DESIGN STATUS OF THE DIAGNOSTIC SYSTEM FOR THE TAIWAN PHOTON SOURCE PROJECT

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Abstract

The Taiwan Photon Source (TPS) is a 3 GeV synchrotron light source being built at the campus of NSRRC. Designs of various diagnostics are under way, and will be deployed in the future, to satisfy stringent requirements of TPS for commissioning, top-up injection, and operation. These designs, including beam intensity observation, trajectory and beam positions measurement, destructive profile measurement, synchrotron radiation monitors, beam loss monitors, orbit and bunch-by-bunch feedbacks, filling pattern, etc., are in the final design phase. Details of current status and implementation of the planned beam instrumentation system for the TPS will be summarized in this report.

INTRODUCTION

The TPS is a state-of-the-art synchrotron radiation facility featuring ultra-high photon brightness with extremely low emittance [1]. Civil construction was started from February 2010. The building will be finished in 2012. The campus of the NSRRC, which host the TPS and the existing 1.5 GeV Taiwan Light Source (TLS), is shown as Fig. 1. Machine commissioning is scheduled in late 2013. User service will start from 2014.

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 latest generation diagnostic systems will help TPS to achieve its design goals. The storage ring has 24 double-bend achromat lattice cells with 6-fold symmetry. The main beam diagnostics related parameters for the booster synchrotron and the storage ring are summarized in Table 1.

Figure 1: Aerial view of the NSRRC campus. The upper left building is the existed TLS facility. The semi-underground building at upper right is the TPS facility.

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	-

To get the benefits of the high brightness and small sizes of TPS sources, photon beams must be exceedingly stable, in position and in angle, to better than 10% of beam sizes and divergence. Table 2 gives 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 an insertion-device source ($\sigma_y = 5.11$ μm); this will require special consideration for measuring both electron and photon beams.

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^o source point)	39.73	76.11	15.81	1.11

LINAC DIAGNOSTICS

The TPS 150 MeV linac system was contracted to the RI Research Instruments GmbH (formerly ACCEL Instruments GmbH) [2]. The schedule for delivery and commissioning is early 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 (FCTs) [3] to monitor the distribution of charge and one integrating current transformer (ICT) for monitoring total bunch train charge. Wall current monitors (WCMs), which are 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. Linac diagnostics are summarized in Table 3. All of these diagnostics will be provided by the vendor. Acceptance test of the linac system will be performed at a temporary site near the TPS main building before its completion and moved to the TPS building later. It is also planned that beam position monitors (BPM) might be added between accelerator sections. These BPMs will be useful for RF phasing monitoring, feedback control and on-line beam position jitter observation.

Table 3: Linac Diagnostics

Monitor	Quantity	Beam parameters
YAG:Ce screen	5	Position, profile
WCM	1	Intensity distribution
FCT	2	Intensity distribution
ICT	1	Charge at exit of the linac

TRANSFER LINE DIAGNOSTICS

Planned diagnostics for the LTB and the BTS [1] are summarized in Tables 4 and 5 respectively. The YAG:Ce fluorescence screens will provide information on beam position and profile. The OTR screens are also to be used for high precision beam emittance and energy spread measurement at the diagnostic branch of the LTB and at a selected position in the BTS to avoid saturation of YAG:Ce screens. Integrating current transformer will provide information of beam charge pass LTB and BTS and hence on the beam losses during the injection cycle. The beam trajectory will be monitored with beam position monitors equipped with Libera Brilliance Single-Pass [4]; its functionality is similar to that of the BPM electronics for the booster and the storage ring, but it is equipped with aq high gain analogue board to improve its performance for single pass measurement.

Table 4: LTB Diagnostics

Monitor	Quantity	Beam parameters
YAG:Ce/OTR screen	6	Position, profile (1 at diagnostic branch). OTR screen will be adopted for the site of high precision profile measurement to avoid saturation of YAG:Ce screen.
FCT	2	Beam intensity
ICT	1	Beam charge
BPM and single pass electronics	7	Beam position
Energy define slit	1	1 pair of horizontal jar

Table 5: BTS Diagnostics

Monitor	Quantity	Beam parameters
YAG:Ce/OTR screen	3	Position, profile, booster extraction beam emittance
FCT	1	Beam intensity
ICT	2	Beam charge, installed at upstream and downstream of the BTS
BPM and single pass electronics	6	Beam position, relative intensity

BOOSTER DIAGNOSTICS

Booster diagnostics [1] will provide beam parameters including orbit, working tunes, circulating current and filling pattern, emittances for both planes, and bunch length. Planned diagnostics are summarized in Table 6. Fluorescent screens will be installed at the injection and extraction sections and at the other lattice cells to facilitate booster commissioning, troubleshooting and psychology needs—to see is to believe. The screen material will be YAG:Ce, which has excellent resolution of the beam image and exhibits high sensitivity and high radiation hardness. 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 to simplify maintenance. The sum signal from the receivers can be used to monitor fast history of the beam current.

Circulating current will be measured with Bergoz's NPCT, while bunch pattern will be monitored with a fast current transformer. For tune measurement, the electron beam will be excited with white noise using striplines. The beam response will be observed with a real-time spectrum analyzer connected to the dedicated BPM buttons with the front end. 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. Synchrotron radiation from a dipole will be used to observe the beam profile during energy ramping and emittance measurements. The capability to monitor bunch length with a streak-camera will be also provided.

Table 6: Booster Synchrotron Diagnostics

Monitor	Quantity	Beam parameters
NPCT	1	Averaged beam current
FCT	1	Filling pattern
BPM (4 button pick-ups)	60 (30)	Beam position
Set of striplines and amplifiers	2	Betatron tune, bunch cleaning system
YAG:Ce screen (Fluorescent screen)	6	Beam profile and position at injection, extraction, and at every lattice cells
Synchrotron light monitor, profile and streak camera (visible light)	2	Beam size (emittance), bunch length
Bunch cleaning system	1	-

STORAGE RING DIAGNOSTICS

The beam diagnostics system is designed to provide a complete characterization of the beam and the TPS 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, etc. A large number of beam monitors and devices will be installed in the storage ring. The types and quantities of these devices are listed in Table 7.

Table 7: Planned Storage Ring Diagnostics

Monitor	Quantity	Beam parameters
NPCT	1	Averaged beam current, beam lifetime
Sum signal of BPM buttons	1	Fill pattern, bunch current
BPM (4 button pick-ups)	168	7 BPM/cell
BPM (4 button pick-ups)	1	For bunch-by-bunch feedback pickups
Striplines	1	Betatron tune measurement
Transverse kickers and amplifiers	2	Horizontal and vertical kicker for transverse feedback and bunch cleaning usage.
YAG:Ce screen (Fluorescent screen)	1	Beam profile and position just after injection septum
PIN diode type beam loss monitors	4~6 per cell	Beam loss pattern
Scintillation loss monitor	24	High counting rate type beam loss monitor
Scrapers	2 sets per plane	1 set = 2 blades

Intensity monitor

A high precision averaged current measurement will be performed by Bergoz's NPCT [3]. 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. Fill pattern of the storage ring observed from the sum signal of BPM buttons by wide bandwidth 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 in top-up operation and various studies.

Electron Beam Position Monitor

Each cell will have five standard RF BPMs mounted on elliptical chambers, and 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 mm button diameter and 17.7 mm separations on the 60 × 30 mm elliptical chamber has been implemented. The BPM constant is around 13 mm in both planes were achieved with adequate linearity. The primary BPM is planned to install in 20 mm height racetrack chamber with monitor constants around 9 mm. The current generation standard BPM electronics—Libera Brilliance [4]—were chosen as the baseline design at the conceptual design phase. Updated BPM electronics platform equipped with more advanced parts and enhanced functionality are in serious consideration and being discussed with the possible vendor. Despite the performance of current generation BPM electronics can meet the stringent requirement of TPS, a new BPM platform is better to avoid obsolescence of parts and improve small defects in the existing products.

X-ray Beam Position Monitor

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, and delivery of slow data (~ 10 Hz rate) for control system access and fast data (~ 10 kHz rate) for feedback purposes. The fast data should be 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 for slow access form the machine control system side and beamline control system side. A commercial product like Libera Photon [4] might be a candidate with required functionalities. A prototype of Libera Photon has been tested intensively at the 1.5 GeV Taiwan Light Source [5].

Infrastructure for Orbit Measurement, Control and Feedback

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 platform at a 10 kHz rate by using FPGA grouping scheme (e.g., Diamond Communication Controller or Gigabit Ethernet Grouping) or a new design. The orbit of the whole ring can be accessed from any BPM platform. Fast data from the XBPM will be integrated with the BPM systems in a seamless way.

The TPS will adopt a specially design high performance corrector power supply. 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. 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 a nano-radian level kick for s slow corrector with maximum ± 600 μrad kick. Control of each cell's corrector will be through a specially designed 20 bits (or 18 bits) DAC module [6] as shown in Fig. 2. This module will provide an EPICS CA interface via cPCI backplane of a standard EPICS IOC, for configuration and for setting and monitoring status. Up to four fast setting ports will be provided for a 10 kHz data stream. The four fast setting ports might configure as Rocket I/O and Gigabit Ethernet for different applications. The Rocket I/O is suitable for orbit feedback application with less overhead. The gigabit Ethernet interface to receive unidirectional UDP package via private Gigabit Ethernet can be used as global feed-forward applications.

The feedback calculation will be performed by the FPGA module in the BPM platform. This FPGA module will perform two functions: grouping the whole ring BPM data by using two counter-rotating redundant links around the ring; and serving as a feedback engine. BPM data grouping provides a way to distributed all BPM and XBPM data around the TPS storage ring at all BPM platforms at a 10 kHz rate. Orbit feedback computation will distribute to the FPGA modules and will be installed at the BPM platform in each cell. One or two sniffer (eavesdropping) nodes will be setup to capture orbit information with 10 kHz rate for more than 10 s of 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.

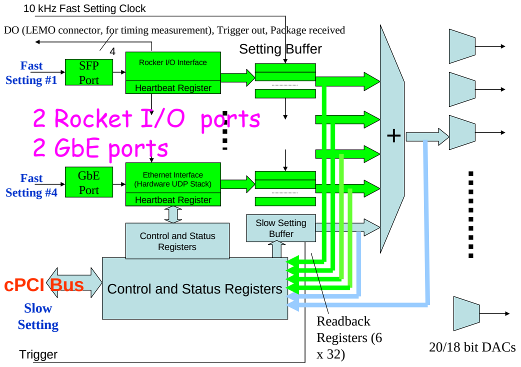

Figure 2: Functional block diagram of the corrector power supply control cPCI DAC module. The EPICS channel access is via backplane. The fast setting from feedback engines or feed-forward engines will sum with the EPICS CA slow setting.

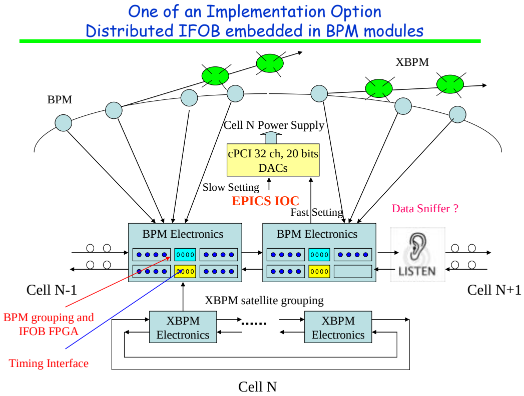

Figure 3: Functional block diagram of the orbit feedback infrastructure.

The DAC modules design will support 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 settings can be issued from EPICS IOCs or dedicated computers; more than 200 Hz rates are feasible. Beam excitation by noise can be performed by a similar scheme.

Bunch-by-Bunch Feedback and Diagnostics

Transverse coupled-bunch instability, mainly caused by the resistive wall impedance and other sources, will deteriorate beam quality. Bunch-by-bunch feedback is planned to suppressed instabilities to ensure TPS will achieve its design goals. The system will be implemented in vertical plane and horizontal plane. Planned transverse feedback kickers will adopt the SLS/ELETRA design and be compatible with the TPS vacuum vessel. A transverse signal pick-up will be used as an extra BPM and installed at a 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, beam excitation, 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 integration with the control system. An on-line control interface to operate feedback system and off-line analysis tools should be included.

A functional block diagram of the planned bunch-by-bunch feedback system is shown as Fig. 4. Commercial feedback processor like Libera Bunch-by-Bunch from I-Tech [4] and iGp12 from Dimtel [7] are the candidates. Both have similar functionalities. Testing of the Libera Bunch-by-Bunch and the iGp are ongoing in the 1.5 GeV Taiwan Light Source.

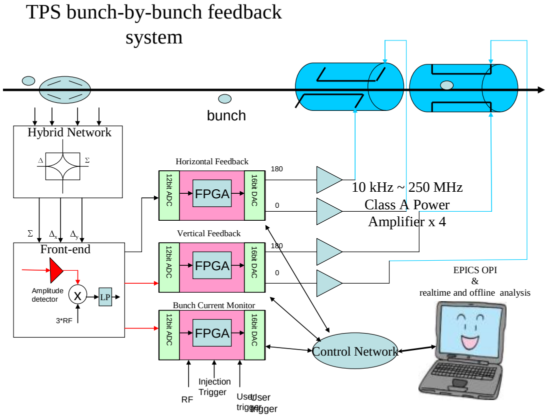

Figure 4: Functional block diagram of the bunch-by-bunch feedback system.

Beam Loss Monitor (BLM)

The storage ring plans to use coincidence PIN diode BLMs for loss pattern measurement. Scintillation detectors will also be used for high counting rate applications, such as loss mechanism selective experiments. Both PIN and scintillation type BLMs will work in counting mode. The data acquisition will be performed by the nearby EPICS IOC and can be performed synchronously. Distributed dosage measured on-line by using RADFET [8] is also under study. Fiber based Cerenkov radiation type BLMs are being considered.

Scraper

Two pairs of two-plane adjustable-position scrapers will be installed on the ring to be used both as protective devices and as diagnostic instruments for accelerator studies. One set of scrapers (H/V) will be installed in the dispersive section to measure the energy distribution of the electron beam. Another set will be installed in a straight section with zero dispersion in order to have information on the transverse size of the electron beam.

Synchrotron Radiation Diagnostics

The photon diagnostics for the TPS storage ring will utilize visible light and X-ray of the synchrotron radiation generated in a bending magnet. Planned photon diagnostics devices are summarized in Table 8. A cisible light beamline will be built to measure various beam parameters with a streak camera [9], CCD camera and interferometer. The streak camera operates at 250 MHz; synchroscan mode is preferred to observe beam behavior of consecutive bunches. Integrating the streak camera system with EPICS is preferred.

Two X-ray pinhole cameras, imaging the electron beam from bending magnets, is the baseline design for the TPS emittance measurement. 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 make it possible to measure very small beam sizes—a few microns typically. Its main function will include measurement of the electron beam energy spread and vertical beam size. Measuring the fill pattern by using time correlated single photon counting (TCSPC) is also being considered. An avalanche photodiode detector (APD) will be used to detect scattered X-ray photon as input of the TCSPC system. More than six orders of magnitude of dynamic range (10^6) can be achieved easily.

Table 8: Synchrotron Diagnostics

Monitor	Quantity	Beam parameters
X-ray pinhole camera	2	Emittance vertical and horizontal planes. Averaged profile as well as single turn profile
Time correlated single photon counting system (Visible light or X-ray)	1	Fill pattern, isolated bunch purity X-Ray APD
XBPM	1 or 2 per beamline	Position and angle of ID radiations
Visible light synchrotron light diagnostic station, Imaging and streak camera	1	Alternative beam size measurement (emittance), either imaging the vertical polarized synchrotron light or interferometer, bunch length
Streak camera	1	Visible beamline, Bunch length

SUMMARY

Beam diagnostics designs and implementation for the TPS are proceeding, as summarized in this report. The critical diagnostic systems, addressing beam stability and low emittance monitoring, are being investigated in the design phase. Major procurement are scheduled in 2011~2012. Optimizing the design, prototyping, and working out = specifications are current efforts. System integration is planned in 2013. Delivering a best diagnostic system to satisfy the stringent requirements of TPS is the goal.

ACKNOWLEDGEMENT

The author K.T. Hsu appreciates help from many experts, especially Robert Hettel, Michael Böge, Guenther Rehm, Greg Portman, Julien Bergoz, Dmitry Teytelman, Peter Milne, and the I-Tech team for brainstorming and discussion.

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