PRELIMINARY TEST OF THE BUNCH-BY-BUNCH TRANSVERSE FEEDBACK SYSTEM FOR TPS STORAGE RING

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Abstract

Commissioning of the Taiwan Photon Source (TPS) is in progress and divided into two phases. The storage ring equips with two five-cell PETRA RF cavities and without insertion devices installed for Phase-I commission to confirm correctness of everything, to do preliminary vacuum clearing, and wait available of cryogenic system available. After finished the Phase-I commissioning in March, 2015, installation of two superconducting RF cavities and 10 sets of insertion devices are ongoing. The commissioning is planned to start around in August. There is a prototype vertical stripline kicker installed in 2014. One horizontal stripline kicker and two vertical stripline kickers were installed in May. Commercial available feedback processor was selected for the feedback system integration. Preliminary feedback loop closed have been tested during Phase-I beam commissioning in early 2015 with prototype vertical kicker. Beam commissioning with new kickers is scheduled when beam stored in Phase-II beam commissioning which will started soon. Final check before beam test is under way.

INTRODUCTION

The NSRRC campus host two synchrotron light source, one is a 1.5 GeV Taiwan Light Source (TLS), and the other is 3 GeV TPS. The TPS was started Phase-I commissioning without IDs and superconducting RF system recently [1]. Phase-II commissioning is started from mid September 2015 with 10 sets of IDs and two KEKB-type superconducting RF modules. Analogue type transverse feedback system for TLS is operated since 1996 [2]. The system convert to FPGA based feedback system in during 2004~2005 for transverse as well as longitudinal planes by using SPring-8 feedback processors [3]. Transverse coupled-bunch instability, caused by the resistive wall impedance and fast ion will deteriorate beam quality. Bunch-by-bunch feedback will suppress various transverse instabilities to ensure TPS will achieve its design goals. The TPS project adopts EPICS toolkits as control system frameworks. To simplify system integration, it was decided to adopt EPICS embedded feedback processor iGp/iGp12 from Dimtel [4] for BBF system for TLS and TPS. First system by use iGp was put into operation in 2009 [5] at TLS. Two transverse loops and one longitudinal feedback loop were convert to iGP12 based system around 2010~2011 at TLS [6]. The TPS system are commissioning in 2015 by using latest revision gateware (FPGA code).

Stored beam current reach more than 100 mA in multi-bunch operation with two five-cell PETRA cavities are expected. Strong synchrotron dipole motion is onset around 30 mA. This strong motion limit maximum stored beam current less than 50 mA. RF experts found that the bandwidth of the RF amplitude feedback loop is too large such that a synchrotron sideband entered the loop in March 26. After cure the problem and increasing the chromaticity, beam stored more than 100 mA soon just before April shutdown. Threshold current for the longitudinal instability appeared at 82 mA. Longitudinal instability will be not a problem after replacement of the five-cell PETRA cavities with SRF in Phase-II commissioning.

Phase-I commissioning of the vertical loop with prototype kicker is performed in mid January 2015. Beam commissioning with new kickers is scheduled when beam stored in Phase-II beam commissioning is scheduled in the last quarter of 2015.

TRANSVERSE KICKERS

In order to suppress coupled-bunch instabilities effectively, transverse kickers with higher shunt impedance are desirable especially in vertical plane. However, due to limited manpower available during the final phase of installation, one simple prototype kicker was implemented and installed at diagnostics straight in June 2004. Only this kicker was available for Phase-I commissioning. Shunt impedance of this kicker at lower frequency is less than 5 k. Drawing and installation photo of this prototype vertical kicker is shown in Fig. 1.

Two new vertical kickers and one new horizontal kicker were designed, fabricated, and installed during April to July, 2015 shutdown. Concept of these kickers is derives from the design of PSI/SLS [7] and adapt to fit vacuum duct of TPS at ID straight. Optimization of geometry and shunt impedance was done by SUPERFISH 2D codes. Length of the electrode is 300 mm. Shunt impedance at low frequency is about more than 50 k for vertical and horizontal kicker respectively. Detailed analysis of the impedance, absorption power is underway. About 10 time large than the prototype, and almost factor of 3 times kick voltage will produce than the prototype when the same driven power level. Perspective drawing and installation at the storage ring are shown in Fig. 2. Original, all transverse kickers were planned to install at one dedicated diagnostics straight. However, to save space to accommodate one more insertion devices, decision was made in March 2015 that all kickers install at upstream of in-vacuum undulator (IU22) at three 7 m

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long insertion devices straights. This prevents the option to install all feedback electronics at the same site. The Horizontal kicker is installed at upstream of SR03 (SRnn consist of upstream ID straight and following lattice cell #nn in the name convention of TPS vacuum system), two vertical kickers are installed at upstream of SR11 and SR12 exit. Three sets of 3 m long in-vacuum undulator were installed at that location.

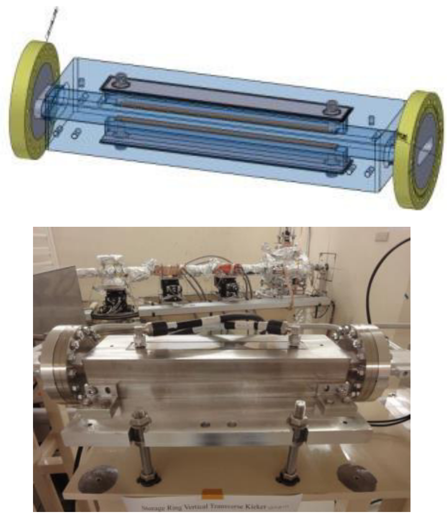

Figure 1: Perspective view (above) and installation picture at diagnostic straight (below) of the prototype vertical kicker.

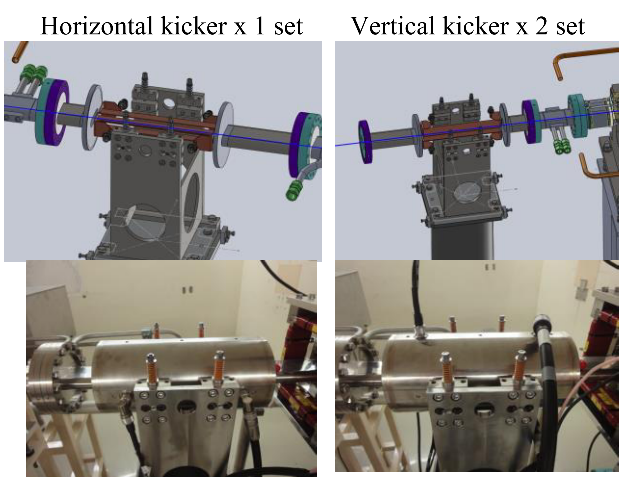

Figure 2: Perspective drawing of transverse kickers (upper) and install at upstream of three 7 m straight which in-vacuum undulators located (lower).

FEEDBACK ELECTRONICS

Feedback electronics of bunch-by-bunch include feedback functionality, such as housekeeping, filter design, timing adjustment, feedback, data capture, etc. It supports bunch oscillation data capture for analysis to deduce rich beam information, tune measurement, bunch clearing, beam excitation, etc. Features of the planned system include the latest high dynamic range ADC/DAC (12 bits), high performance FPGA, flexible signal processing chains, flexible filter design, bunch feedback, tune measurement, bunch cleaning, various beam excitation scheme, flexible connectivity, and seamless integration with the control system. An on-line control interface to operate feedback system and off-line analysis tools should be included.

Commercial feedback processor with EPICS IOC embed are used. This option is simply system integration efforts. A functional block diagram of the bunch-by-bunch feedback system will delivery for TPS is shown as Fig. 3 for horizontal feedback loop and Fig. 4 for two vertical feedback loops. Frontend for the horizontal is plane is Libera Bunch-by-Bunch Front End [8] is use. Dimtel Bunch-by-bunch Front/Back End FBE-LT [4] is used for vertical plane. Commercial feedback processor iGp12 are selected for three feedback loops. Three iGp12s already serve for the transverse as well as longitudinal feedback loops for the existed 1.5 GeV Taiwan Light Source for several years already [6].

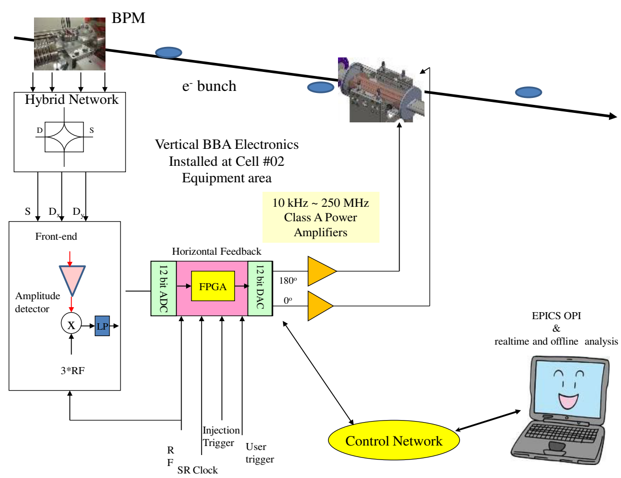

Figure 3: Configuration of the horizontal bunch-by-bunch feedback loop.

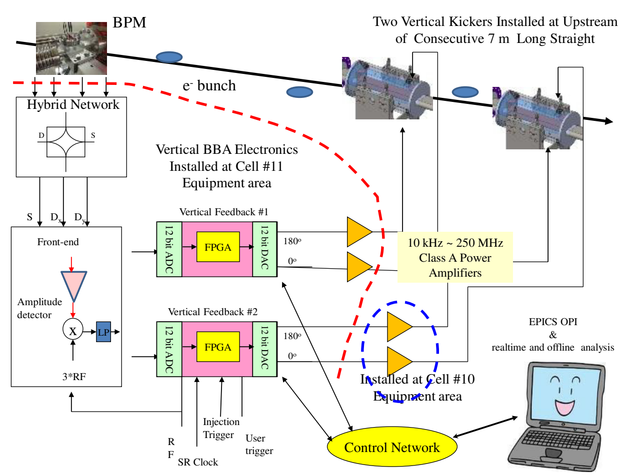

Figure 4: Configuration of the vertical bunch-by-bunch feedback loops.

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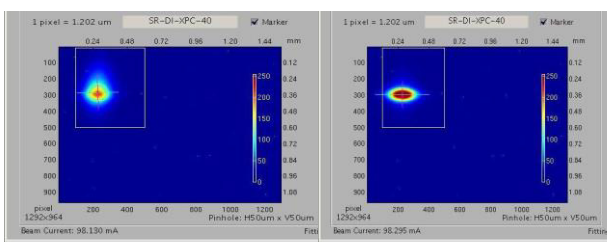
PHASE-I COMMISSIONING

Loop closed of the prototype vertical feedback loop was done in January 14 to check functionalities of the system. However, due to very strong synchrotron oscillation existed, a lot of efforts devote to study try to dig out the problem, no much efforts to do for feedbacks before problem was identified and solved in late March. Various measurements [9] are possible just a few days before machine shutdown in April. Transverse instability threshold is around 30 mA when near zero chromaticity. The vertical instability in vertical plane was damped by the bunch by bunch-by-bunch feedback loop.

Feedback Functionality

Vertical beam blow up due to vertical instability at stored beam current 98 mA shown in Fig. 5(a). After feedback loop engage, instability is suppressed as shown in Fig. 5(b). Beam spectrum show that the betatron sidebands are suppressed by the feedback loops as shown in Fig. 6.



(a) Feedback "Off" (b) Feedback "On"

Figure 5: Beam profile observed by pinhole camera when vertical instability appeared (a) and instability suppressed by the bunch-by-bunch feedback loop (b).

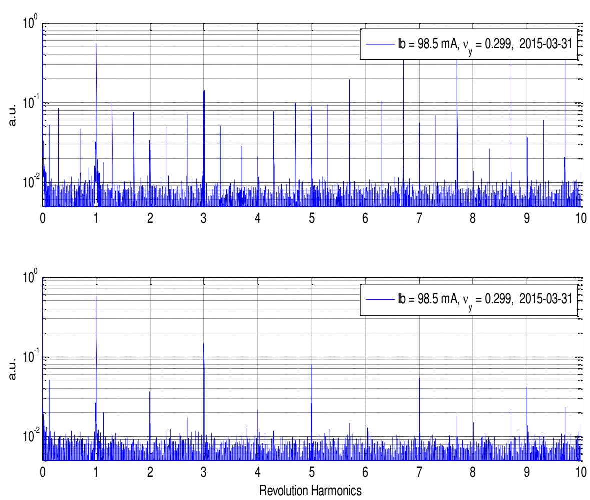


Figure 6: Vertical betatron sideband (above) suppressed by the feedback loop (below).

Grow-Damp Measurement

Grow/damp experimental for vertical plane was performed during test session. Fig. 7 shows that the experimental perform at stored beam current 98.5 mA. Growth rate is in the order of 0.2 ms^{-1}, while 10 ms^{-1} damping rate ensure beam is stable.

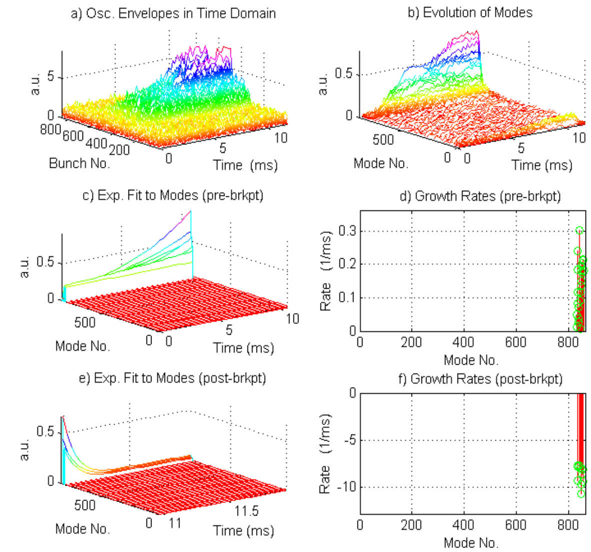


Figure 7: Grow/damp experiment of vertical plan at beam current 98.5 mA. Resistive-wall and fast ions are major sources of instability.

Instability in Horizontal Plane

Horizontal instability is onset around 70 mA also. Strength is weak than vertical plane. Evolution of envelop and modal spectrum of the horizontal plane are shown in Fig. 8. Most prominent modes with mode number are large than 800. There are peaks within the modal spectrum. Resistive-wall and fast ion related instability might major contribution the horizontal instability. Rich betatron sidebands in beam spectrum is shown in Fig. 9.

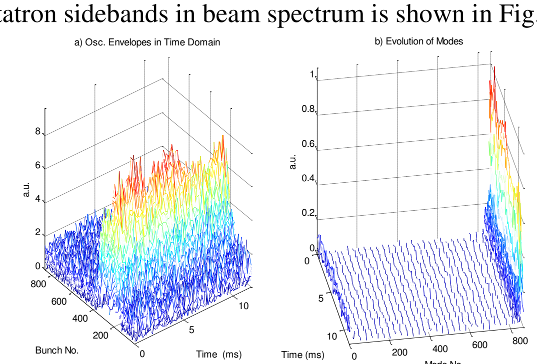


Figure 8: Oscillation envelope and modal spectrum at 93.274 mA.

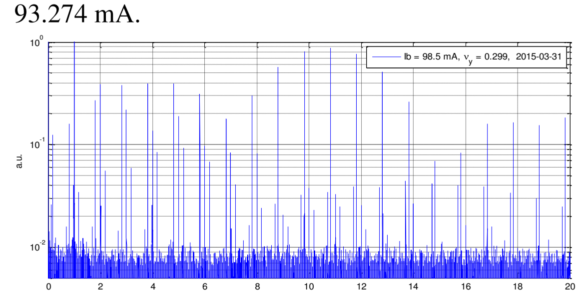


Figure 9: Rich betatron sidebands in beam spectrum of horizontal plane.

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Longitudinal Motion

Strong longitudinal was observed when current large than 20 mA which limited stored beam current around 50 mA maximum. Streak camera observed the oscillation amplitude can be large than 350 psec (peak-to-peak), it corresponding to about +/- 30 RF degree. The problem was identified by RF experts and solved in March 26, 2015. Large zero mode oscillation come from wrong parameters setting of the amplitude loop of the low level RF system. After problem cured on March 26, the beam can store up to 100 mA soon before shutdown started from April. Typical behaviour in longitudinal plane is shown in Fig. 10. Strong in-phase synchrotron motion and a strong mode 800 for all stored bunches were observed. The mode 800 might cause by the TM_{021} high order mode of five-cell PETRA cavity [10]. Fig. 11 compare the longitudinal modal spectrum, strong mode zero oscillation at lower current. After problem of feedback loop solved, mode zero motion is negligible compare to the instability driven by the TEM_{021} high order mode of RF cavity near mode 800. Threshold current is near 82 mA.

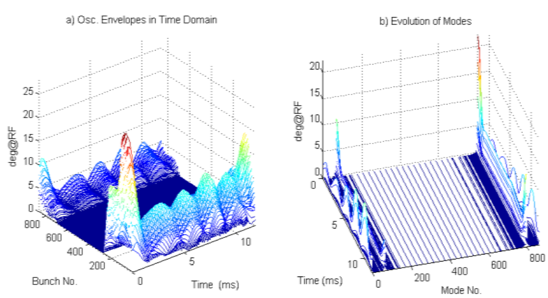

Figure 10: Evolution of longitudinal oscillation envelope and modes at 92 mA. Threshold current is about 82 mA.

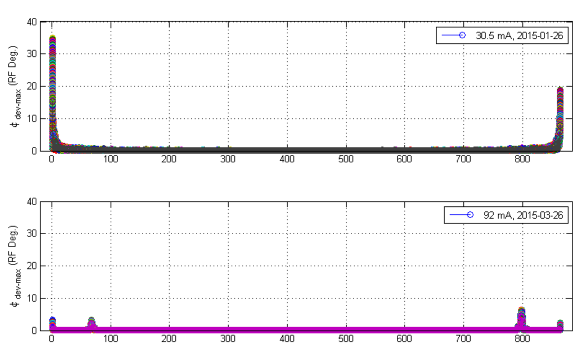

Figure 11: Comparison of modal spectrum before RF fixed its amplitude loop at stored beam current 30 mA before (a) and 92 mA after (b).

Single Bunch Transfer Function

Current version of gateware support single bunch excitation and data capture functionality. Sweep the excitation frequency and demodulated beam signal quadrature can be deduced transfer function. Fig. 12 shows a transfer function measurement for selected bunch in a bunch train in multi-bunch mode. Study transfer function a function of single bunch current is planned after beam available.

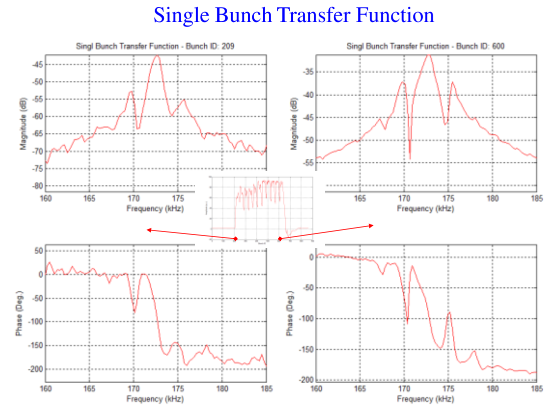

Figure 12: Individual bunch transfer function in multi-bunch fill mode at 93 mA.

Bunch Cleaning

Single bunch beam is used to measurement bunch length versus beam current during the Phase-I commissioning. However, high purity single bunch beam from Linac not always available during the study. Impurity can be a few percents to a few tens of percents. Bunch cleaning functionality have been applied continuously to keep population of the satellite bunches small than the main bunch more than 10^{-4} even the system is still no optimized. Fig. 13 is a snapshot during the bunch cleaning process in proceeding.

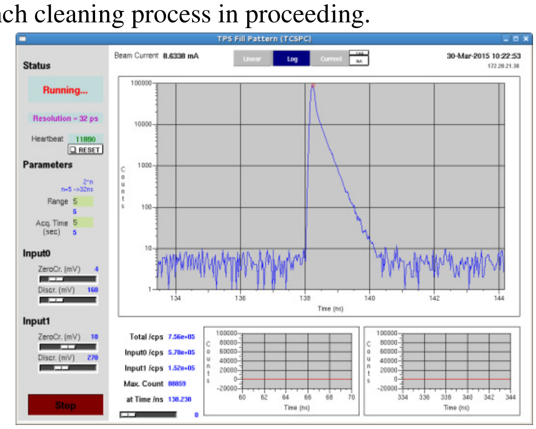

Figure 13: Single bunch impurity is achieved more than $10^{-4}$by bunch cleaning process.

PREPARTION FOR PHASE-II COMMISSIONING

During April to August shutdown, all feedback kickers were installed. Electronics installation and interconnectivity are done before September. Horizontal kicker is installed at upstream of the straight SR03, two vertical kickers were installed at the upstream of straight of cell SR11, and SR12 respectively. In-vacuum insertion devices installed during the shutdown, three kickers are installed accompany with these installation to minimize various efforts. Feedback electronics is installed also as shown in Fig. 14 are installed at nearby equipment areas.

Investigate instabilities modes and ion effects are plans. The commissioning schedule of SRF and ten IDs is scheduled in September 2015. Superconducting RF

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system need more time to ensure everything are correctness, the possible commissioning schedule of the bunch-by-bunch feedback system will be possible in the 4th quarter of 2015.

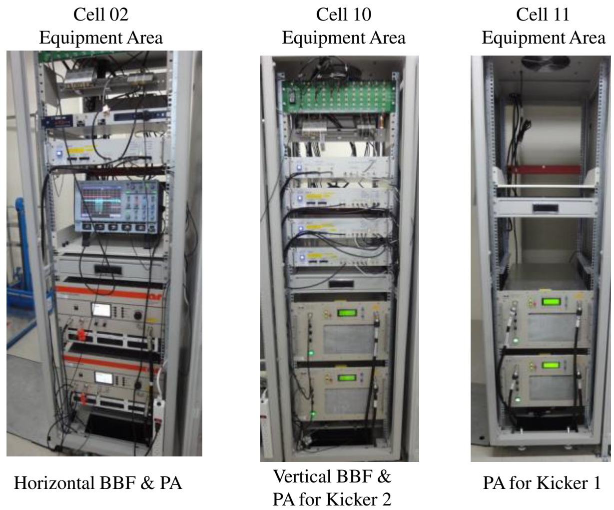

Figure 14: Photos of the installed feedback electronics.

SUMMARY

Preliminary test of the bunch-by-bunch system were performed in early 2015 during Phase-I commissioning of the TPS. Resistive wall induced instability was observed for stored beam current up to 100 mA. All components for Phase-II commissioning were prepared. The system is ready for further study soon. Experiences gain during the test will useful to help future optimization.

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Thanks for the help from T. Nakamura of RIKEN/Spring-8 to introduce FPGA based BBF technology for TLS. Many technical discussions with Dmitry of Dimtel are fruitful. Encourage from Prof. J. H. Wang of USTC/NSRL during last decade are highly appreciated. Helps from vacuum group are crucial for their high efficiency to implement current version of kickers in the second quarter of 2015 which is impossible to achieve if contract to vendor within such short period. In-house made kickers option is also relax pressure due to limited budget available.

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