DIAGNOSTICS OVERVIEW FOR THE TAIWAN PHOTON SOURCE

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Abstract

A new high brilliant 3 GeV storage-ring-based light source - Taiwan Photon Source (TPS), is planned to be built at National Synchrotron Radiation Research Center. Various diagnostics will be deployed to satisfy stringent requirements for commissioning, operation, and top-off injection of the TPS. Specifications and overview of the planned beam instrumentation system for the TPS are summarized in this report. The efforts including diagnostic devices and subsystems will be addressed also.

INTRODUCTION

The TPS project will be a state-of-the-art synchrotron radiation facility featuring ultra-high photon brightness with extremely low emittance. It 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. Latest generation diagnostic systems will equip TPS to fulfill its design goals. The storage ring has of 24 DBA lattices cells. It is a 6-fold symmetry configuration. The main beam diagnostics related parameters for the storage ring are shown below in Table 1.

Table 1: Major Parameters of the TPS 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
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)	-	8.40338
Repetition rate (Hz)	3	-

To realize the benefits of the high brightness and small sizes of TPS sources, photon beams must be exceedingly 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 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 2: The Electron Beam Sizes and Divergence

Source point	σ_x (μm)	$\sigma_{x'}$ (μrad)	σ_y (μm)	$\sigma_{y'}$ (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 (former ACCEL Instruments GmbH) in December 2008 [1]. The delivery schedule is around the border of 2010/2011. 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) formed by equally spaced broadband ceramic resistors mounted on a flexible circuit board, wrapped around a short ceramic break, will also give information on beam charge as well as longitudinal profiles of electron bunches. Linac diagnostics are summarized in Fig.1 and Table 3. All of these mentioned 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 move to the TPS building later. It is also planned that beam position monitors (BPM) might be added between accelerator sections are also planned. These BPMs will be useful for RF phasing monitoring, feedback control and on-line beam position jitter observation.

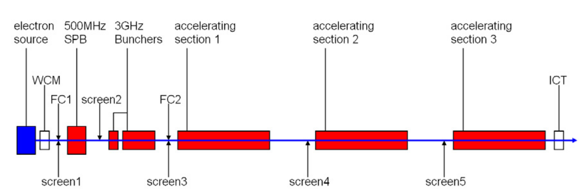

Figure 1: Functional block diagram of the linac diagnostic devices.

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 [2] are summarized in Table 4 and 5 respectively. The YAG:Ce fluorescence screens will provide information on beam position and profile. 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 selected position of 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 [3], its functionality is similar as the BPM electronics for the booster and the storage ring but is equipped with 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 slits	1	1 pair of horizontal blade

Table 5: BTS Diagnostics

Monitor	Quantity	Beam parameters
YAG:Ce/OTR screen	3	Position, profile, booster extraction beam emittance.
FCT	1	Beam intensity
ICT	1	Beam charge
BPM and single pass electronics	6	Beam position, relative intensity.

BOOSTER DIAGNOSTICS

Booster [4] diagnostics will provide beam parameters including orbit, working tunes, circulating current and filling pattern, emittances for both planes, bunch length. Planned diagnostics are summarized in Table 6. 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 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 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, 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	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 every lattice cells.
Synchrotron light monitor, profile and streak camera (visible light)	1	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 [5], including beam closed orbit, size, tune, circulating current, filling pattern, lifetime, chromaticity, beam loss pattern, beam density distribution, emittance, and bunch length. A large number of beam monitors and devices will be installed in the storage ring. The types and quantities of these devices are given in Table 7.

A high precision DC current measurement will be provided by Bergoz's NPCT. The NPCT device provides a resolution of better than 1 $mA/Hz^{1/2}$ and has large dynamic range/ bandwidth, making it a versatile device for measuring lifetime and injection efficiency. Filling 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 fill charge distribution of each bunch to better than 0.5% accuracy. This information is sufficient for filling pattern control in top-up operation and various studies. Each cell will have five standard RF BPMs mounted on elliptical chambers, up to two primary RF BPMs located in the ID straight section mounted on racetrack chambers; and up to two X-ray photon BPMs (XBPM) per beamline. To achieve the highest level of orbit measurement resolution, the optimization of the button geometry to obtain a high level of BPM resolution for both standard and primary BPMs is in progress. Prototype BPM equipped with 6.5 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 is planned to install in 20 mm height racetrack chamber with monitor constants around 9 mm. BPM mounted on 11 mm small gap ID chamber is also considered. Striplines and a bunch-by-bunch feedback system is also in design phase.

Table 7: Storage Ring Diagnostics

Monitor	Quantity	Beam parameters
NPCT	1	Averaged beam current Beam lifetime
Sum signal of BPM buttons	1	Filling pattern Bunch current
BPM (4 button pick-ups)	168	7 BPM/cell
Set of striplines and amplifiers	2	Betatron tune, bunch cleaning system 2 sets, 1 set = 4 electrodes.
YAG:Ce screen (Fluorescent screen)	1	Beam profile and position just after injection septum
PIN diode type beam loss monitors	2 per cell	Beam loss pattern
Scintillation loss monitor	10	High counting rate or integrated type beam loss monitor
Scrapers	2 sets per plane	1 set = 2 blades

TPS will utilize a distributed beam loss monitoring system based on p-i-n diodes, which are commercially available. For the temporal distribution of the loss particles (on the scale of one turn) scintillation detectors will be used. These can also be used for monitoring the losses of injected electrons near the injection and RF straights.

Two pairs of two-plane adjustable-position scrapers will be installed on the ring to be used both as protective devices as well as diagnostics 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, and to eliminate possible beam halos capable of affecting the insertion devices.

The photon diagnostics for the TPS storage ring will utilize visible and X-ray synchrotron radiation generated in a bending magnet. Planned photon diagnostics devices are summary in Table 8. Visible light beamline will be built to measure various beam parameters by streak camera, CCD camera and interferometer. One or two X-ray pinhole cameras imaging 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 accurately measure the electron beam size, typically 40x15 μm^2 for 1% coupling, at all currents from below 1 mA to 400 mA. Optimization of the X-ray pinhole system will give the possibility to measure very small beam sizes in a few microns typically. Its main function will be measurement of the electron beam energy spread and monitoring vertical beam size. Measuring the filling pattern by using time correlated single photon counting (TCSPC) method is also considered.

Table 8: Storage Ring Synchrotron Diagnostics

Monitor	Quantity	Beam parameters
X-ray pinhole camera	1	Emittance vertical and horizontal planes. Equilibrium profile Single turn profile Bunch-by-bunch profile.
Time correlated single photon counting system (Visible light or X-ray)	1	Filling pattern Isolated bunch purity
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 interfereometer.
Streak camera	1	Bunch length

SUMMARY

Beam diagnostics plans for the TPS project are summarized in this report. Detailed design is underway. The critical diagnostic systems, addressing beam stability and low emittance monitoring, are being investigated in the design phase. Delivering a best diagnostics system to satisfy stringent requirements of TPS is the goals.

REFERENCES

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