PIN type and scintillation type BLM will be working in counting mode. A scaler in industry pack (IP) form factor [11] with history buffer and shadow register will installed in cPCI IP carrier module which will install on the EPICS IOC. The data acquisition will be performed by the nearby EPICS IOC and can be performed in synchronous way by the help of timing system.

Some novel BLM are possible to adopt for some applications. Scintillation fiber based BLM with Silicon Photomultiplier (SiPM) might also adopt for beam loss detection [12]. Glass rod based Cerenkov radiator with SiPM is also in evaluation for beam loss detection. Distributed dosage is measured on-line by using RADFET [13] is also in study.

ORBIT FEEDBACKS

Slow orbit acquisition will perform by channel access to the BPM platform embedded EPICS IOC up to 10 Hz rate. Fast orbit beam position will circulate around all BPM platforms at 10 kHz rate by using BPM grouping scheme. Orbit of the whole ring can be accessed from any BPM platform. Fast data of XBPM is also possible to be integrated with BPM system for feedback purpose later..

The TPS will adopt modularized high performance corrector power supply which was developed in-house [14]. The power supply will use analog regulator, adopt biased analogue PWM scheme to improve zero current crossover problem. The current sensing element is the LEM Danfysik Ultrastab 868-20I DCCT for slow corrector and shunt for fast corrector. Combining all of these schemes improves integrated noise level from DC to 1 kHz down to a few parts per million of the output full scale corresponding to nano-radian level kick for slow corrector with maximum ±600 μrad kick. Control of each cell's corrector will be through a custom designed 20 bits DAC in corrector power supply controller (CPSC) [15]. This module will provide EPICS CA interface via embedded EPICS IOC for configuration, setting and status monitoring. Two fast setting ports support 10 KHz sustain setting stream. Two fast setting ports might configure as AURORA and Gigabit Ethernet for different

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applications. The AURORA is suitable for fast orbit feedback application with less overhead. The gigabit Ethernet interface is supported to receive unidirectional UDP packet via private network. The CPSC embedded an waveform generator, it can serve various beam excitation scheme for beam response observation, fast transfer matrix measurement, …etc.

The DAC modules design will be also supported feed-forward applications as well, such as, global feed-forward orbit control and global skew quadrupoles feed-forward coupling control for elliptical polarized insertion devices operation. These feed-forward setting can be issued from EPICS IOCs or dedicated computers more than 200 Hz rate are feasible.

The feedback calculation [16] will be performed by the FPGA module installed in the BPM platform. Two functionalities of this FPGA module will perform: one is grouping the whole ring BPM data by using two counter rotating redundant links around the ring, the other is used as feedback engine. BPM data grouping provides a way to distributed all BPM around the TPS storage ring at all BPM platforms in 10 kHz rate. Orbit feedback computation will distribute to the all 48 FPGA modules and install at the BPM platform. Half will serve. Half FPGA module will serve for horizontal plane and the other half serve vertical plane. One or two sniffer nodes (eavesdropping) will be setup to capture orbit information with 10 kHz rate for more than 10 sec record time and decimated data at lower rate with much longer record time will be supported for various applications and analysis. The functional block diagram of the orbit feedback infrastructure is shown in Fig. 3.

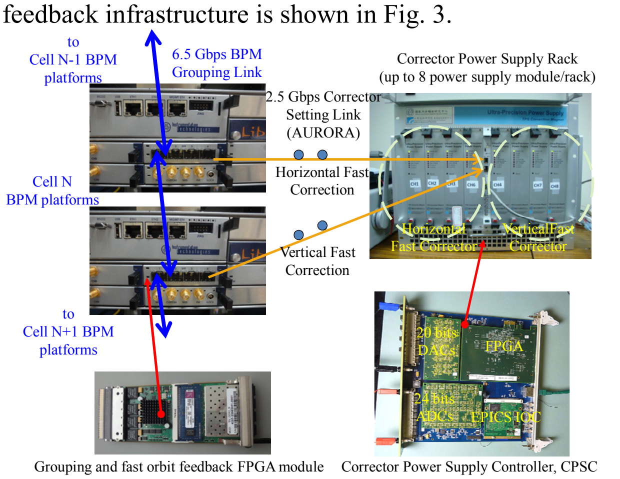

Figure 3: Functional block diagram of the fast orbit feedback infrastructure on each cell.

There are 4 fast correctors per cell and total 96 fast correctors in each plane. All fast correctors are mounted at bellow site with maximum 30 μrad kick angle. The FPGA responsible to fast orbit feedback using fast correctors as actuator. Seven BPM electronics are hosted in two BPM platforms, so 48 BPM platform in total. To simply the system configuration, the FPGA of one BPM platform will serve for the horizontal plane fast orbit feedback, the other will serve for vertical plane. The control rule will apply on the eigenmode space rather than on real space directly This will delivery robust and insensitive to single or a few BPMs reading error and possible to apply different control parameters for difference eigenmodes.

There are two difference schemes for the slow orbit control. The first option is to implement an independent slow orbit feedback loop and communication with the fast orbit feedback loop – move DC component of fast corrector to slow corrector regularly in the second order. The second option is move the DC component of fast corrector to nearby slow corrector. Both scheme were simulated can achieve desired performance.

BUNCH-BY-BUNCH FEEDBACKS AND DIAGNOSTICS

Transverse coupled-bunch instability mainly caused by the resistive wall impedance and other sources will deteriorate beam quality. Bunch-by-bunch feedback system is planned to suppressed instabilities to ensure TPS to achieve its design goals. The system will be implemented in vertical plane and horizontal plane. Transverse feedback kickers are planned to adopt the SLS/ELETRA design and compatible with TPS vacuum vessel. Transverse signals pick-up will be used as an extra BPM and installed at location of high beta function. Beside feedback functionality, the feedback electronics and software also support bunch oscillation data capture for analysis to deduce rich beam information, tune measurement, bunch clearing, and beam excitation and etc. Features of the planned system include the latest high dynamic range ADC/DAC (12/16 bits), high performance FPGA, flexible signal processing chains, flexible filter design, bunch feedback, tune measurement, bunch cleaning, various beam excitation scheme, flexible connectivity, and seamless integrated with the control system. On-line control interface to operate feedback system and off-line analysis tools should be included. Functional block diagram of the planned bunch-by-bunch feedback system is shown as Fig. 4. Commercial feedback processor iGp12 from Dimtel [17] will serve for the TPS. Prototype test is ongoing.

Figure 4: Prototype electronics for bunch-by-bunch feedbacks.

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SYNCHROTRON RADIATION MONITOR

Synchrotron radiation from a dipole will be used to observe the beam profile during energy ramping and emittance measurements. Beam size of the booster synchrotron during the ramping will shrink from (σ_x= 0.7 mm, σ_y= 1.5 mm) at 150 MeV to (σ_x= 0.15 mm, σ_y= 0.1 mm) at 3 GeV due to radiation damping. It will measure by two synchrotron radiation monitors working in center wavelength of 400 nm or less. Short wavelength can reduce diffraction contribution slightly. The capability to monitor bunch length with a streak-camera will be also provided.

Beam size of the storage ring bending magnet 1^o source point (σ_x = 39.73 μm, σ_y = 15.81 μm) is small. It prevents conventional imaging method at visible light wavelength for precision beam size measurement is possible due to ~50 μm diffraction contribution which is about three times of the vertical beam size. So, X-ray imaging system is needed for precision beam size measurement. The visible light is still need for temporal, longitudinal and transverse dynamic observation. Since the beam size is in the small prevent imaging method in visible light region useless. However, interferometer and p-polarization beam size measurement will implement as complementally tool for the x-ray pin-hole camera.

Two X-ray pinhole cameras imaging of the electron beam from bending magnets is the baseline design for the TPS emittance measurement. As they offer the required resolution and the dynamic range to measure the electron beam size accurately at all currents from below 1 mA to 500 mA stored beam current range. Optimization of the X-ray pinhole system will give possibility to measure very small beam sizes in a few microns typically. Its main function will include measurement of the electron beam energy spread and vertical beam size.

The filling pattern measured by TCSPC will used avalanche photodiode detector (APD) to detect scattered X-ray photon or visible light. The APD will mound on the synchrotron radiation monitor station also.

Visible light beamline will be built to measure various beam parameters include longitudinal and transverse parameters. Streak camera operates at 250 MHz synchroscan mode is preferred to observe beam behavior of the consecutive bunches. Integrating the streak camera system with EPICS is planned. The contract was award to the Hamamatsu newly delivery C10910 universal streak camera [18] system and accompany with necessary sweep units and accessories with 1 psec temporal resolution. It will available in 2013. Beam size measurement by visible light interferometer and π-polarization method is also considered.

SUMMARY

Update of diagnostics system for TPS are summarised in this report. Detailed engineering design of various diagnostics devices and electronics are in proceeding include scraper, stripline kicker, synchrotron diagnostics, data acquisition for specific diagnostic application which are not includes in this report are still on the way. Control system supports and applications are in development phase. Refining of interfaces among different systems and groups is underway. Efforts to dig out insufficient parts and avoid last minute wonder are continue watch. Prepare for installation is the current focus. Installation and integration of accelerator system are scheduled in 2013.

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REFERENCES

[1] TPS Design Handbook, version 16, June 2009.
[2] K. T. Hsu, "Design Status of the diagnostic system for the Taiwan Photon Source project", Proceedings of BIW2010, TUPSM101.
[3] K. L. Tsai, et al., "Beamline design and beam measurement for TPS linac", Proceedings of IPAC2011, WEPC038, San Sebastián, Spain.
[4] C. Y. Liao, et al., "Diagnostics for the 150 MEV linac and test transport line of Taiwan Photon Source", Proceedings of DIPAC 2011.
[5] Bergoz Instrumentation: http://www.bergoz.com.
[6] PicoQuant: www.picoquant.com.
[7] C.Y. Liao, et al., "Image profile diagnostics solution for the Taiwan Photon Source", these proceedings.
[8] Instrumentation Technologies: http://www.i-tech.si.
[9] P. C. Chiu, et al., "TPS BPM electronics performance measurement and statistics", these proceeding.
[10] C. H. Kuo, "Modernized of the booster synchrotron diagnostics in the Taiwan Light Source", these proceedings.
[11] MCS8522 Multi-channel Scaler – Industry Pack User's Manual, Hytec Eelectronics Ltd., 2012.
[12] uBLM: http://www.microsensor.it.
[13] RADFET: http://www.radfet.com/id4.html.
[14] Y. D. Li, K, B, Liu, "TPS Fast Corrector Magnet Power Converter", Proceedings of IPAC2011, San Sebastián, Spain.
[15] D-TACQ: http://www.d-tacq.com.
[16] P. Leban, at al., "Fast orbit feedback calculation implementation for TPS**"**, these proceedings.
[17] Dimtel, Inc.: http://dimtel.com.
[18] http://sales.hamamatsu.com/en/products/system-division/ultra-fast/streak-systems/part-c10910.php.