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

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Abstract

Taiwan Photon Source (TPS) finished its Phase II commissioning in December of 2015 after installation of two superconducting RF cavities and ten sets of insertion devices in mid-2015. The storage ring achieved to store beam current up to 520 mA. Intensive insertion devices commissioning were performed in the second quarter of 2016 and delivered beam for beam-line commissioning and performed pilot experiments. One horizontal stripline kicker and two vertical stripline kickers were installed in May 2015. Bunch-by-bunch feedback system were commissioning in the last quarter of 2015 and the second quarter of 2016. Commercial available feedback processors and power amplifiers were selected for the feedback system integration. Beam property and performance of the feedback system were measured. Problems and follow-up measures are also addressed. Results will be summarized in this report.

INTRODUCTION

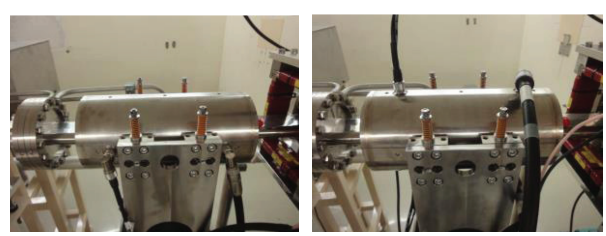
The TPS is a 3 GeV synchrotron light source which was performed Phase I commissioning without insertion devices (ID) and with two 5-cell Petra cavities in the last quarter of 2004 and the first quarter of 2015 up to 100 mA stored beam [1]. Phase–II commissioning was done in the last quarter of 2015 with 10 sets of IDs and two KEKB-type superconducting RF modules and reached 520 mA stored beam maximum. 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 achieve its design goals. Vertical bunch by bunch feedback loop was commissioning [2] in the first quarter of 2015 with prototype vertical kicker to test functionality includes feedback, bunch cleaning, single bunch transfer function, tune measurement. Power amplifier from AR and R&K were tested. One horizontal kicker and two vertical kickers were installed in the shutdown period of the second and the third quarter of 2015. Commissioning of both planes with insertion devices operation was started in the last quarter of 2015 and the second quarter of 2016.

Threshold current for the longitudinal instability appeared at ~80 mA when using with two 5-cell Petra cavities without insertion devices. Longitudinal instability disappeared up to 500 mA stored beam current during phase-II commissioning equip with two KEK-B type superconducting cavities with 10 sets of insertion devices in the last quarter of 2015. Transverse instabilities are dominated by wall resistivity and ion in TPS storage ring.

STATUS OF THE FEEDBACK SYSTEM

Two vertical kickers and one horizontal kicker were installed during mid-2015 shutdown. Concept of these kickers is derives from the design of PSI/SLS [3] and adapt to fit vacuum duct of TPS at ID straight. Length of the electrode is 300 mm. Shunt impedance at low frequency is about 40 kΩ and 25 kΩ for vertical and horizontal kicker respectively, Perspective drawing and installation at the storage ring are shown in Fig. 1. To save space to accommodate more insertion devices, all kickers install at upstream of in-vacuum undulator (IU22) at three 7 m long straight. Three kickers are distributed at three short straight. This prevents the option to install all feedback electronics at the same site. Three in-vacuum insertion devices were install at these kickers respectively.

The horizontal kicker was installed at upstream of SR03 (upstream straight of lattice cell #3), and two vertical kickers were installed at upstream cell SR11 and SR12. Feedback electronics for horizontal and vertical planes where installed at different areas in which shared RF front-end is impossible. The kicker electrodes are not well match to 50 Ohm. Measured impedance is around 75~95 Ohm between the feedthrough structure and electrode respect to the vacuum chamber. This leads to large broadband beam power picked up which prevent power amplifier work properly, high power low pass filter with cut off frequency 350 MHz were installed at each power amplifier output to block high frequency beam power to enter power amplifier output.



Horizontal kicker x 1 set   Vertical kicker x 2 sets

Figure 1: Transverse kickers install at upstream of three 7 m short straight which in-vacuum undulators located.

Feedback electronics of bunch-by-bunch equip feedback functionality, such as housing keep, filter design, timing adjustment, 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

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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.

The iGp12 feedback processor from Dimtel [4] were selected with EPICS embedded. This simplify the system integration efforts a lot. A functional block diagram of the bunch-by-bunch feedback system current delivery for TPS are shown as Fig. 2 for horizontal plane and Fig. 3 for vertical planes.

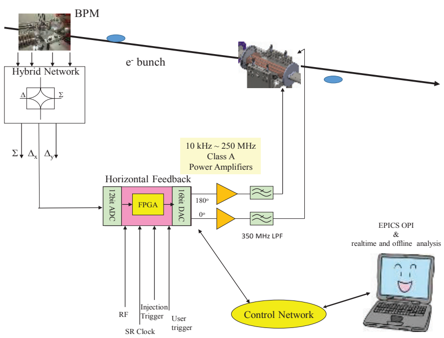

Figure 2: Configuration of the horizontal bunch-by-bunch feedback loop.

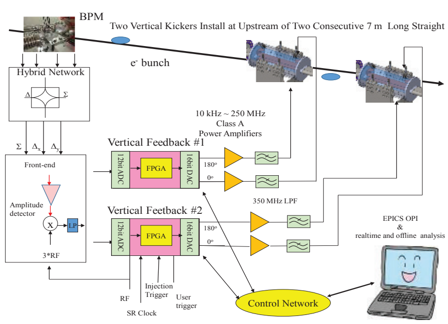

Figure 3: Configuration of the vertical bunch-by-bunch feedback loops.

COMMISSIONING OF HIGH STORED BEAM CURRENT

Commissioning of the prototype vertical feedback loop was performed in January 2015 to check functionalities of the system up to 100 mA stored beam [2]. Commissioning both horizontal and vertical feedback loops were performed in the last quarter of 2015 and the second quarter of 2016 after SRF cavities and 10 sets of insertion devices installed. Feedback functionalities have been tested for the stored beam current more than 500 mA. However, current version of stripline kickers especially horizontal plane suffered from higher outgassing due to over temperature issues happened when operate at high current (450~520 mA) for a short duration at this moment. New kickers are in design and implementation, these kickers are scheduled installed to replace current kickers in 2017.

Horizontal Plane

Grow/damp experimental and analysis [5] for horizontal plane was performed. Figure 4 shows that the experimental performed at stored beam current 300 mA. Growth rate is around of 0.2~0.3 $ms^{-1}$of the strongest modes, while damping rate is about 3 ms^{-1}. Similar measurement is performed at 400 mA also as shown in Fig. 5. Growth rate is around of 0.5 ms^{-1}, while damping rate is 10 ms^{-1}. Sufficient damping for high stored beam current will not cause any problem. However, damping rate can be varied by adjust feedback gain. Horizontal instability are contributed by resistive wall and ion related instability. Strength is weak compare to vertical plane.

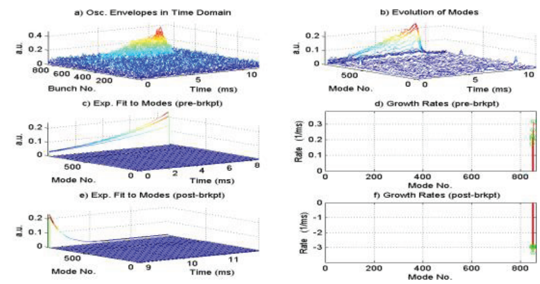

Figure 4. Grow/damp experiment of horizontal plane at beam current 300 mA with five in-vacuum IDs close gap. Resistive wall and ion induced instabilities are dominated. Feedback gain is set at minimum. Increase damping rate is easily by increase gain of the feedback loop.

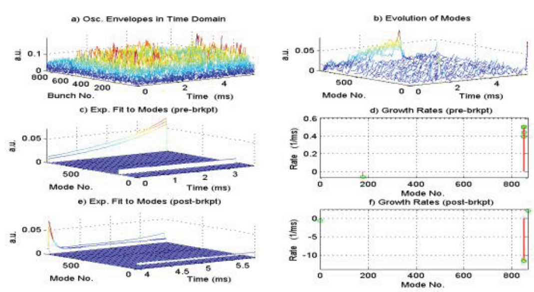

Figure 5: Horizontal modal spectrum at 400 mA with all IDs open gap.

Vertical Plane

Grow/damp experimental for vertical plane was performed at several stored beam current. Figure 6 shows that the experimental perform at stored beam current 93 mA without insertion devices. Growth rate is in the order of 0.2 ms^{-1}, while damping rate is the order of 10 ms^{-1}. Feedback loop gain is set at minimum.

Figure 7 shows that the experimental perform at stored beam current 300 mA with 5 insertion device closed its gaps out of 10 installed insertion devices. Growth rate is in the order of 0.5 ms^{-1}, while damping rate is the order of 40 ms^{-1}. Strength of vertical plane is large than horizontal plane. Figure 8 shows that the experimental perform at stored beam current 360 mA with all insertion device open gaps; growth/damping rate are 1 ms^{-1}/40 ms^{-1} respectively. For beam current 400 mA with all insertion device open gaps; growth/damping time are 1 ms^{-1}/40 ms^{-1} respectively as shown in Fig. 9. The growth rate will be increase three time to about 3 ms^{-1} when number of insertion devices increase to more than 20 sets and all insertion devices close

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gap in future, Growth rate of vertical instability is large than horizontal plane due to small vertical aperture and small gap insertion devices.

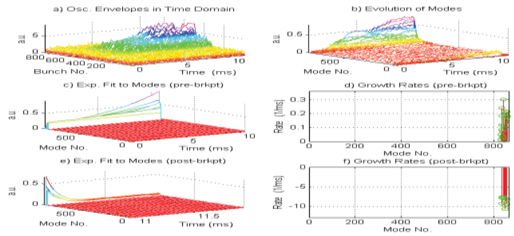


Figure 6: Grow/damp experiment of vertical plane at beam current 93 mA.

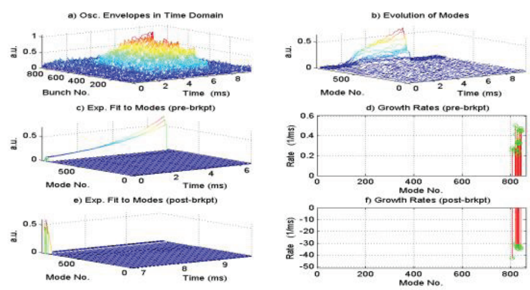


Figure 7: Grow/damp experiment of vertical plane at beam current 300 mA with five in-vacuum IDs close gap.

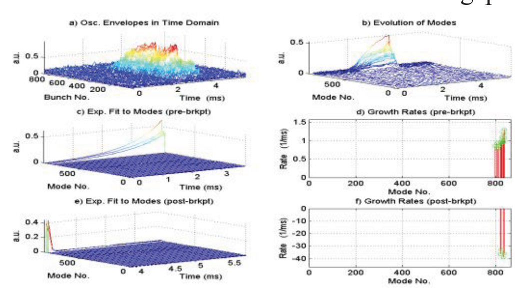


Figure 8: Grow/damp experiment of vertical plane at beam current 360 mA.

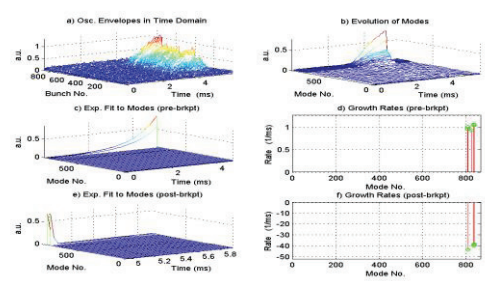
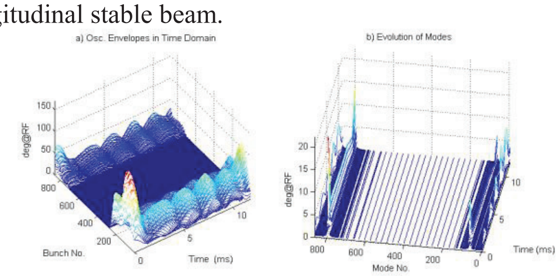


Figure 9: Grow/damp experiment of vertical plane at beam current 400 mA.

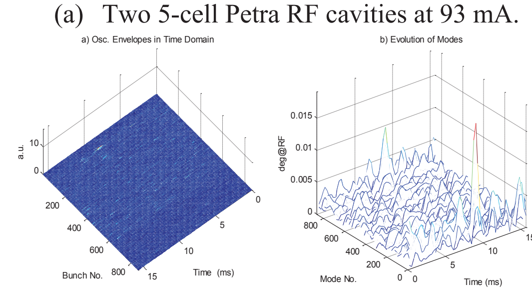
Longitudinal Plane

Longitudinal motion at Phase I commissioning before April 4, 2015 with two 5-cell Petra cavity are strong. In late March 2015, the beam can be stored up to 100 mA before April shutdown. Typical behaviour in longitudinal plan is shown in Fig. 10. Strong in-phase synchrotron motion and a strong mode 800 for all stored bunch was observed. The mode 800 might be caused by the TM_{021} high order mode of 5-cell Petra cavity [6].

Phase II commissioning started from September 2015 after install two superconducting RF cavities and 10 sets of insertion devices. To compatible with beamline optic and machine safety, 300 mA was chosen for beam line commissioning and pilot experiments maximum at this moment. Higher stored beam current were tested during some specific window to check weakness of the TPS. Modal spectra is shown in Figure 11 for 400 mA stored beam. No unstable longitudinal mode observed. Figure 11 shows the streak camera observation for 480 mA longitudinal stable beam.



(a) Two 5-cell Petra RF cavities at 93 mA.



(b) Two KEKB type superconducting RF cavities at 400 mA.

Figure 10: Evolution of longitudinal oscillation envelope and modes for TPS working with Petra cavities and SRF cavities before April 2015 and after August 2015.

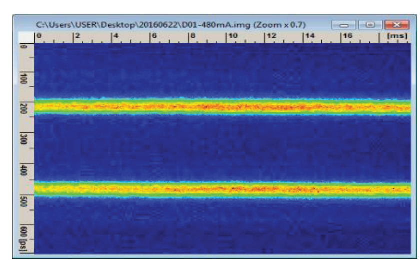


Figure 11: Longitudinal stable beam observed at 480 mA on June 22, 2016.

PROBLEMS AND SOLUTIONS

Current version of transverse kickers operate at higher store beam current (450 ~ 520 mA) has higher gassing especially of the horizontal kicker. TPS have been several chance test stored 500 mA to test tolerance of hardware and RF system, the first one is in December 12, 2015 maximum stored beam current reach more than 520 mA. However, the reading of nearby ion gauge of transverse kickers increase two order of magnitude for the horizontal kicker and one order of magnitude in vertical kicker. The burst of the vacuum pressure cause stored beam current sudden loss about 50 mA stored beam current as shown in Fig. 12. Outgassing rate abrupt increase when stored beam current

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higher than 450 mA. Vacuum pressure double compare with 30 mA at these area for 400 mA continue operation (12 hours) without big problem happened as shown in Fig. 13. Oxidation of the N-type feed-through centre pin due to overheat at downstream of outside electrode and inner electrode are observed, they might due to heat transfer from electrode to the centre pin and/or bad RF connect of the of feedthrough and the cable connector.

Revise horizontal kicker design to reduce the pick-up beam power and to improve RF contact of the feedthrough centre pin; 7/8" EIA feedthrough with water cooling [7] will adopt to increase safety margin for new kickers. Implement new horizontal kicker and install are the short term goal which are necessary for 500 mA stored beam current operation in future. Vertical kickers are slightly better but still have outgassing phenomenon. New vertical kickers will implement and install later after the horizontal kicker problem solved.

Horizontal feedback channel adopt direct RF sampling without RF front-end. Signal quality of the horizontal plane is bad due to small signal level which need further improvement. Implement a RF front-end is the current efforts.

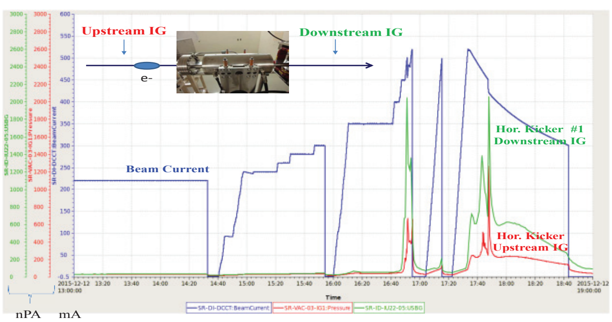

Figure 12: Vacuum burst happened when stored beam current over certain threshold (450 mA~ 520 mA) for a short duration on December 12, 2015. Ion gauge near downstream of horizontal stripline kicker detect a huge pressure spike which caused sudden reduce of beam current.

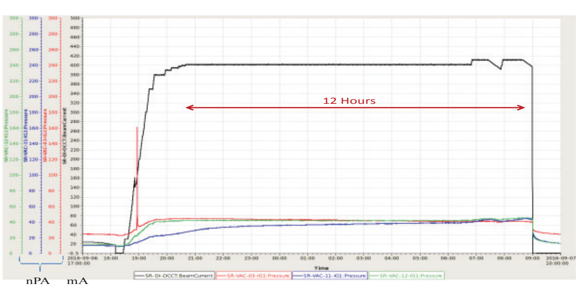

Figure 13: Vacuum pressure increase two times compare to 30 mA observed by the downstream ion gauge of horizontal kicker and vertical kicker #1 for 12 hours 400 mA operation from 21:00, September 6 to 09:00, September 7.

SUMMARY

Commissioning of the bunch-by-bunch system was performed in the last quarter of 2015 and the second quarter of 2016 during Phase II commissioning of the TPS accompany with commissioning of the phase I seven beamlines. Functionalities of the feedback were tested for stored beam current up to 520 mA with all insertion devices open gap and 300 mA for five installed ID closed gap. Hugh outgassing was happened near the horizontal kicker site when stored beam current in the range of 450 mA to 520 mA, new horizontal stripline kickers will be installed at early 2017. The system are ready for various study soon. Due to machine time, there is no chance to do systematic study up to now, such as measure growth/damping rate as function of beam current and feedback parameters, fast ion effect should be done as soon as possible. Resistive wall induced instability are dominated accompany with ion caused instability based upon analysis of the measured data. Lots of information accumulated during commissioning, it will useful for future optimization.

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