CHARACTERIZATION OF BEAM PROPERTIES USING SYNCHROTRON LIGHT AT TAIWAN PHOTON SOURCE

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Abstract

Taiwan Photon Source (TPS) is a third-generation 3-GeV synchrotron light facility, located in National Synchrotron Radiation Research Center (NSRRC) at Hsinchu Science Park. After overcoming many challenges, the storage beam current attained 520 mA in 2015 December. The synchrotron light monitors, including X-ray and visible light, are important diagnostic tools to characterize the various machine conditions. The booster beam dynamics during ramping and the beam properties of the storage ring were studied with synchrotron light. The results of measurements are presented in this report.

INTRODUCTION

On 2015 December 12, TPS with two superconducting RF cavities and insertion devices in ten sets achieved the storage beam current of 520 mA. The phase-I commissioning of TPS is available in this report [1]. The synchrotron light monitors play an important role during beam commissioning. Synchrotron light generated from a dipole bending magnet contains X-rays and visible light, which serve to characterize the beam properties with various machine conditions for the booster synchrotron and the storage ring. In this report, the characterization of the injected beam behaviour from the LINAC to the booster; the beam size with an X-ray pinhole camera, the bunch length and longitudinal dynamics with a streak camera of the storage ring are addressed.

SYSTEM DESCRIPTION

The synchrotron light monitors are designed in the booster and storage ring of TPS. The synchrotron light of the booster serves to characterize the energy ramping, which is observed with a CCD camera and a streak camera. In the storage ring, it can be useful to characterize the beam size, bunch length and beam behaviour with an X-ray pinhole camera and a streak camera. The design overview and experimental setup are presented in this section.

Synchrotron Light Monitor Setup

Synchrotron light generated by a bending magnet is guided by mirrors to outside of shielding wall through a small hole at downstream of booster injection section. In normal operation, it can be used for beam size and temporal behaviour measurement during energy ramping using the CCD camera and streak camera. The variation of the beam profile during the ramping of the booster energy from 150 MeV to 3 GeV was studied [2]. In this report, the injection behaviour was observed by the streak camera. The experimental setup is same as previous report [2].

The photon-diagnostics beamline with visible light and X-rays for the TPS storage ring is located at port #40. The X-ray pinhole camera was set up in a tunnel to measure the transverse beam size using a CCD camera [3]. The visible light is led from the wall and a hutch was built; the streak camera was used to characterize the beam properties. The detailed layouts of the booster synchrotron and storage ring are presented in a previous report [4].

Streak Camera

The streak camera is a powerful diagnostic tool in a synchrotron light facility, which can be used to characterize the varied beam properties [5]. A picosecond resolution with a dual-sweep streak camera (C10910, Hamamatsu Photonics) is used in TPS; this streak camera was commissioned in 2013 [6]. A 250-MHz synchroscan as fast axis (vertical) and dual-time sweep as slow axis (horizontal) is used in the report. The range of the synchroscan unit is about 170 ps to 700 ps; it is synchronized with the master clock (~500 MHz) through a divider to ~250 MHz. The slow time axis with a range 100 ns to 100 ms is triggered with a 10-Hz trigger unit and locked with the revolution frequency (booster, 603.8 kHz; storage ring, 578.3 kHz). To decrease the effect of space charge in the streak tube, the input light intensity is controlled with the slit (100 μm) to obtain satisfactory resolution of the image, but, in some cases, a wider slit (500 μm) and multiple exposures are required because of the low light intensity at low energy in the booster synchrotron.

INJECTION BEAM TO BOOSTER

The performance of the booster ring has been studied continuously [7]. There is a synchrotron diagnostic port located at the injection of the booster synchrotron; it is possible to observe synchrotron light produced with the 3-GHz LINAC beam. Three individual bunches with separation ~333 ps were injected into the booster synchrotron in a single-bunch mode, as shown in Fig. 1. The intensity indicates that the three bunches had different populations. The synchrotron frequency (~10 kHz) is clearly observed. The RF station phase can affect the capture behaviour of the beam. A properly RF station phase setting will improve capture efficiency. As shown in Fig. 2, the booster longitudinal beam motion vs. RF station phase at 180°, 175°, 140°, and 110° are presented. The station phase setting at 175°, the injected beam can capture better then at 110°. The synchronous phase shift is about 40° during booster ramping, which can be extracted from the streak image, as shown in Fig. 3. The injection behaviour measured by the streak camera provide an alternative tool for the LINAC and injection tuning of the booster synchrotron.

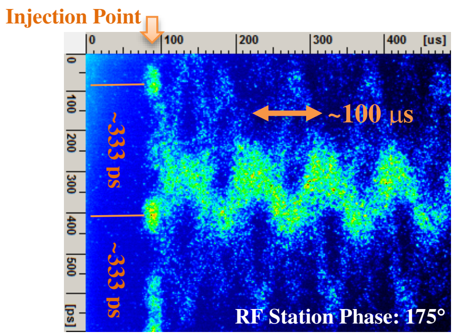

Figure 1: Injection point of the booster under a single-bunch mode, vertical time scale = 700 ps, horizontal time scale = 500 µs (~300 turns).

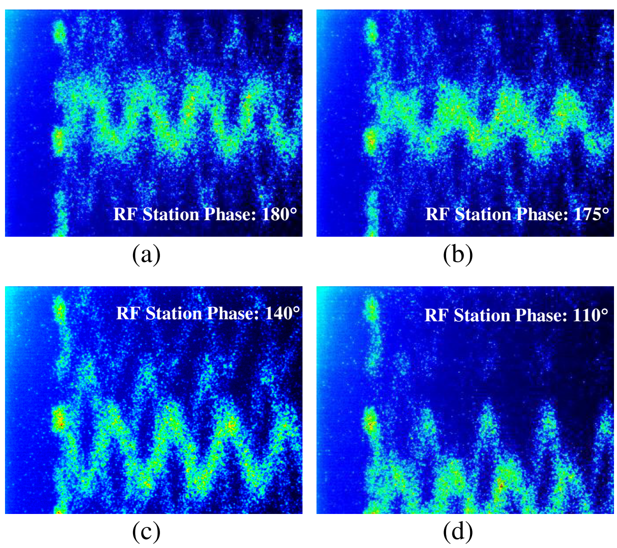

Figure 2: Booster longitudinal beam motion versus RF station phase (a) 180º, (b) 175º, (c) 140º, (d) 110º, vertical time scale = 700 ps, horizontal time scale = 500 µs.

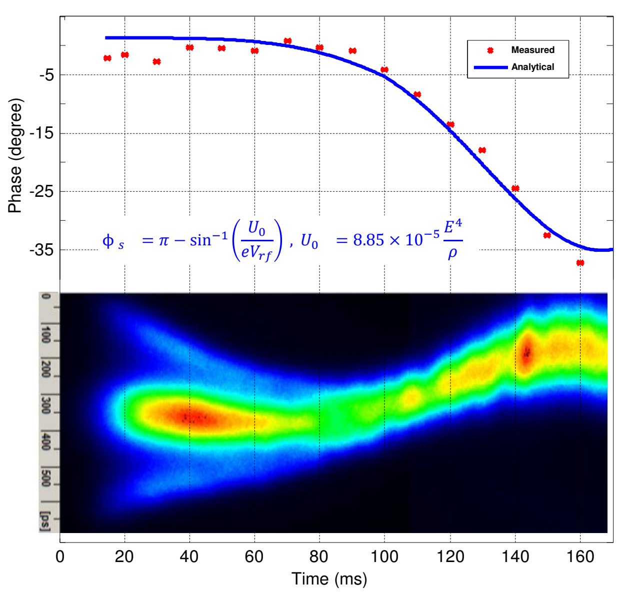

Figure 3: Synchronous phase shift during the booster ramping from 150 MeV (~20 ms) to 3 GeV (~160 ms).

MEASUREMENTS OF THE BUNCH LENGTH AND PHASE SHIFT

The bunch length as a function of bunch current up to 10 mA in a single-bunch mode at three RF gap voltage settings has been measured at the TPS 3-GeV storage ring, as shown in Fig. 4. The bunch length measured with the streak camera shows that the bunch became lengthened approximately in proportion to the cube root of the bunch current. The TPS phase-I insertion devices (ID) include seven sets of in-vacuum undulators (IU), two sets of EPU48 and one set of EPU46. Closing the IU gap can alter the geometry and decrease the impedances of the storage-ring vacuum tube. The impedance is flatter when all IU gaps are near 24 mm; the bunch length variation is shown in Fig. 5. There is only a slight effect on the bunch length, but a smaller impedance producing a smaller bunch length can still be found. The bunch phase shift with respect to the master clock for five sets of IU open (40 mm) and closed (7 mm) is ~30 ps due to the synchrotron radiation loss and longitudinal path change, as shown in Fig. 6.

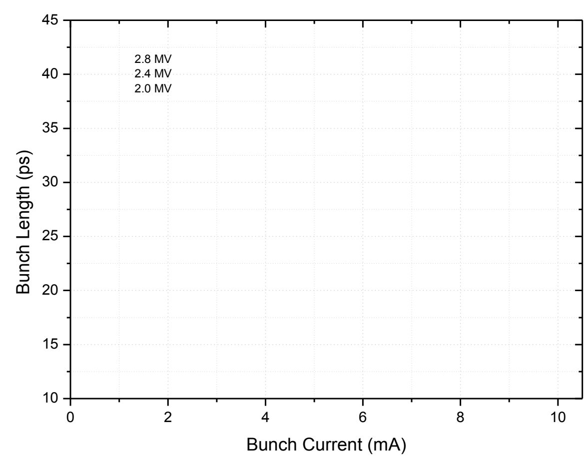

Figure 4: Single-bunch beam current versus bunch length (one σ) for RF gap voltages 2.0, 2.4 and 2.8 MV.

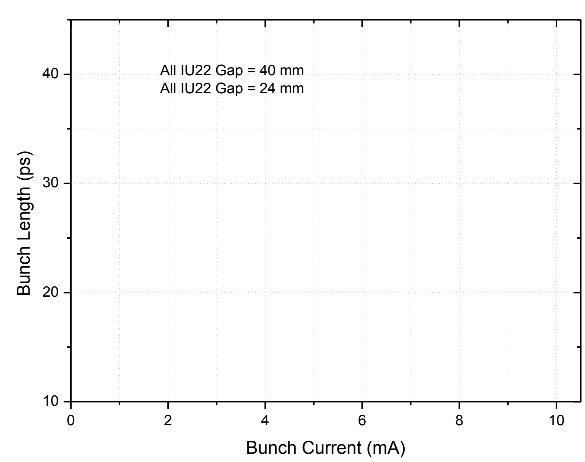

Figure 5: Dependence of bunch length (one σ) as a function of bunch current with varied IU22 gap setting with 2.8 MV RF gap voltage.

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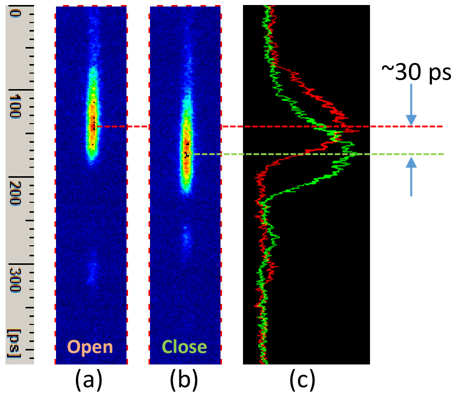

Figure 6: Bunch phase shift with ID gap open (a), closed (b); vertical time scale is 400 ps, horizontal is in pixel. The vertical projected profile (c) shows that there is a shift about 30 ps.

MEASUREMENTS OF BEAM SIZE

The X-ray pinhole camera was designed [3] and used to measure the beam size. The pinhole 50 µm × 50 µm is selected to measure the single-bunch beam size at a beam current from 0.5 mA to 10 mA at the storage ring. The results are shown in Fig. 7. In this case, the measured beam size at current 0.5 mA is about 58 µm in the horizontal and 18 µm in the vertical directions. The CCD exposure time is adjusted by maintain the peak value of the vertical projected profile during the measurement.

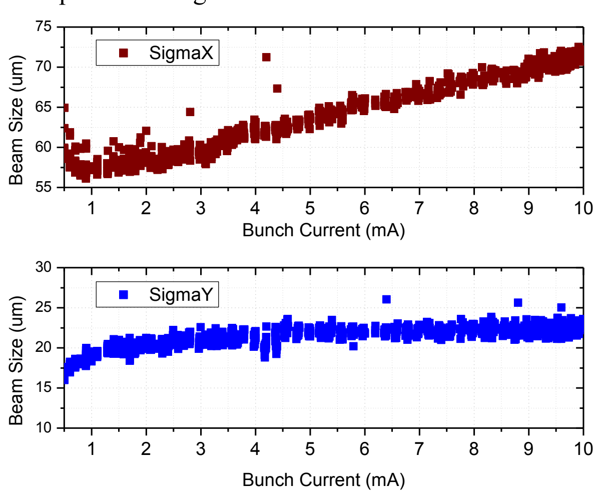

Figure 7: Measurement of single-bunch beam size as a function of bunch current.

In the multi-bunch operation, the interaction of bunches with the environment in which they move can cause issues about the coupled-bunch instabilities. These collective instability effects are curable with bunch-by-bunch feedback systems. Figure 8 shows that for the stored beam current from zero to 300 mA, the horizontal beam size blows up after about 100 mA. After the beam current reaches 300 mA, the beam sizes are horizontal ~75 µm, vertical ~28 µm. On actuating the feedback system, the horizontal beam size decreases significantly ~53 µm; the vertical beam size slightly increases to ~32 µm, which might be due to over-exciting the feedback loop during the measurement. When the top-up mode is operated, that condition maintains a steady beam current in the storage ring on periodically injecting small currents; it can also affect the beam size in the horizontal plane during the injection.

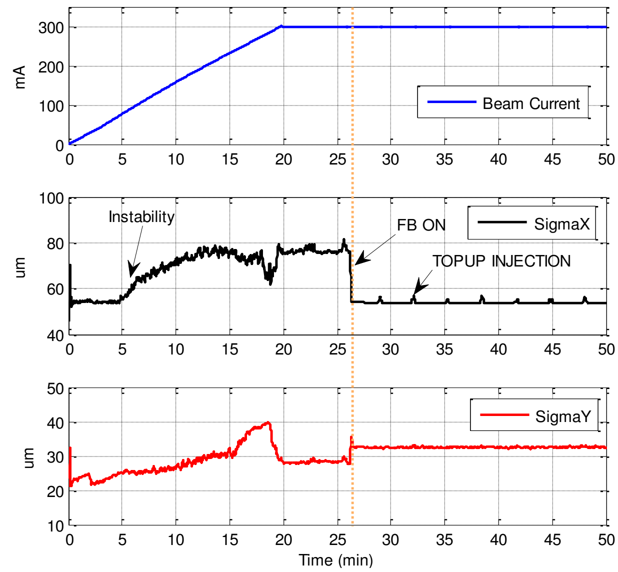

Figure 8: Measurement of multiple-bunch beam size with bunch-by-bunch feedback on or off and top-up injection operation.

SUMMARY

The TPS storage beam current is able to achieve the designed value, and is now in a tuning stage. The synchrotron light monitors are important diagnostic tools to characterize the beam parameters. This report presents the measurements of synchrotron light with the streak camera and a CCD to provide longitudinal (bunch length, synchronous phase, motion) and transverse (beam size) information about the booster and storage ring.

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