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STATUS OF FAST ORBIT FEEDBACK SYSTEM IN TPS

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Abstract

TPS has provided its user service since 2016. To ensure stable beam can be delivered to users, the fast orbit feedback system were deployed to ensure the stable electron orbit. The system have been commissioning in the second quarter of 2016. Later, rf frequency adjustments are also included to compensate the path length changes due to ambient temperature variations, earth tides and etc. Improvement of the system has continued to solve various unexpected problems. This report will summarize the system configuration of the fast orbit feedback.

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. Later, closed orbit correction methods by RF frequency correction have been developed to compensate for orbit path length changes. FOFB together with RF frequency corrections have been in routine operation since September 2016. The orbit stability has been effectively improved and can achieve sub-micron stability in both horizontal and vertical planes.

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 as Fig. 1 shown. 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.

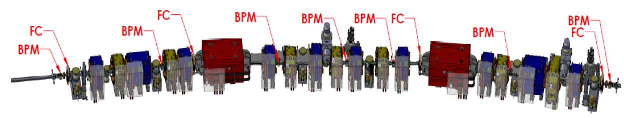

Figure 1: One cell of 24 double-bend cells for TPS lattice layout.

The overall infrastructure of FOFB is as Fig. 2. 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].

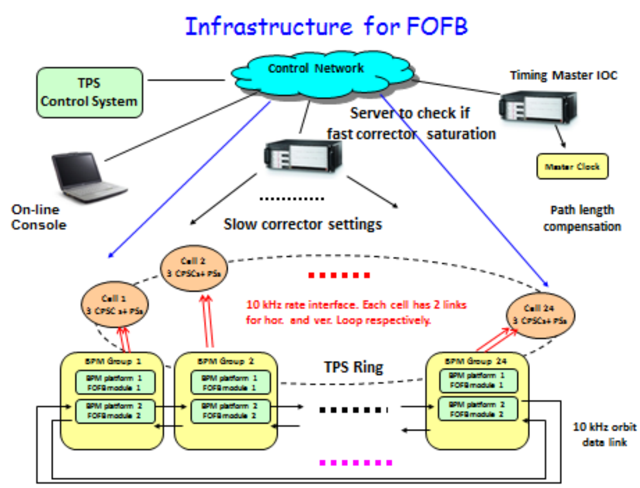

Figure 2: FOFB infrastructure.

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 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

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(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.

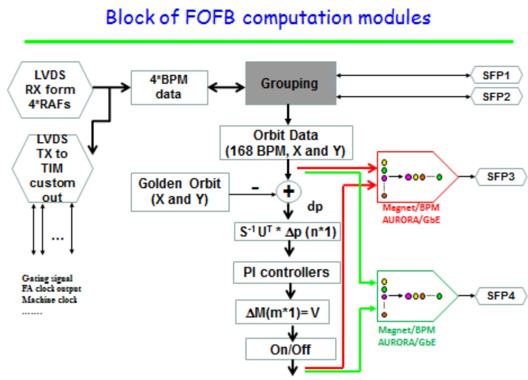

Figure 3: Functional block of FOFB computation module.

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 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 as Fig. 4. 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.

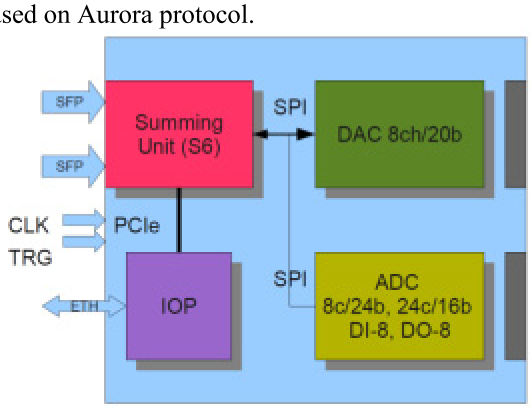

Figure 4: There are four major modules inside Corrector Power Supply Controller (CPSC): IOP, ADC unit, DAC unit and FPGA for FOFB fast setting.

The estimated bandwidth of FOFB is around 250 Hz for horizontal plane and 300 Hz for vertical plane as Fig. 5 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.

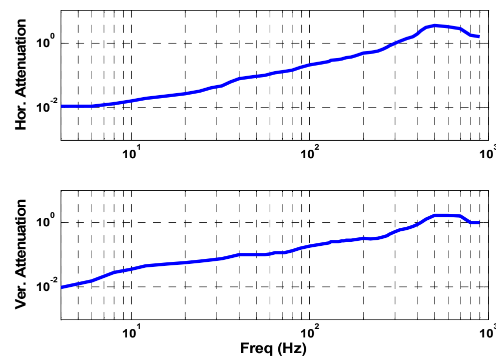

Figure 5: The measured bandwidth of FOFB. Horizontal is around 250Hz and vertical around 300 Hz.

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 [6,7]. A process which flow chart is shown as Fig. 6 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.

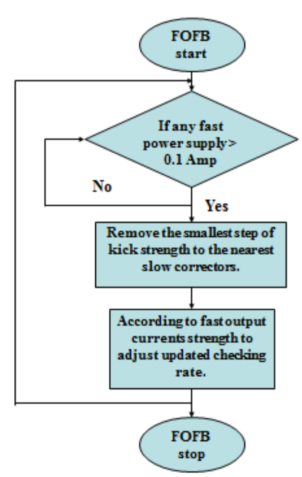

Figure 6: FOFB with slow corrector compensation to avoid fast corrector saturation.

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RF FREQUENCY CORRECTION FOR PATH LENGTH COMPENSATION

RF frequency correction is used to minimize path length changes caused mainly by temperature drifts and earth tides. Although the FOFB system could compensate some of these path length changes, residual differences up to several tens of microns remain after some 24-hour operation. Furthermore, this error would be amplified ten times as observed at the end of beamline XBPM which was unacceptable. Thus, RF correction was soon implemented and applied after FOFB commissioning. As a result, the orbit drift can be controlled and limited to less than 1 um from day to day.

The FOFB is applied to suppress horizontal orbit disturbances or drifts. The RF correction process polls all fast horizontal corrector currents, ΔI, at 1 Hz and converts them to corresponding orbit deviations with the response matrix R. Then, the dispersion function D is used to calculate the required RF frequency change Δf_{rf} to be applied to the RF cavities. The RF frequency correction is a slow process and restricted to less than 1 Hz change per step to prevent overshooting the frequency change given by

$$\Delta f_{rf}=D^{+}*RM*\Delta I,$$

where D^{+} is the pseudo-inverse of D. Figure 7 shows the block diagram for RF compensation.

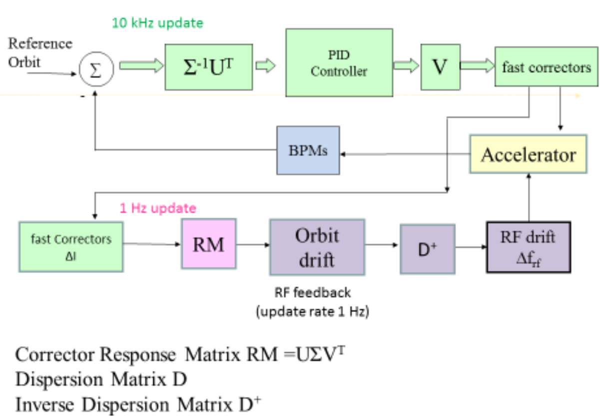

Figure 7: FOFB with RF correction (schematic).

Without FOFB and RF path length compensation, the horizontal orbit drift during one day can be up to one hundred microns as shown in the blue line of Fig. 8. When applying FOFB, it can correct some part of this orbit drift due to the circumference change, but there is still a residual error with respect to the golden orbit which cannot be fixed by FOFB and can be up to 20 um in high dispersion areas. However, with RF path length compensation, the orbit stability can be controlled below the submicron level as shown in Fig. 8 (black line). The spike on the data is caused by the injection transient which is not removed in this figure.

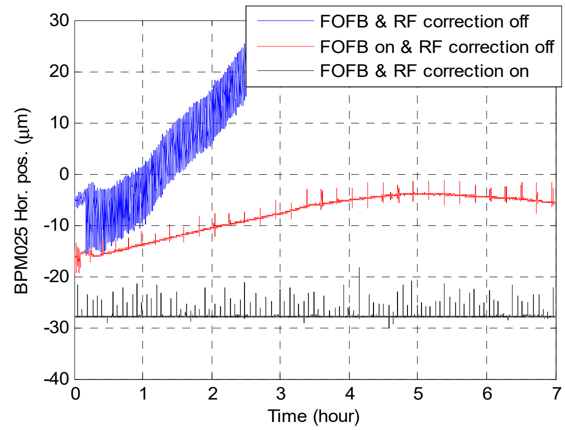

Figure 8: Orbit stability comparison with/without FOFB and RF path length compensation. The spikes are due to regular injection when FOFB and RF frequency correction is temporarily inactive.

CONCLUSION

Fast orbit feedback system for TPS are summarized. The measured bandwidth for noise suppression is around 250 Hz for the horizontal plane and 300 Hz for the vertical one. There are 173 BPMs and 96 fast correctors used in FOFB loop. RF frequency correction is also included for path length compensation. With FOFB and RF frequency correction, orbit variations can be kept below one micron during routine TPS operations.

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