MODERNIZED OF THE BOOSTER SYNCHROTRON DIAGNOSTICS IN THE TAIWAN LIGHT SOURCE

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Abstract

Taiwan Light Source (TLS) is a 1.5 GeV synchrotron based light source which was dedicated 20 years ago. After several major and minor upgrades, the TLS now operated in top-up mode since late 2004. A new 3 GeV Taiwan Photon Source (TPS) is in construction to provide more x-ray users. To provide a test bed for the diagnostic devices in booster synchrotron for the TPS project, the diagnostics of the TLS booster synchrotron is revised recently. It can also provide up-to-date diagnostics for the TLS booster to help to achieve a better operation of the injector for the TLS storage ring. Efforts of these upgrades and modifications are summary in this report.

INTRODUCTION

The TLS booster synchrotron was delivered in 1992 [1]. Some diagnostics of the TLS booster revised in recently by borrow components for the TPS project before its commissioning in 2014. Two goals of these revised efforts, the first goal is as test bed for the TPS project to do hardware, software, and application development. The second goal is to provide better understanding its characteristics of the TLS booster synchrotron. The major parameters of the TLS booster synchrotron are summarized in Table 1. This study focus on BPM electronics, tune monitor, synchrotron radiation monitor, and perform some preliminary test to check functionality and performance.

Table 1: Major design parameters of the TLS booster synchrotron relate to diagnostics.

Parameters	Value
Energy	1.5 GeV (operated at 1.3 GeV before 1999)
Circumference	72 m
Periodicity	12
Energy spread	5 x 10^{-4}
Momentum compaction factor	0.058
RF frequency	499.654 MHz
Harmonic number	120
Tune	$\nu_x \sim 4.4$, $\nu_y \sim 2.43$
Chromaticity	$\xi_x \sim -6.5$, $\xi_y \sim -2.8$
Betatron function (max)	$\beta_x \sim 11.9$ m, $\beta_y \sim 11$ m
Repetition rate	10 Hz

BPM ELECTRONICS

Beam position monitor (BPM) in the TLS booster synchrotron was mounted 45 degrees on the chamber at between the dipole and the quadrupoles. The lattice of the booster synchrotron is FODO type with periods of 12. There are 23 BPMs used around the synchrotron, because one location is used as a photon port. The BPM location on the booster is shown in Fig. 1. Past efforts to measure closed orbit and turn-by-turn position of in the TLS booster synchrotron during ramping from 50 MeV to 1.3 GeV are summarized in references [2, 3, 4]. Energy ramping of the TLS storage ring from 1.3 GeV to 1.5 GeV was done in 1995 to enhance x-ray emission. The booster synchrotron was raised from 1.3 GeV to 1.5 GeV in 1999 to provide full energy injection for the storage ring.

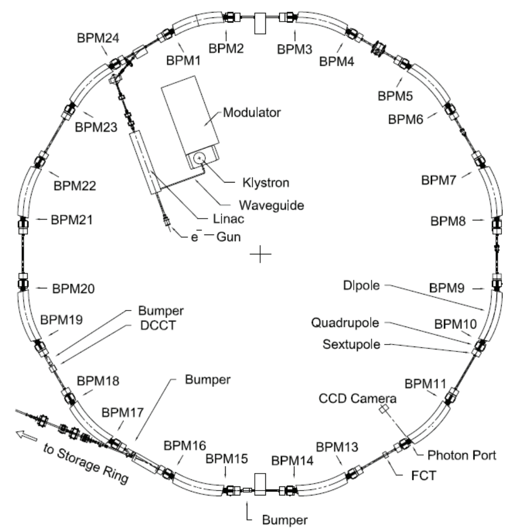

Figure 1: BPM layout of the TLS booster synchrotron.

The BPM cabling and electronics were completely modified during shutdown in August, 2012. BPM electronics borrow from the TPS project. These BPM electronics will available before TPS commissioning in 2014. The four buttons of each BPM were connected to a Libera Brilliance+ [5] BPM module directly. The BPM electronics provide turn-by-turn data for x, y, and sum signals. Further processing include spectral analysis, decimated raw data to reduce amount of data, data averaging, etc. are easy to do by various software applications after data readout from BPM electronic.

Validation checking and preliminary measurement are in proceeding since the accelerator startup from shutdown in the early September. The preliminary measured orbit is shown in Fig. 2. The extraction is disabled, so, the beam can survive almost full booster cycle (100 msec).

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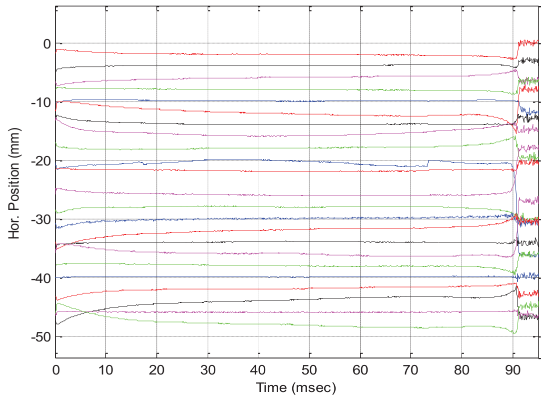
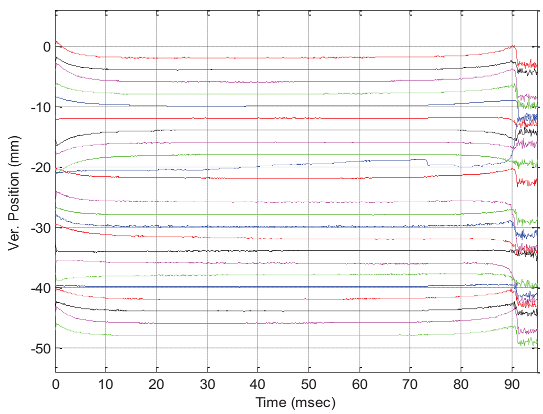


(a) Horizontal beam position



(b) Vertical beam position

Figure 2: Beam position variation during the booster energy ramping. Extraction is disabled. Each curve represents one BPM reading, consecutive BPM data vertical offset is -2 mm for clear visualization. The first BPM trace is in the injection straight, the last trace corresponding on the last BPM just at upstream of injection straight.

The extraction of the TLS booster done by three bumpers excited by 2 msec half-sine current, a septum excited by 500 μsec half-sine and a extraction kicker by an PFN type pulser. Bumpers were excited for 1 msec before extraction. The septum is triggered 250 μsec before extraction. The orbit excursion during the extraction process proceed is started about 44.5 msec and end at 45.5 msec is clear visible in Fig. 3. The maximum beam excursion should appear at BPM within the three bumper magnet bump. However, the measurement shows that the extractions bump is not a closure bump. The BPM reading will help to adjust extraction condition setting of the booster synchrotron.

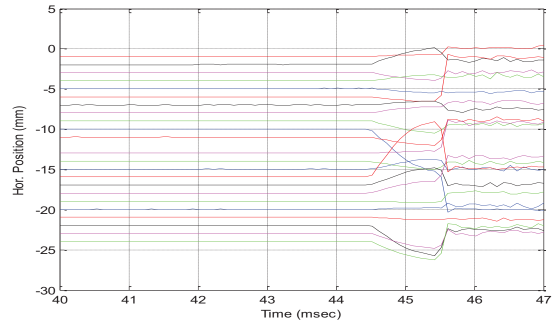


Figure 3: Horizontal beam position variation during beam extraction bumper magnets triggered. Each curve represents one BPM readings; vertical data of consecutive BPM is offset -1 mm for visualization purpose.

TUNE MONITOR

Efforts to measure working tune for the TLS booster synchrotron were described in reference [1, 6, 7]. Early efforts adopt extraction kicker as beam excitation with shift timing and strength adjustment setting at different energy and use digital oscillator to capture demodulated signal and perform FFT analysis to extract tune. The method can only capture single tune value at specific energy during the ramping; it needs many booster cycles to construct the tune variation along ramping. Excitation of booster magnets system should stable enough to achieve useful measurement. This pulsed kicker is a window framed, two-turn, ferrite magnet capable of providing 1.4 mrad horizontal kick to the extraction energy. Since the accelerating electron beam covers a wide range of energy change, the kicker strength has to be finely tuned so as not to over-kick and loss the electron beam. Since the excitation kicker produces only horizontal deflection to the electron beam, it is difficult to identify the vertical component. However, there is a small coupling between horizontal and vertical tune signals can be identified successfully.

In the latest effort [7], a dedicated diagnostic kicker was installed over a ceramic chamber. This kicker can provide horizontal and vertical kick simultaneously and adopt log-ratio BPM electronics to extract beam oscillation information. The stored electron beam in the booster was excited with a magnetic pulse from the kicker. While the electron beam executed betatron oscillation along the booster ring, the transverse motion of the beam signal was picked up by the stripline through a log ratio amplifier. The associated turn-by-turn information was recorded with a transient digitizer where the length of the recording data was defined. The raw data was then saved to the control console where the FFT analysis and peak identification were performed. It still need many booster cycles for measurement to construct full cycle tune variation.

There are two stripline electrodes on the TLS booster, however, small shut impedance due to large aperture prevent its in-effective as beam excitation in higher energy portion. It was decided to modify the diagnostic

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X-Y kicker as magnetic shaker [8, 9]. Single turn coil of X-Y kicker was removed. Multi-turn coils are mound on the existed ceramic chamber of the diagnostic kicker. There are two coils in each plane enclosed surrounding ferrite box with ceramic chamber surrounding them. The kickers with 50Ω terminated load have calibration factor of 3 mG/A. The kickers are driven by a 50W amplifier in each plane. The input signal is a band-limited white noise in a bandwidth from 1 MHz to 2 MHz. The turn-by-turn beam oscillation data is observed by the Libera Brilliance+ [5] BPM electronics. The functional block diagram of this new tune monitor system is shown in Fig. 4. A digital step attenuator is used to control the excitation level [10].

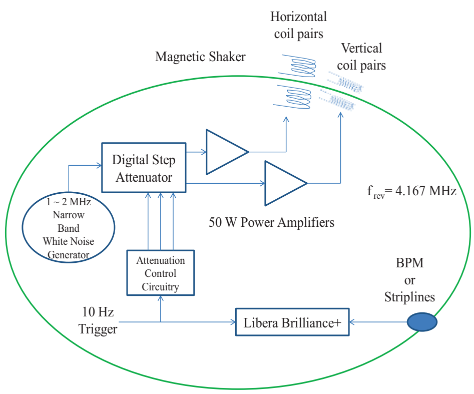


Figure 4: Functional block diagram of the new tune monitor for TLS booster.

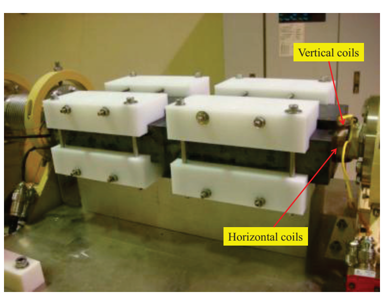
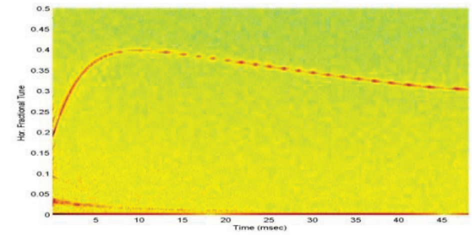
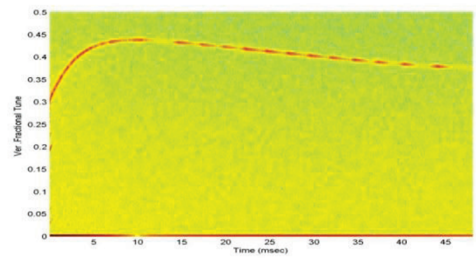


Figure 5: Magnetic shaker.

Preliminary test show that the beam can be excited effectively during the whole ramping cycle. A digital stepping attenuator is added to adjust the attenuation excitation level to prevent too large excitation at low energy which will cause beam loss. The BPM can observed betatron sideband with acceptable signal to noise ration. Figure 6 shows the spectrogram of the horizontal and vertical of BPM turn-by-turn data. The spectra line is clean visible. We excite the beam oscillation using magnetic shaker. Owing to the fast data acquisition and calculation capability, the tune drift during ramping can be observed in cycle to cycle basis.



(a) Horizontal tune variation during ramping cycle.



(b) Vertical tune variation during ramping cycle

Figure 6: Spectrogram of the turn-by-turn beam position data. Tune shift in the booster ramping can be observed clearly.

Tune information was obtained by spectra analysis of the FFT of turn-by-turn beam position data. Tune variation during ramping was observed in current routine operation setting. The fractional tune drift can be as large as 0.2. It is related to the tracking errors among focusing/defocusing quadrupoles and dipole. In cooperating with the monitoring system of FQ and DQ to dipole magnet strength, optimization of the booster working point can be efficiently achievable in tuning the booster synchrotron.

SYNCHROTRON RADIATION MONITOR

The synchrotron radiation monitor of the booster synchrotron has been replaced the original Firewire camera [11] by GigE Vision camera. Data acquisition and analysis is done by an EPICS IOC which embedded Matlab [12]. The layout of the synchrotron radiation monitor is same as reference [4]. The two axes translation stage is added to easy align the light to enter the CCD camera as shown in Fig. 7 (b). The monitor contains a computer, GigE Vision CCD camera, lens, molybdenum mirror, band-pass filter (centre wavelength at 550 nm with 10 nm spectral width) and motion stage. In this new design, a CCD camera comply with GigE Vision standard allows maximum data bandwidth 125 Mbytes/s over Cat 5e/6 cables up to 100 m, and a motorized translation stage moves the camera in XZ directions to adjust the CCD position. The photons of synchrotron radiation emitted by the electron bunches passing through a bending magnet in the booster ring are reflected by a molybdenum mirror and passed through a convex lens (f = 500 mm) to form image at CCD image sensor. The magnification factor is 2:1 to save for current setup.

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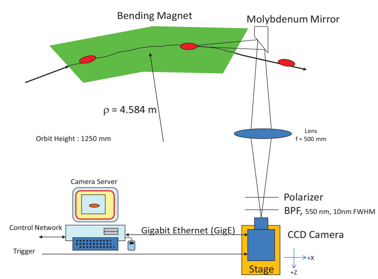
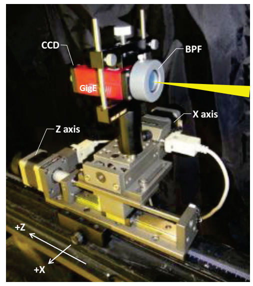


(a)



(b)

Figure 7: Layout of the synchrotron radiation monitor and photo of the CCD camera mounted on two axes translation stage.

The display GUI for the booster synchrotron radiation monitor is shown in Fig. 8, which has been developed and has the same features as previously. The CCD exposure time and trigger delay are set to 1 ms and 30 ms (corresponding to energy about 0.8 GeV); as a result, the beam size is 0.74 mm (σ_x), 0.34 mm (σ_y). Raw data and fitted parameters are published as EPICS PV such that EPICS clients can readily access for further usage.

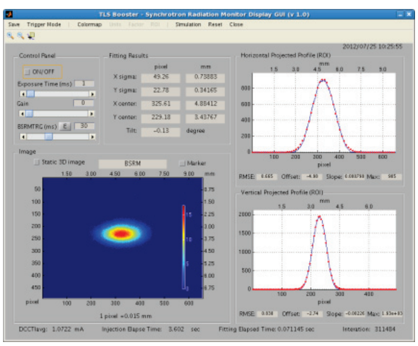


Figure 8: User interface for the booster synchrotron radiation monitor.

A beam profiles during energy ramping is shown in Fig. 9; Extracted variation of the beam emittance is shown in Fig. 10. The emittance decreases when the energy increases due to radiation damping. A significant shift of position occurs near 45 msec in ramping cycle in horizontal is due to the extraction bumpers are excited.

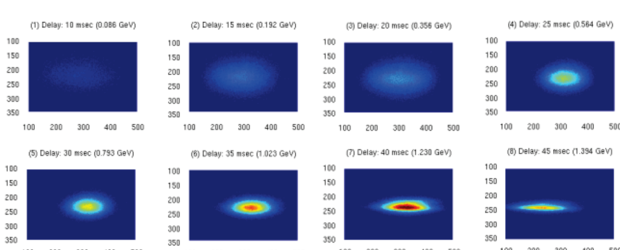


Figure 9: synchrotron radiation profiles at several different energy during energy ramping, the CCD exposure is 1 ms (energy scan mode).

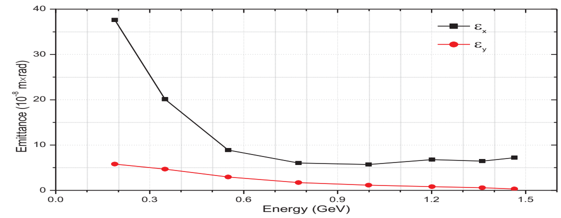


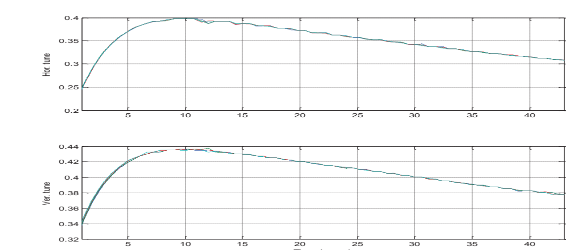
Figure 10: Deduced beam emittance from measured beam size variation during energy ramping.

PRELIMINARY EXPERIMENTS

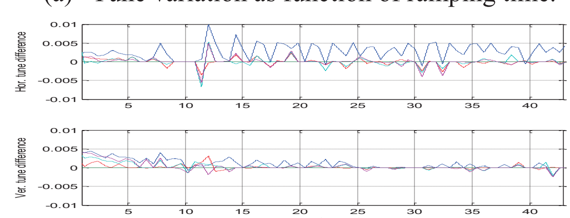
When good diagnostics are available, parameters of the booster can be check routinely. We performed several simple experiments in a limited available time of the booster synchrotron in machine start up and summarized in this paragraph.

Tune Stability

It can monitor the tracking stability of dipole and quadrupole power supplies, when tune variation data of each booster cycle available. Figure 11 shows the 5 continuous tunes measured in an interval of 100 booster cycles (10 seconds). There is no sensible tune variation. The difference of these measured tunes is shown that the repeatability of tune is good for 5 times measurement. The fractional tune difference is less than 0.005. The difference looks like form the data fluctuation rather than form the contribution of power supplies. Long-term stability for hours will be further studies.



(a) Tune variation as function of ramping time.



(b) Fractional tune difference.

Figure 11: Reproducibility of tune is good for 5 times measurement. The fractional tune difference is less than 0.005.

Chromaticity Measurement

The chromaticity of booster has been calculated as RF frequency and measured tune change during the ramping. For a small variations, the chromaticity should be a linear function of the tune shift, $\xi_{x,y} = -\alpha_x f_{RF} \Delta\nu_{x,y}/\Delta f_{RF}$. The momentum compaction factor ac is normally a constant depending on the lattice. The measurement result is

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shown in Fig. 12.

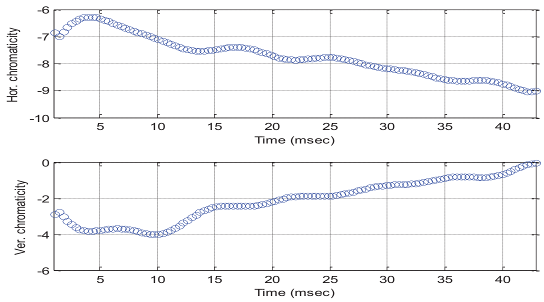

Figure 12: Measured uncompensated chromaticity.

Turn-by-turn Data Analysis

Independent component analysis (ICA) [13] method is used to analyze turn-by-turn data to calculate horizontal beta function as Fig. 13. The spatial and temporal function of ICA shows the integer part and the fractional part of horizontal tune are 4 and 0.31 respectively. The lattice is symmetric where odd BPMs location have low beta value and even's BPMs are located at high beta section. The ICA analysis result shows that they are consistence from model. There is a little bit nonlinearity and distortion effect that are contributed in the high beta BPM location. Systematic study to improve reliability of BPM data by the usage of ICA that is a short-term effort.

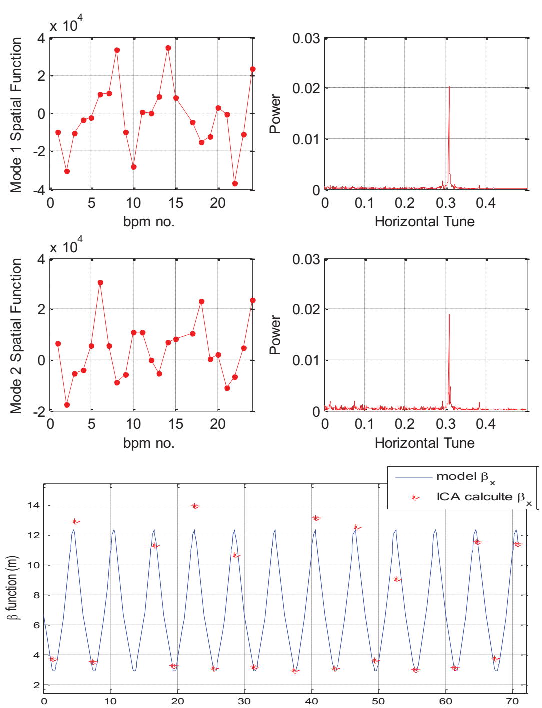

Figure 13: Preliminary results to apply ICA to calculate horizontal beta function using BPM turn-by-turn data.

SUMMARY

In this report, we are performed some minor modification of the TLS booster synchrotron to modernize orbit, tune, synchrotron radiation monitor. The system can be used as test bed for the similar system for the TPS booster synchrotron and software development. The schedule of TPS is still for one year, a plan to test hardware and software supporting are in proceeding. Plan to study the TLS booster synchrotron is also launched.

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