BEAM COMMISSIONING OF TPS FAST ORBIT FEEDBACK SYSTEM

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Abstract

TPS (Taiwan Photon Source) is a 3 GeV synchrotron light source which had be successfully commissioning with SRF up to 500 Amp in 2015 and Phase I beamline commissioning have followed soon. It has been scheduled to open user operation in 2016. To provide stable and reliable beam, the fast orbit feedback system is indispensable. Due to the vacuum chamber material made of aluminum with higher conductivity and lower bandwidth, extra fast correctors mounted on bellows will be used for FOFB correction loop and DC correction of fast correctors would be transferred to slow ones and avoid fast corrector saturation. Besides, the path length compensation by RF feedback is also tested. This report summarizes the infrastructure of the FOFB and the preliminary beam test is also presented.

INTRODUCTION

The TPS is a state-of-the-art synchrotron radiation facility which consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. This synchrotron machine featuring ultra-high photon brightness with low emittance [1] requires beam position stability less than 1/10 beam size. FOFB is therefore implemented to achieve sub-micron orbit stability and it has been tested together with beamline commissioning since 2015. The orbit stability had been effectively improved with FOFB and it showed that the suppression bandwidth could achieve 250 Hz in both horizontal and vertical plane. This had been considered quite helpful for beamline commissioning, especially that TPS had strong 3 Hz booster ramping disturbance and 60 Hz power line noise. After applying RF feedback and resolving long-term reliability related problem, FOFB would be officially operated in September 2016.

FOFB INFRASTRUCTURE

The design of the TPS storage ring has 24 cells, each cell is equipped with 7 BPMs and 7 horizontal/vertical correctors winding on the sexupoles. These kinds of slow correctors could provide about 500 μrad kick while their bandwidth could be limited only several tens of Hertz due to the eddy effect of the alumina vacuum chamber. This bandwidth is not sufficient to eliminate perturbation with frequency above several hundreds of hertz. Therefore, extra four horizontal/vertical correctors per cell are installed on the bellows site to obtain higher correction bandwidth. These horizontal/vertical correctors have fast response but smaller kick strength around 100/50 μrad. Thus the orbit feedback system would adopt two kinds of correctors simultaneously. The DC component of the fast correctors will transfer from fast to slow correctors smoothly and avoid saturation of the fast correctors as well as provide capability to suppress orbit disturbance. The overall infrastructure of FOFB is as Fig. 1. It is mainly implemented by three parts: BPM, feedback computation unit and corrector power supply control interface. TPS BPM electrical system will adopt the latest I-tech product: Brilliance+ [2]. It also offers a large playground for custom- written applications with VirtexTM 5, Virtex 6 in the gigabit data exchange module (GDX) to be used as orbit feedback computation. The corrector power-supply controller (CPSC) is designed for FOFB corrector control interface. This module is embedded with Intel XScale IOP and Xilinx Spartan-6 FPGA which will interface the fast setting from feedback engines. It was contracted to D-TACQ [3].

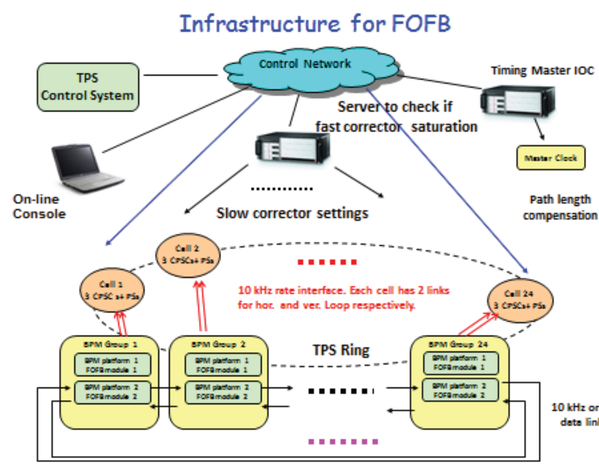

Figure 1: FOFB infrastructure.

BPM and GDX Interface

The TPS BPM electronics had commission with TPS beam commissioning in 2014 [4, 5]. It consists of four kinds of modules: The timing module for clock locking and trigger; up to four BPM modules for receiving button pick-ups and signal processing, the inter-connection board (ICB) module for SW and HW interface; the GDX (Gigabit data exchange) module as Fig. 2 shown for FA data grouping and FOFB computation which could support at most 256 BPMs and 128 correctors feedback computation. The magnet correction output is transmitted to CPSC (corrector power supply controller) based on AURORA protocol of Xilinx. It also provides 10 kHz BPM grouping data through Gigabit Ethernet to support the angle interlock functionalities of TPS. The functional block of FOFB is shown as Fig. 3.

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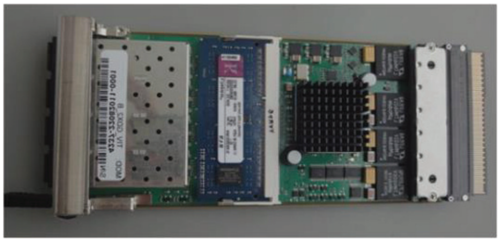

Figure 2: GDX module for FA data grouping and FOFB computation. There are 4 SFP ports provided: two SFP ports for FA data grouping; one SFP for magnet output; one SFP for BPM grouping data output (Gigabit Ethernet).

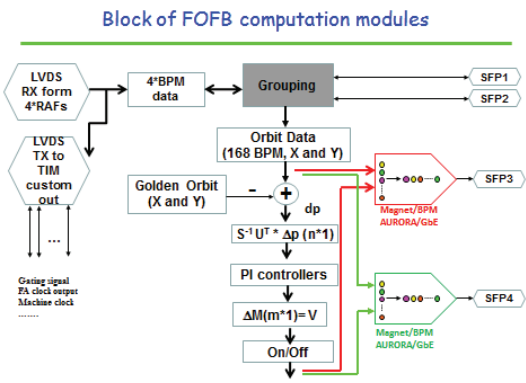

Figure 3: Functional block of FOFB computation module.

Corrector Power Supply Controller Interface

To support diverse functionalities of fast orbit feedback [6], booster ramping, compensations for insertion device and skew quadrupoles, the CPSC for TPS corrector power supply is proposed. CPSC is installed into the center slot of power supply rack as Fig. 4. It was contracted to D-TACQ and consists of four mouldes of boards: IOP, ADC unit, DAC unit and FPGA for summing of FOFB fast setting and EPICS slow setting. This functional block is shown as Fig. 5. It is embedded with EPICS IOC for slow access of the EPICS clients and its FPGA supports fast settings from GDX modules via fibre link based on Aurora protocol.

Figure 4: Power supply rack. CPSC is plugged in the center slot and could controller 8 channels of power supplies.

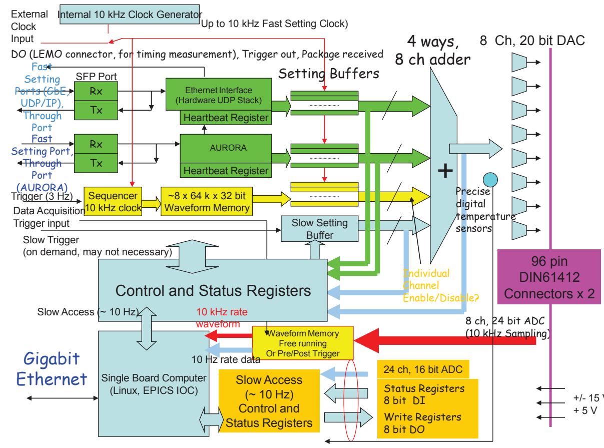

Figure 5: Functional block diagram of the corrector power supply controller module. The EPICS channel access is via a dedicated embedded IOC. The fast setting from feedback engines would sum with the EPICS CA slow setting.

ORBIT STABILITY IMPROVED WITH FOFB

FOFB has continuous tested and operated with beamline commissioning since 2016 February both for horizontal and vertical planes. It has been proven to suppress the noise from DC to 200 Hz effectively.

For beam position stability of the raw TPS machine without FOFB, as Fig. 6 shown, most of horizontal position disturbance (blue line) is contributed from mechanical vibration which is excited by cooling water majorly [7], distributed below 80 Hz. There is also strong 3 Hz up to tens of micron meter from field leakage during booster power supply ramping. For the vertical position plane, there were also very strong 60 Hz powerline noises which were later identified as contribution from grounding problem of RF system.

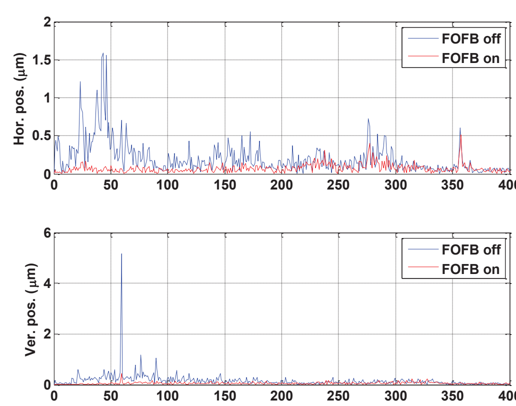

Figure 6: Beam Spectrum (no booster power supply ramping).

With FOFB applied, it could be observed that beam stabilities of horizontal and vertical planes are both much

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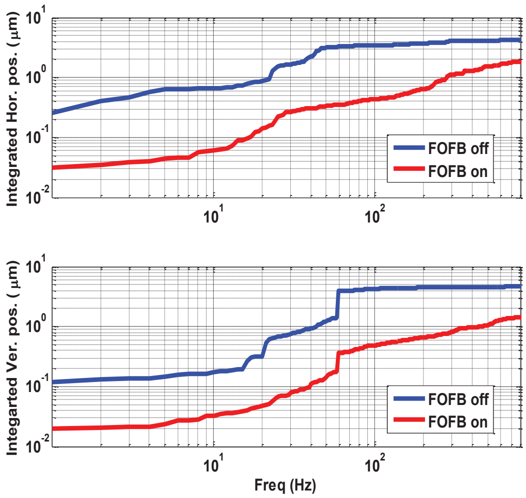
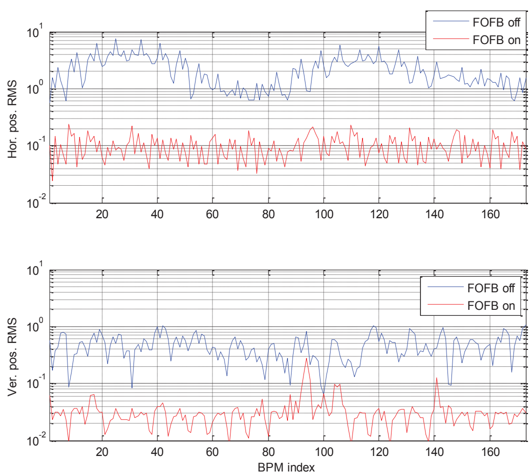
improved. The integrated displacement of the straight line BPM from DC to 200 Hz could achieve 0.5 um for both of horizontal and vertical planes and it is satisfied the one tens of beam size stability as Fig. 7(a) shown. Besides, the overall BPM 10 Hz data RMS comparison of FOFB on and off is also presented as Fig. 7(b). The overall orbit stability is improved one order of magnitude.



(a) Integrated BPM position displacement



(b) BPM 10 Hz data RMS comparison.

Figure 7: BPM orbit stability comparison between FOFB on and off.

The estimated bandwidth of FOFB is around 250 Hz for horizontal plane and 300 Hz for vertical plane as Fig. 8 shown. It could suppress ten times of noise around 50 Hz which is the major noise source of TPS. FOFB would also amplify noise around 400~700Hz while the beamline experiments would not be concerned about these frequency range. The parameter optimization of which BPMs and eigenmodes selected and PI coefficient weighting adjustment would be based on beam condition. The performance and reliability should be both considered and it would be required further studied.

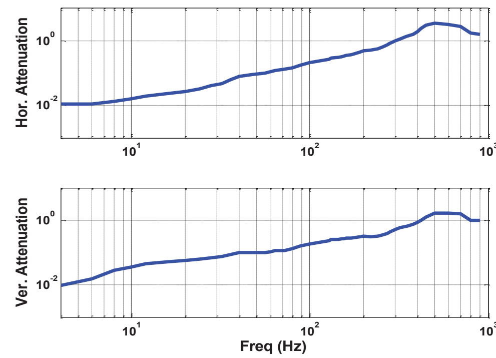


Figure 8: The measured bandwidth of FOFB. Horizontal is around 250Hz and vertical around 300 Hz.

FAST ORBIT FEEDBACK WITH SLOW CORRECTOR COMPENSATION

Since the slow correctors' bandwidth would be limited much less than 100 Hz due to the TPS alumni vacuum chamber, the fast corrector would be used only for feedback correction to suppress various disturbance form DC to 300 Hz [8, 9]. A process which flow chart is shown as Fig. 9 would check the fast corrector output current periodically and transfer DC part correction to the nearby slow correctors when accumulating greater than acceptable value to avoid saturation. According the experience, FOFB operation would cause maximum 2~3 Amp accumulating value of the fast correctors since beam current injection from 30 mA to 500 mA. And after thermal equilibrium reached at top-up mode, the drift could be controlled below 0.5 Amp with RF feedback but could be over 4 mA without RF feedback.

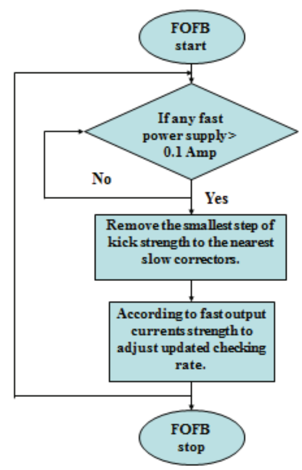


Figure 9: FOFB with slow corrector compensation to avoid fast corrector saturation.

RF FEEDBACK FOR PATH LENGTH COMPENSATION

RF feedback is used to minimize the effects of path length change mainly caused by temperature drift. Although FOFB could compensate some parts of the path

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length change, there are still some residual orbit difference remained up to several tens of microns during 24 hours operations. Furthermore, this difference would be amplified ten times observed at the beamline XBPM where it was unacceptable. The RF feedback thus was soon implemented and applied with FOFB. The orbit drift could be controlled and limited less than 1 um for one day operations as shown in Fig. 10. There are some spikes observed due to injection around every 5 minutes. The RF feedback process would poll the horizontal correctors' current ΔI at 0.1 Hz, convert it to the corresponding orbit deviation by response matrix R, and then dispersion function D is used to calculate the required RF frequency change ΔRF.

$$\Delta RF = D^{+} R \Delta I$$

where D^{+} is pseudo-inverse of D. The longer orbit stability test with FOFB and RF feedback would be done after long shut down of TPS.

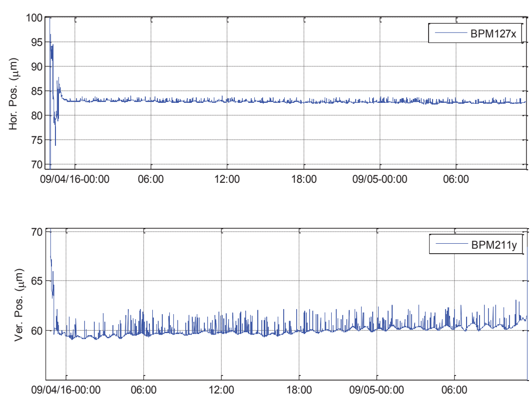

Figure 10: Horizontal and vertical orbit with FOFB and RF feedback during 36 hours of operations. There are some spikes due to injection around every 5 minutes.

CONCLUSION

BPM electronics and integrated orbit feedback system combined with slow and fast correctors of the TPS are summarized. All major components were tested and verified its functionalities. Testing is on-going and long-term reliability would be continuously improved. There are 170 BPMs and 96 fast correctors used in FOFB loop. The proper BPM selected would be adjusted according to the beamline experiments and the optimization would be the next efforts.

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