CONCEPTUAL DESIGN AND PERFORMANCE ESTIMATION OF THE TPS FAST ORBIT FEEDBACK SYSTEM

P.C. Chiu, C.H. Kuo, Jenny Chen, K. H. Hu, K.T. Hsu
NSRRC, Hsinchu 30076, Taiwan

Abstract

A 3 GeV synchrotron light source (Taiwan Photon Source, TPS) is proposed in Taiwan. Its storage ring consists of 24 double-bend cells with 6-fold symmetry and the circumference is 518.4 m [1]. The report presents the initial design of the fast orbit feedback system (FOFB) for TPS. The system uses 168 BPMs and 168 correct magnets to stabilize global closed orbit at 10 kHz updated rate. The different subsystems are modelled, the BPM systems, the corrector magnet, vacuum chamber, and etc. The latency of the communication and computation is also studies. The preliminary calculation on the stability performance for the orbit feedback system is presented in the report. The FOFB is expected to achieve a submicron stability of the electron beam working at a bandwidth of at least 100 Hz.

INTRODUCTION

The lattice of the TPS which consist of 24 double-bend cells with 6-fold symmetry is shown in Figure 1. It is designed to achieve a low emittance and a small beam size. The small beam size requires a tight stability of the closed orbit of electron beam---usually smaller than 10% of the beam transverse size and of the angular divergence. In the vertical plane, where the beam size is of the order of 5~10 m, it will be corresponding to have a submicron orbit stability. Therefore, the fast orbit feedback system is designed to provide such a stable beam [2][3][4]. There are different subsystems involved in FOFB: BPM electronics, power supply, corrector magnet, vacuum chamber and etc. In the following sections, we will describe these different subsystems and provide a sketch of baseline infrastructure design of the system.

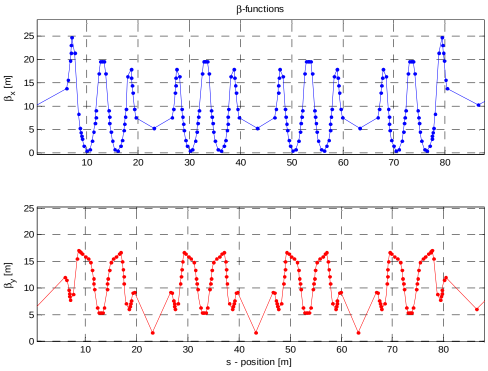

Figure 1: Optical functions of the TPS supercell.

BASELINE DESIGN OF FAST ORBIT FEEDBACK INFRASTRUCTURE

Advanced Telecom Computing Architecture (AdvancedTCA or aTCA) is a series of industry standard specifications for the next generation of carrier grade communications equipment. It incorporates the latest trends in high speed interconnect technologies, next generation processors, and improved reliability, resulting in a new form factor optimized for communications. Combined features of high throughput communication and high performance computing capabilities in the aTCA crate seem to be a promising solution for the TPS fast orbit feedback. Possibility to adopt the aTCA architecture for a future infrastructure of TPS is being under investigation. The proposed structure is shown in Fig. 2.

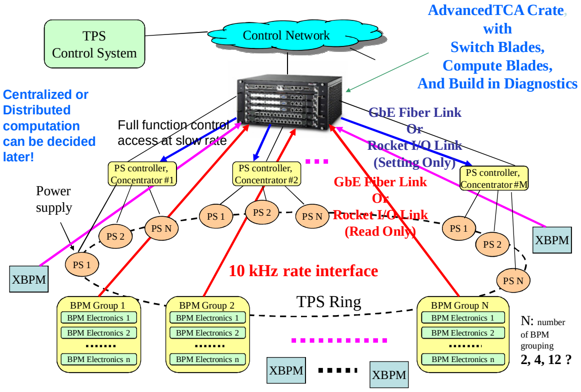

Figure 2: Architecture of the proposed orbit feedback system for TPS.

With diverse communication applications supported by aTCA, the system can accommodate vast and various interface ports such that data acquisition of BPM position, correction computation, corrector settings and diagnostic can be processed and executed at one single crate. A redundant group link between EBPMs will be adopted as an efficient method to achieve low latency. The framework of power supply controller to control 8 or 16 power supplies is also under survey. How to synchronize the operation of a feedback system between different processors via fast serial links requires further investigation. Event System could be another solution.

ORBIT PERFORMANCE STUDY

The closed orbit distortion due to uncorrelated random magnet motion is a critical issue on orbit stability [5]. To study the effects of this motion, we assign a displacement to each quad with different random Gaussian-distributed numbers with 1 μm rms value. According to dipole kick form, we can express the closed orbit as Eq. 1:

$$y_{co}(s)=\frac{\sqrt{\beta(s)}}{2\sin\pi\nu}\sum_{i=1}^{N}\sqrt{\beta(s_i)}\cos(\pi\nu-|\psi(s)-\psi(s_i)|)(kl)_i\Delta y_i \tag{1}$$

where β,ψ are the beta function and beta phase, ν is the tune. The kick strength including the quad displacement is $(kl)_i\Delta y_i$. This distorted orbit can be minimized at the location of BPMs by applying proper a set of corrector trims. Singular value decomposition, as a most commonly used correction algorithm, is employed to resolve the least-square problems and avoid the unnecessary large strengths in correctors.

Given the orbit response matrix R, it relates the orbit shifts Δy to the steering magnet changes $\Delta\theta$ as a linear form (Eq. 2):

$$\Delta y = R\Delta\theta \tag{2}$$

By the SVD of a matrix, the response matrix can be written as Eq. 3:

$$R=\Sigma u_k w_k v_k^T \tag{3}$$

Figure 3 shows the plot of the singular value w_k in descending order. The correction mode with the singular value less than 0.5 will be neglected. We thus has a more robust pseudo-inverse matrix as Eq. 4,

$$R^+ = V\Sigma^+ U^T \tag{4}$$

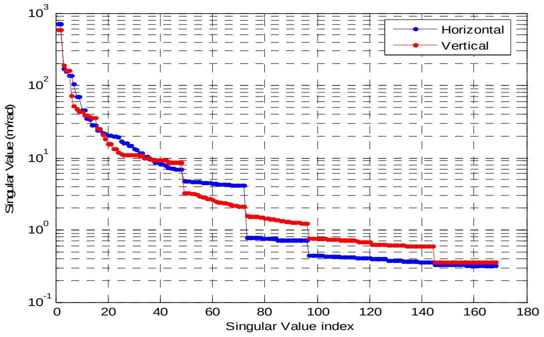

Figure 3: Singular value of Accelerator Response Matrix.

In the low frequency range, the gain of PID controller is so high that we can simplify the calculation of the correction as Eq. 5:

$$\Delta\theta = -R^+\Delta y \tag{5}$$

Once the corrector strength is obtained, we can calculate the real orbit motion due to both quads vibrations and steering magnet corrections. We also introduce BPM rms (root mean square) measurement errors on the order of 0.25 μm and corrector trims noises on the order of 7 nrad. For the model of TPS storage ring shown in Figure 1, we average the 250 sets of the random machine. The results are present in Figure 4 and Figure 5 as the blue curves for the horizontal and vertical plane respectively. The similar calculation is carried out including steering magnet corrections as the red curves shown. It is clear from the plots that 0.5 μm orbit stability can be achieved when the orbit feedback system is employed.

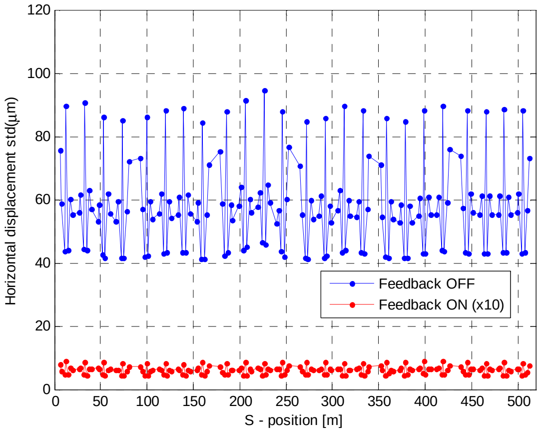

Figure 4: Orbit displacement deviation with/without the orbit feedback system in the horizontal plane.

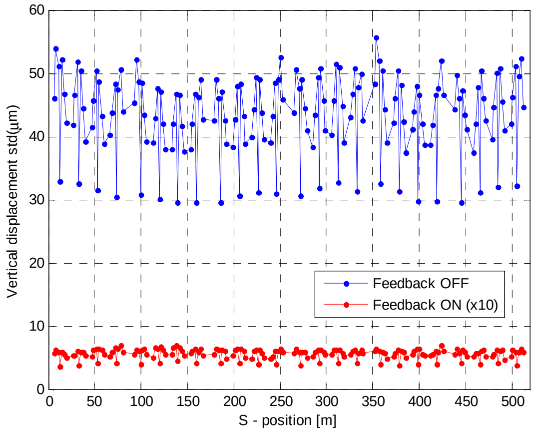

Figure 5: Orbit displacement deviation with/without the orbit feedback system in the vertical plane.

DYNAMIC RESPONSE STUDY

In the high frequency domain, the system's performance is limited by all of the subsystems' bandwidth. To study how the dynamics responses of the power supply, vacuum chamber and BPM electronics' effect on the performance of the feedback system, Matlab scripts were developed. The latency due to computation and communication is also included. Functional block diagram of the simulation scripts is shown in Fig. 6. We can analyze that different BPMs have respective characteristic against disturbance. Frequency response of the feedback loop is then studied so that we could adopt various controllers and apply optimum PID parameters.

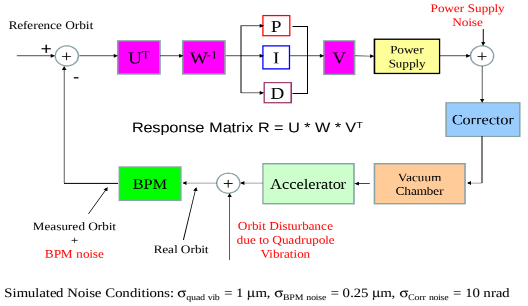

Figure 6: Block diagram for the fast orbit feedback system simulation.

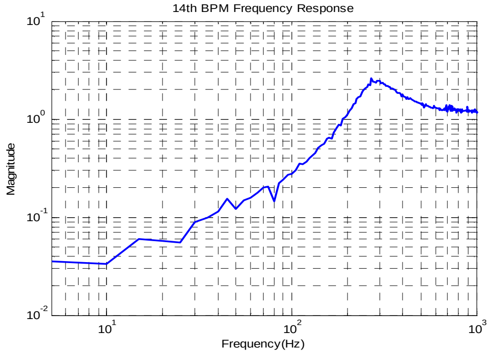

Figure 7: Sensitivity function of quad vibration to bpm sensors.

According to the above Figure 7, we roughly estimate the possible performance of the feedback system to suppress disturbance. The system's bandwidth can achieve 100 Hz while the noises will be amplified at higher frequency between 200~400 Hz. Now it is just the initial evaluation. The relative coefficients are required to have more precise measurement such as the latency, vacuum chamber, and BPM electronics. Controllers design is also being further studied.

PERFORMANCE REQUIREMENT OF BPM AND CORRECTOR POWER SUPPLY

The performance of orbit control is quite related to the accuracy and resolution of the BPM system. Libera Brilliance [6] is now our baseline design for the BPM electronics of Taiwan Photon Source. Intensive tests are undergoing for Liberas including the latency measurement, step response, current dependency and etc. The resolution of Libera are around 0.1~0.3 microns at a 10 KHz data acquisition [7]. About measurement delay, to improve the GbE jitter, Libera grouping is developed to reduce jitters due to overload GbE UDP/IP packet and improve communication latency in TPS. By means of grouping, the overall latency less than 500 sec is expected achieved. Besides, we propose that each BPM electronics is equipped with both of GbE and RocketIO port to provide more diverse implementation options. Libera, with 8 reserved SFP ports, should be easily revised to have this function by recompiling FPGA.

Corrector power supply of the TPS has not yet determined. It could be digital regulation or analogue interface. Digital regulator, or PSI type power supply, has an advantage of possessing a standard configuration while analogue type power supply costs less. However, no matter which one is chosen, the PSC (power supply controller) will be developed to support controlling 8~16 power supplies with 2 GbE interfaces or 1 GbE and 1 RocketIO interface, one for console's slow setting while the other for feedback fast setting. The Figure 8 shows the functional diagram of PSC. According to simulation results, we suggest that the noise of power supplies may be less than 7 nrad. Since the functionality of DC correction and fast orbit feedback will share the same corrector, it corresponds that the control interface should provide at least 18 effective bits in the case of which full range is 1mrad.

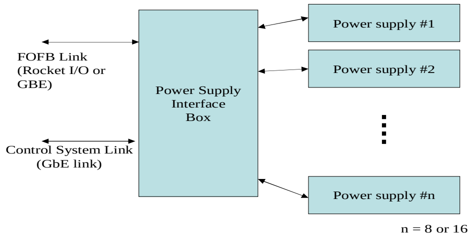

Figure 8: Functional Diagram of Corrector Power Supply Controller

SUMMARY

Conceptual design of the fast orbit feedback system of the TPS at the NSRRC is presented in this report. We survey aTCA architecture as our baseline infrastructure to implement the feedback system. In-house design of corrector power supply controller is inevitable and being planned. Simulations help to evaluate the system performance and characterize the specification requirement of the various subsystems such as power supply, BPM electronics and etc.

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