SYNCHROTRON RADIATION MEASUREMENT AT TAIWAN PHOTON SOURCE

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Abstract

The synchrotron radiation light produced from a dipole magnet is widely used to characterize beam parameters in synchrotron light source (photon synchrotron). The synchrotron radiation monitor (SRM) systems were implemented for the booster synchrotron and the storage ring at Taiwan Photon Source (TPS). The beam parameters of the booster were recorded during the energy ramping process through the CCD camera and streak camera. The beam size measurement and beam behavior observed of the storage ring were performed by X-ray pinhole camera and streak camera respectability. The results are summarized in this report.

INTRODUCTION

The Taiwan Photon Source (TPS) with low emittance and high photon brightness is a state-of-the-art synchrotron radiation facility. The TPS accelerator consists of a 150 MeV S-band linear accelerator (LINAC) system, 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 consists of 518.4 m circumference and 24 DBA lattice cells with 6-fold symmetry [1]. The TPS commissioning is divide into two phases. Phase-I commissioning, two 5-cells Petra cavities without insertion device was done in the first quarter of 2015. Phase-II commissioning will start in the third quarter of 2015 with two superconducting RF cavities and 10 sets of insertion devices.

The SRM play an important role during the Phase-I beam commissioning, which is designed for the booster synchrotron and storage ring of the TPS. Synchrotron radiation generated from a dipole bending magnet serves to characterize energy ramping process for the booster synchrotron. In the storage ring, SRM is used to characterize beam size by x-ray pinhole camera, bunch length and longitudinal dynamics by streak camera, and fill pattern by photon counting technique. The outline of design and preliminary beam test results are presented in this report.

SYSTEM DESIGN

Synchrotron Radiation Monitor for Booster

Synchrotron radiation light from a bending magnet is guided to outside of shield wall via a four-piece adjustable mirror. The light is focus by a lens with 1 m focal length. A band-pass filter is insert before the GigE Vision camera. The camera trigger is synchronized with the booster ramping trigger; change delay time will change the energy point of observation. This synchrotron radiation diagnostic port is located at downstream of the booster injection section, so it can used to observe linac beam and booster stored beam with streak camera. Setup for the CCD camera and streak camera is shown in Fig. 1.

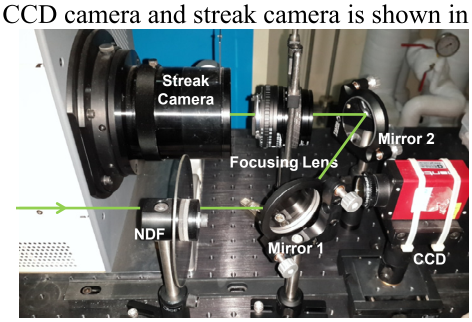

Figure 1: Optical layout of SRM measurement for booster synchrotron. The synchrotron light leads to the wall via a four-piece adjustable mirror and a lens (which are not shown here) then through a band-pass filter and additional two mirrors and focusing lens, finally to the streak camera system. Without the mirror 1, the synchrotron light is guided to the CCD camera.

Diagnostics Beamline for Storage Ring

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

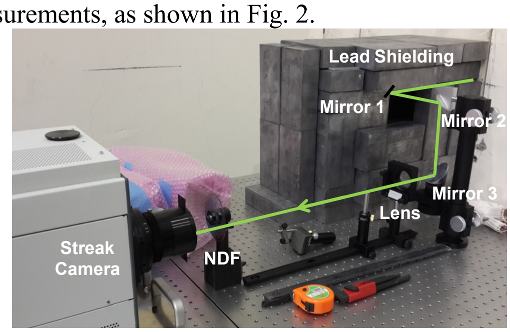

Figure 2: Temporary optical layout of SRM measurement for storage ring. The visible light of synchrotron radiation leads out of the tunnel, then through three mirrors, Lens, and band-pass filter, finally to the streak camera system.

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Table 1: The Monitors of Diagnostics Devices for SR

Monitor	Beam parameters
X-ray	
Pinhole camera	Beam size and emittance
TCSPC[a]/APD[b]	Filling pattern and purity of isolated bunch
Visible light	
Interferometer	Beam size
Gated camera	Beam size
Streak camera	Bunch length, Longitudinal and transverse dynamic
TCSPC/APD/ MCP[c] PMT[d]	Filling pattern and purity of isolated bunch

[a] Time-correlated single photon counting
[b] Avalanche photodiodes
[c] Microchannel plates
[d] Photomultiplier tubes

SRM OF BOOSTER SYNCHROTRON

The beam size of the electron vary during the booster energy ramping from 150 MeV to 3 GeV, as shown in Fig. 3.

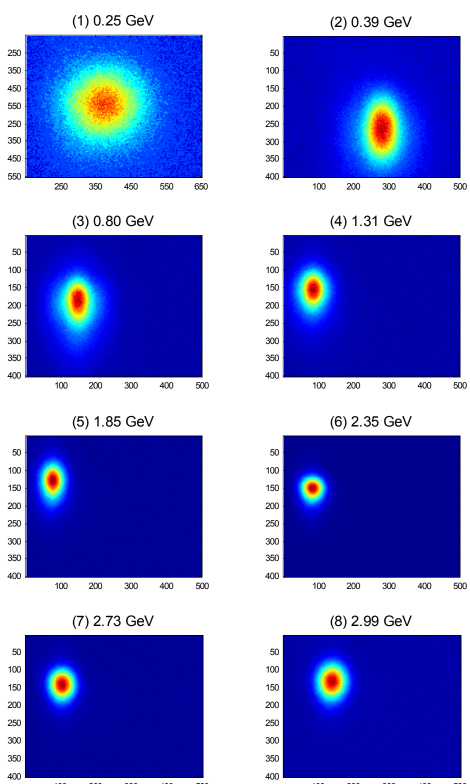
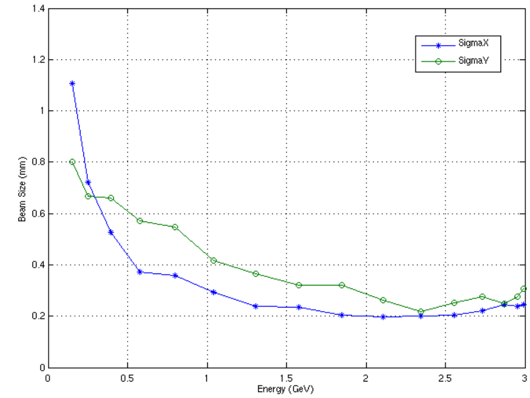
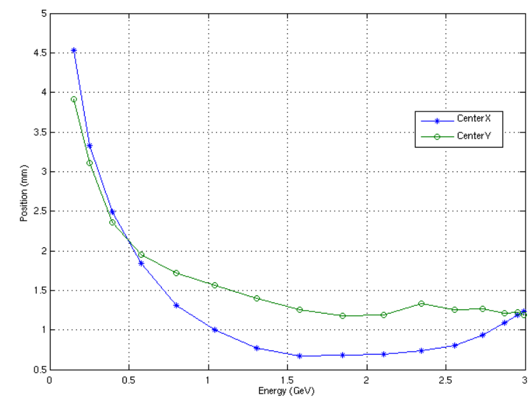


Figure 3: TPS booster synchrotron radiation profiles at varied energy during energy ramping, one pixel corresponding to 9 µm.

The beam size in both axes decreases when the energy increases due to radiation damping clearly, as shown in Fig. 4(a). This result is agree with the design [2]. The beam center position also change around 3.5 mm during the energy ramping as shown in Fig. 4(b) which are confirmed by the ramping orbit measurement BPM [3].



(a)



(b)

Figure 4: SRM measured of booster synchrotron during energy ramping from 150 MeV to 3 GeV, the variation of (a) beam size and (b) beam center position.

X-RAY PINHOLE OF STORAGE RING

Resolution Measurement

The in situ resolution of the X-ray pinhole camera was analysed by using the sharp edge from a Tungsten bar which mounted in front of the fluorescent screen. Fitting a complementary error function (see Eq. 1) to the edge image, the system resolution can be deduced to be about 5 µm [4].

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

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.

Beam Size Measurement

The X-ray pinhole camera is used to measure the beam size. The beam size versus beam current in single bunch mode as shown in Fig. 5. In low current (0.2 mA), the beam size around ~38 µm in horizontal and ~19 µm in

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vertical. 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.

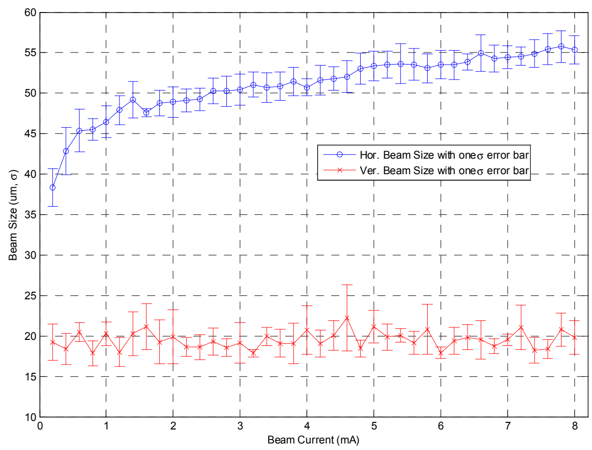

Figure 5: Plot of beam size measurement by X-ray pinhole camera in horizontal and vertical direction versus beam current under single bunch mode.

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 summary in previous report [5]. The streak camera for synchrotron light measurement on the TPS storage ring includes bunch length, longitudinal instability, and bunch length vs. bunch current up to now.

Injection Point and Energy Ramping of Booster

The TPS linac system consists e-gun, a 500 MHz subharmonic prebuncher (SPB), a 2998 MHz buncher and three 2998 accelerator linacs to producing 150 MeV electron beam. Electron gun have two operation mode, one is multi-bunch mode which electron beam generated by the 500 MHz modulated pulser, the other is single bunch mode which is generated by an avalanche transistor based pulser with base width less than 2 nsec. To produce pure single bunch at booster synchrotron should optimized timing setting and SPB setting [6]. Usually there will produced two to six s-band bucket dependent on tuning of the SPB and timing of e-gun pulser. For an optimized setting, the s-band bunch consists one main bunch and two small consecutive bunches before and after the main bunch. The synchrotron diagnostic port is located at the injection of booster synchrotron, it is possible to observed synchrotron radiation produce by linac beam. Figure 6 shown that three individual bunches with 333 psec separation are injected to the booster synchrotron. Following a beam capture process in the booster. The intensity indicated three bunches have difference population. Further study is needed and is planned to understand behind physics. This might provide an alternative tools for linac and injection tuning of the booster synchrotron. After beam injected to the booster, the SRM capture the ramping process as shown in Fig. 7. Measured bunch length around 17 psec (1 σ) at the setting of measure time. The bunch length and bunch phase are changing during the process, shown in Fig. 8.

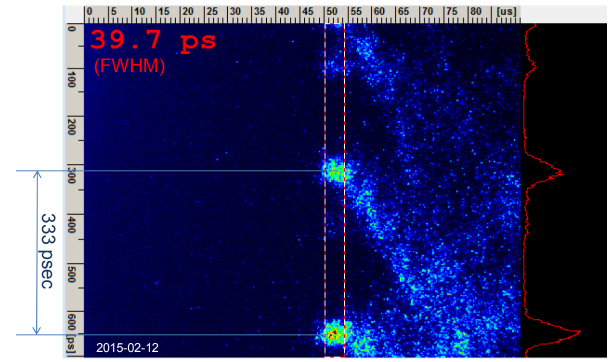

Figure 6: Injection point of at booster under single bunch mode, the bunch length ~17 ps (1 σ), vertical time scale = 700 ps, horizontal time scale = 90 μs.

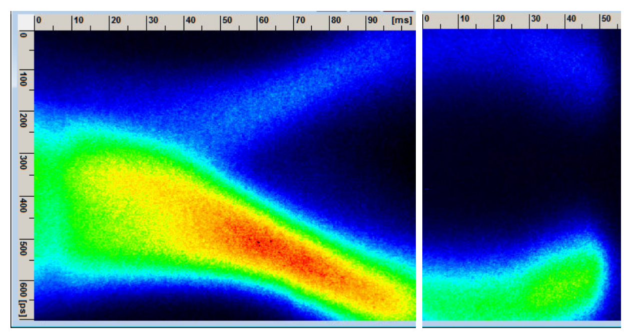

Figure 7: Bunch length as shrink during booster energy ramping observed by streak camera, vertical time scale = 700 ps, time scale for horizontal is millisecond.

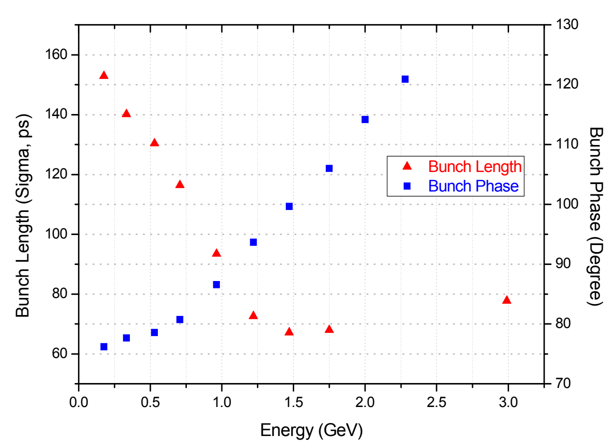

Figure 8: Bunch length and phase variation during the energy ramping process. Bunch length changes around 85 psec, bunch phase change around 45 degree.

Bunch Length Measurement of Storage Beam

The 250 MHz synchroscan unit is used for the bunch length measurement. The bunch length of the TPS storage ring is around 11.4 psec (sigma) in low current (~0.2 mA) single bunch mode [7]. When the current is increased, resistive-wall impedance contributed RF potential-well distortion as shown in Fig. 9. The Fig. 10 shows the bunch length as function of stored beam current at RF gap voltage 2.4 MV. The curve is fitted with Zotter's potential-well distortion cubic equation, longitudinal broadband impedance of |Z/n|=0.12 Ω is deduced [7].

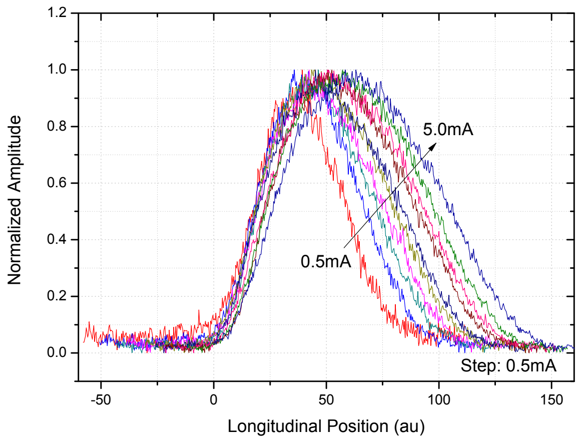

Figure 9: Single bunch profile distortion as function of beam current.

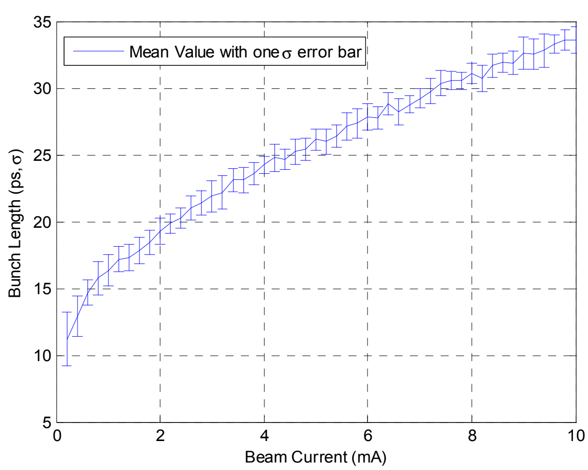

Figure 10: The relative relationship between the beam current and bunch length under the single bunch mode.

Longitudinal Instability

In the TPS commissioning beginning, there are many type of longitudinal beam motion (phase information) was observed by streak camera using the synchroscan unit (operate at 250 MHz) with dual-sweep unit, as shown in Fig. 11. The more stable situation is achieved through the concerted efforts of all groups, most of the longitudinal beam motion in the low current can be eliminated. However, there is a significant longitudinal motion occurs occasionally when beam current greater than a certain threshold value (~80 mA) in multi-bunch filled. The width of the streak trace growth up to around 144 psec (FWHM) which composed bunch length and energy oscillation amplitude, as shown in Fig. 12.

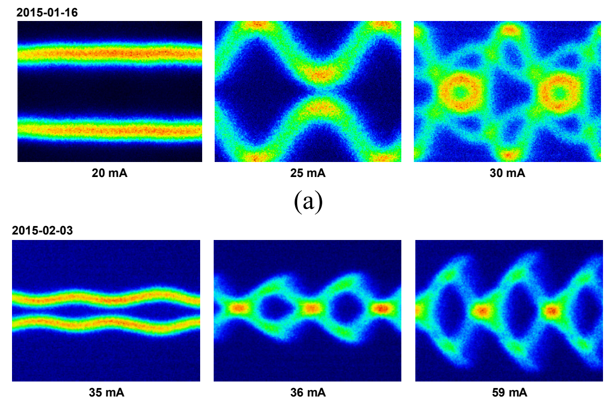

Figure 11: Longitudinal instability behavior of the stored beam observed by streak camera in TPS commissioning before amplitude feedback loop problem of RF system was identified. Both cases with difference chromaticity setting. (a) Stored beam current increase from 20 mA to 30 mA, (b) from 35 mA to 59 mA. Vertical time scale = 700 ps, horizontal time scale = 1 ms.

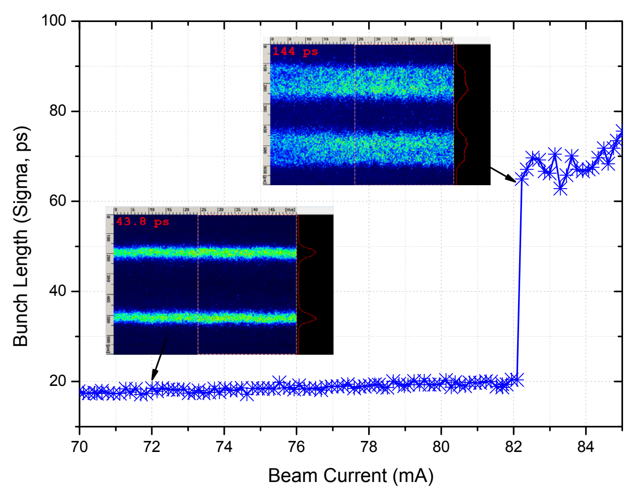

Figure 12: Longitudinal instability onset at 82 mA is indicated by the trace width of the streak camera increase in multi-bunch mode. Bunch length can measure before by the trace width below instability threshold. However, it failed after instability appeared.

FILL PATTERN MEASUREMENT

The time-correlated single-photon counting (TCSPC) technique is installed and used for fill pattern measurement from the synchrotron radiation in storage ring. It provides high dynamic range measurement with picosecond time accuracy high dynamic ranges. Typical stored single bunch beam at the storage ring is shown in Fig. 13(a) if linac parameters not optimized and special care. One main bunch accompany two satellite bunches existed. To obtain a pure single bunch beam, bunch cleaning by bunch-by-bunch feedback system is applied. It can keep bunch purity around 10^{-5} (5 sec accumulation of TCSPC counter) shown in Fig. 13(b) easily.

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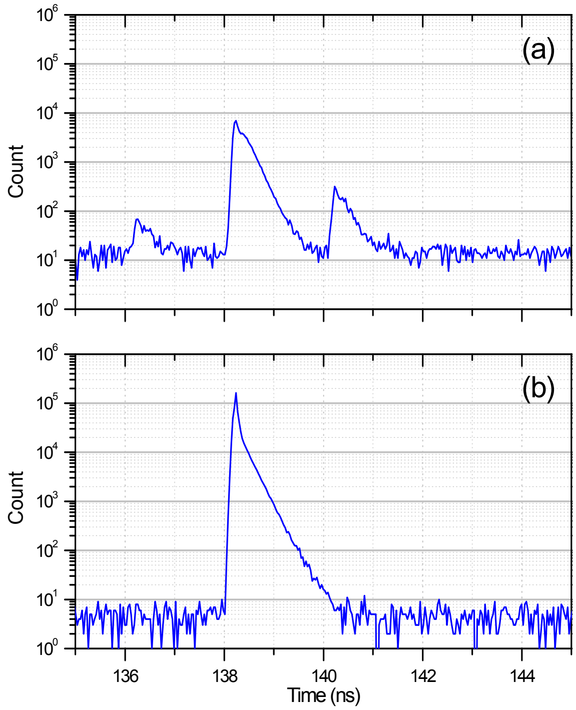

Figure 13: Single bunch purity measurement by TCSPC technique (5 sec accumulation), (a) before and (b) after bunch cleaning applied.

CONCLUSIONS

The synchrotron radiation monitor systems were designed, implemented and test for the booster synchrotron and storage ring during the Phase-I beam commissioning of TPS. It plays an important role for beam parameters measurement. Improvement is underway, preparation for Phase-II commissioning is in proceeding.

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