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PRELIMINARY BEAM TEST OF SYNCHROTRON RADIATION MONITORING SYSTEM AT TAIWAN PHOTON SOURCE

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Abstract

Taiwan Photon Source (TPS) is a third generation 3 GeV synchrotron light facility. The synchrotron radiation from a dipole can be used to observe the beam parameters. The synchrotron radiation monitor (SRM) systems were designed and implemented for the booster synchrotron and storage ring. The SRM for the booster synchrotron can serve to diagnose the energy ramping process. The beam size decreases when the energy increases was observed. In the storage ring, the streak camera was preferred to observe the beam behaviour of the consecutive bunches. The bunch length and longitudinal instability were observed. The preliminary beam test results are summarized in this report.

INTRODUCTION

The Taiwan Photon Source (TPS) is a state-of-the-art synchrotron radiation facility featuring ultra-high photon brightness with extremely low emittance. 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 has 24 DBA lattices cells with 6-fold symmetry configuration [1]. The TPS commissioning is separated into two phases. Phase I commissioning was done in the first quarter of 2015 with two Petra 5-cells cavities and without insertion devices. Phase II commissioning is scheduled to start in the third quarter of 2015 with two superconducting RF cavities and insertion devices.

The synchrotron radiation monitors are designed in the booster and storage ring of the TPS, which play an important role during the commissioning. The SRM for the booster synchrotron serves to characterize energy ramping process. In the storage ring, SRM can be used to measure the beam size, bunch length and beam behaviour, and fill pattern by X-ray pinhole camera, streak camera, and photon counting technique, respectively. The design overview and preliminary beam test results are presented in this paper.

SYSTEM DESIGN

Synchrotron Radiation Monitor for Booster

The SRM design of booster synchrotron was shown in Fig. 1. The light leads to the wall via a four-piece adjustable mirror, focusing through a lens (f = 1 m) and band-pass filter to GigE Vision camera. The camera trigger is synchronized with the machine cycle; change the delay time will change the energy point of observation. A 1-inch size CCD is used to quickly and easily to find a first-time beam spot. During the commissioning, a few times entering the tunnel is necessary to adjust the lens until the light beam is within the CCD's sensing area. This synchrotron light monitoring port was used for streak camera measurement for linac beam and booster stored beam also.

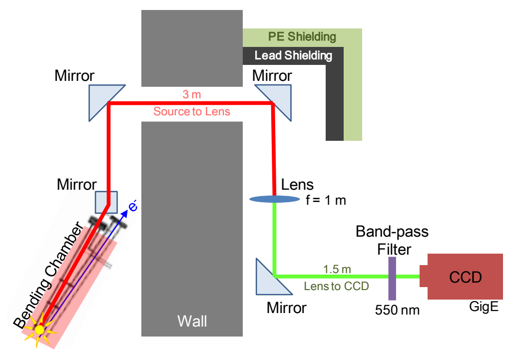

Figure 1: A side-view scheme of the synchrotron radiation monitor for the booster ring.

Diagnostics Beamline for Storage Ring

The photon diagnostics beamline for the TPS storage ring utilized visible light and X-ray of the synchrotron radiation which generated in a bending magnet. The photon diagnostics devices are summary in Table 1. The X-ray pinhole camera design as shown in Fig. 2, which is imaging the electron beam from bending magnet for the beam size and emittance measurements. They offer the required resolution and the dynamic range to measure the electron beam size accurately at all currents. The visible light of synchrotron radiation was design for streak camera, interferometer and fill pattern measurements, as shown in Fig. 3.

Table 1: The SRM Diagnostics Devices for Storage Ring

Monitor	**Beam parameters**
X-ray pinhole camera	Beam size and emittance
Fill pattern monitoring	Fill pattern and isolated bunch purity
Visible light interferometer	Alternative beam size
Visible light streak camera	Bunch length and behaviour

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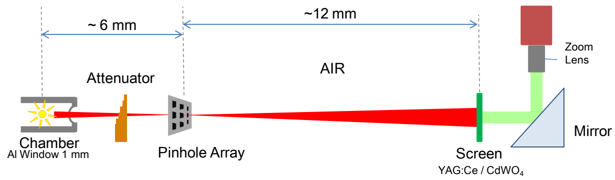

Figure 2: A side-view scheme of the X-ray pinhole camera for the storage ring.

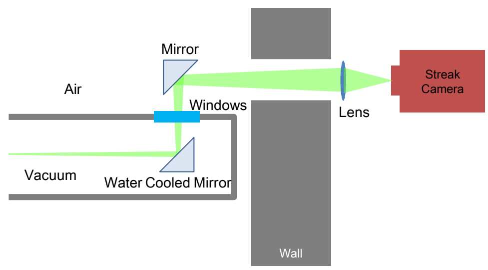

Figure 3: A top-view scheme of the visible light synchrotron radiation monitor for the storage ring.

SRM OF BOOSTER SYNCHROTRON

The shape and size of the electron beam profile vary during the energy ramping from 150 MeV to 3 GeV, as shown in Fig. 4. The beam size in both axes decreases when the energy increases due to radiation damping clearly (see Fig. 5). This result is consistent with the design [2].

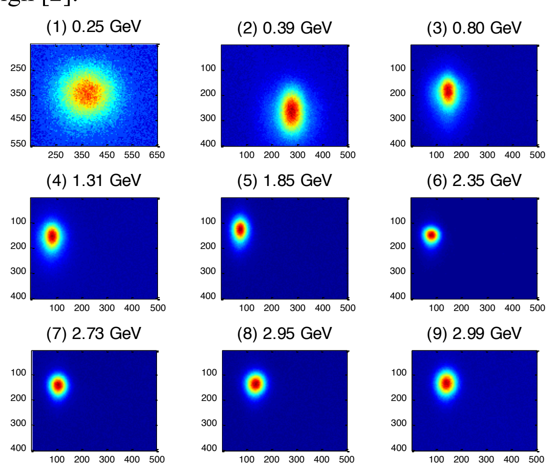

Figure 4: TPS booster synchrotron radiation profiles at varied energy ramping point, 1 pixel is around 9 μm.

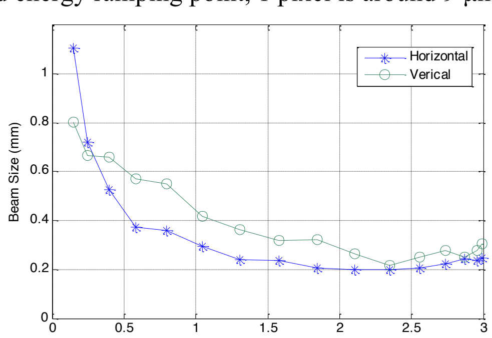

Figure 5: Measured variation of beam size with energy ramping of booster synchrotron.

X-RAY PINHOLE OF STORAGE RING

Beam Size Measurement

The beam size of single bunch measured via X-ray pinhole camera in low current (~2 mA) is 39.1±0.6 μm in horizontal and 15.7±1.5 μm in vertical, shown in Fig. 6. When the storage beam current increases, the beam size of the horizontal axis also increases, but the vertical axis is no significant change. The CCD exposure time is reduced (~10 ms) to avoid the measurement error caused by the beam oscillation due to mechanical vibration. The calculated emittance and coupling are $\varepsilon_x \approx 1.64$ nm·rad, $\varepsilon_y \approx 15.7\pm3$ pm·rad, and k ≈ 0.96% [3]. The TPS design natural emittance (ε_{x0}) is 1.6 nm·rad.

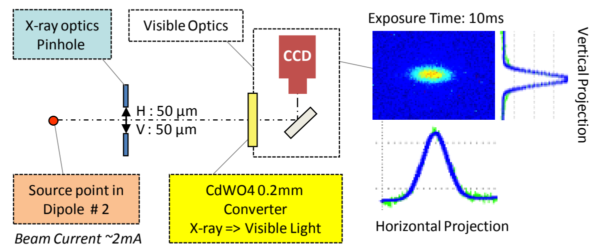

Figure 6: The pinhole camera parameters and measurement result under the single bunch mode. The storage beam current ~2 mA, the pinhole is set to 50 μm × 50 μm; CCD exposure time is 10 ms.

Resolution Measurement

The in situ resolution of the X-ray pinhole camera was analyzed by using the sharp edge from a Tungsten bar which mounted in front of the screen. Fitting a complementary error function (see Eq. 1) to the edge image, as shown in Fig. 7, the system resolution can be deduced. The resolution σ_{screen} is about 5 μm.

$$BG(X) = a_0 \cdot erfc\left(\frac{(a_1 - X)}{a_2}\right) + a_3 \tag{1}$$

, where BG is measured background intensity as a function of X position, a_0 is half-magnitude of the step, a_1 is location of the step, $(2\sqrt{\ln 2})a_2$ is the full width at half maximum (FWHM) of the Gaussian used to compute the complementary error function and a_3 is a constant offset.

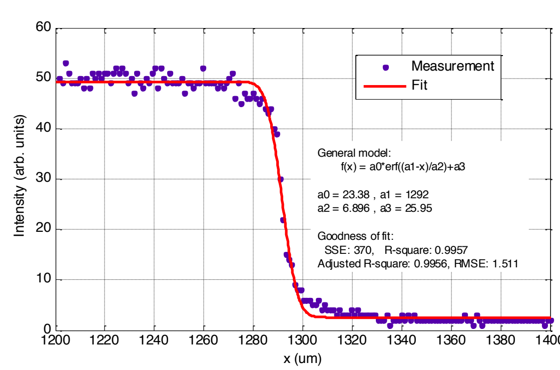

Figure 7: Resolution measurement of the X-ray pinhole camera, the resolution $\sigma_{screen} \approx 5$ μm.

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STREAK CAMERA MEASUREMENT

The streak camera is widely used in accelerator system for longitudinal as well as transverse dynamics study. A dual sweep streak camera (Model C10910, Hamamatsu Photonics) with one fast, one slow and two frequency of synchroscan sweep unit is used to perform temporal/longitudinal measurements on the beam at TPS. The commissioning of this streak camera was done in previous study [4]. The streak camera measurements of the synchrotron light measurement on the TPS storage ring includes bunch length, longitudinal instability, and bunch length vs. bunch current up to now.

Bunch Length Measurement

For the bunch length measurement, the synchroscan unit of 250 MHz is used. As shown in Fig. 8, the result shown that the bunch length of the TPS storage ring is around 11.4 psec (sigma) in low current (~0.2 mA) single bunch mode [3]. When the current is increased, the bunch length is also significantly increased shown in Fig. 9.

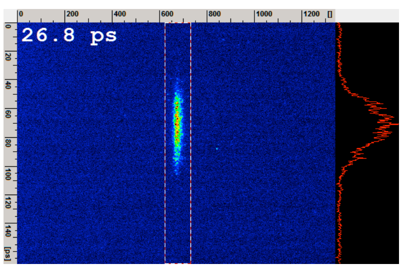

Figure 8: Typical streak image of bunch length measurement at TPS storage ring under single bunch mode, the bunch length ~26.8 ps (FWHM), storage beam current ~2 mA, vertical scale = 150 ps.

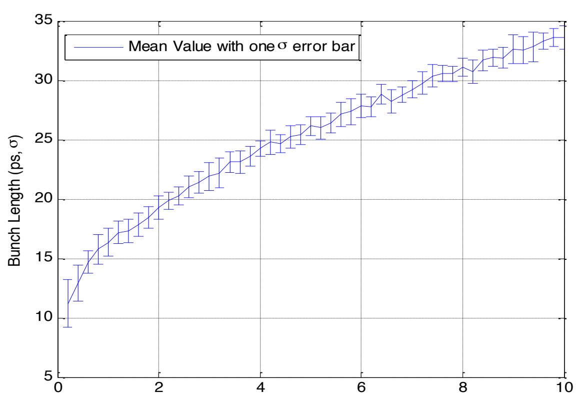

Figure 9: The relative relationship between the beam current and bunch length under the single bunch mode.

Longitudinal Instability

The longitudinal beam motion (phase information) could be observed by streak camera using the synchroscan unit (operate at 250 MHz) with dual-sweep unit. There will be a significant longitudinal motion occurs when beam current greater than a certain threshold value (~80 mA) in multi-bunch filled. The energy motion amplitude up to 150 psec was observed, as shown in Fig. 10.

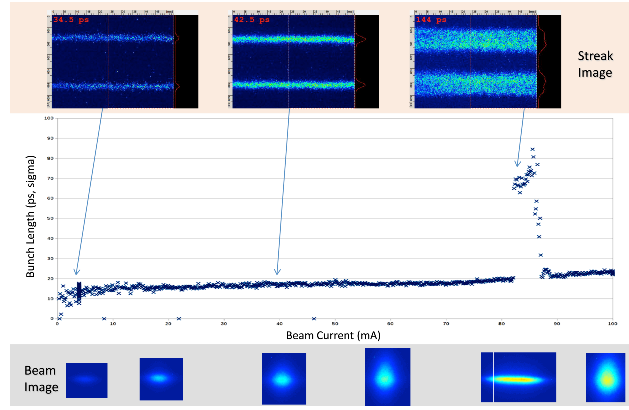

Figure 10: Longitudinal instability observation under multi-bunch via streak camera and X-ray pinhole camera.

FILL PATTERN MEASUREMENT

The TCSPC (time-correlated single-photon counting) technique is used for fill pattern measurement from the synchrotron radiation in storage ring. It provides measurement with picosecond time accuracy and many order of magnitude dynamic ranges. Preliminary single bunch impurity can achieve 10^{-5} (accumulated in 5 sec) shown in Fig. 11.

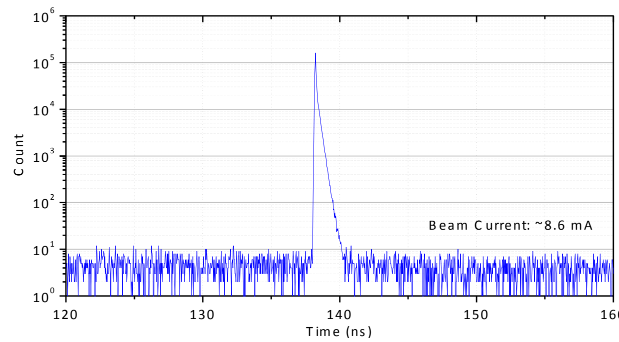

Figure 11: Preliminary single bunch purity measurement by time-correlated single-photon counting technique.

CONCLUSIONS

The synchrotron radiation monitor systems were designed and implemented for the booster synchrotron and storage ring, which play an important role for understanding the machine condition. Preliminary beam parameters measurements were done during phase I beam commissioning of TPS.

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