PERFORMANCE STUDIES OF AN INTEGRATED ORBIT FEEDBACK SYSTEM WITH SLOW AND FAST CORRECTORS

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

Abstract

Simulation study and experiments of an integrated orbit feedback system of the combined slow and fast correctors is under way. The slow correctors have the stronger trim strength with slower response while the fast ones have weaker strength but faster response. The integrated system can transfer DC corrections smoothly from fast correctors to slow ones to avoid possible saturation of the fast correctors as well as has an advantage of capability to suppress fast transient orbit drift. This kind of combined slow and fast system has been implemented or planned by several facilities [1][2][3]. Taiwan Photon Source is also proposed to apply the scheme in the orbit feedback system design. In this paper, the simulation of the system performance will be presented and its application for TPS will also be discussed.

INTRODUCTION

The lattice of the TPS consists of 24 double-bend cells with 6-fold symmetry, which is designed to achieve a low emittance and a small beam size [4]. 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 µm, it will be corresponding to have a submicron orbit stability. Therefore, the orbit feedback system is designed to provide such a stable beam. Moreover, to achieve better performance of orbit feedback system, besides the original seven correctors winded on seven sextrupole, four correctors with faster response are arranged dedicatedly for orbit feedback system in each cell of TPS lattice layout. In the following sections, we will study modeling of different subsystem, the resulting performance of the integrated orbit feedback system and present a sketch of baseline infrastructure design of the system.

INTEGRATED ORBIT FEEDBACK SYSTEM MODEL WITH FAST AND SLOW CORRECTOR

MIMO Model

Figure 1 shows the TPS lattice layout for each cell. We choose 5 slow correctors of 7, all of 4 fast correctors and all of 7 BPMs in each cell for the FOFB preliminary design. The response matrix R_s and R_f, which relates the orbit shifts to the slow and fast correctors respectively could be decomposed by singular value decomposition as Eq. 1 and Eq. 2.

$$R_s^{+} = V_s \Sigma_s^{+} U_s^{T} \tag{1}$$

$$R_f^{+} = V_f \Sigma_f^{+} U_f^{T} \tag{2}$$

where R_s is 168×120 matrix; R_f is 168×96 matrix. Their eigenvalue for vertical plane are shown as Fig. 2. The factors of maximum eigenvalue to minimum eigenvalue are 725.8 and 328.6 for slow and fast correctors respectively.

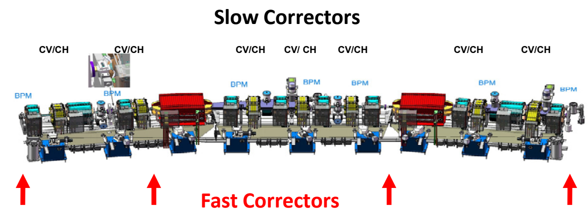

Figure 1: One cell of 24 double-bend cells for TPS lattice layout.

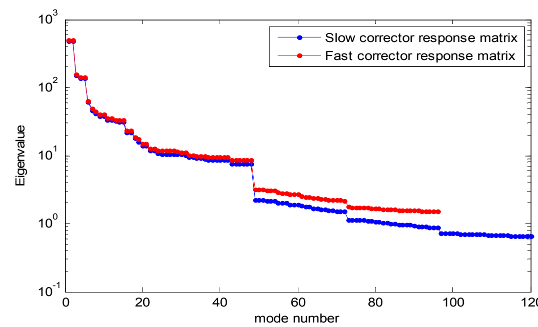

Figure 2: Eigenvalue of vertical response matrix for fast and slow correctors respectively.

Loop Latency

In orbit feedback system study of Taiwan Light Source, the overall loop latency which is the I/O latency time 500 µsec plus computation latency 120 µsec is 620 µsec [5]. We apply the same latency value for the TPS case. In digital model, it can be approximately $\tau_{delay} = 620$ µsec sample delay as Eq. (3).

$$H_{delay}(z) = z^{-\tau_{delay}\times f_s} \tag{3}$$

The sampling frequency f_s is temporarily set to 10 kHz therefore the delay number select the integer 6.

Dynamics Response Model

We consider the overall responses including power supply, magnet and vacuum chamber are approximately a forth order system. The rising time is $\tau_s = 13$ ms for slow correctors and $\tau_f = 0.6$ ms for fast correctors. Figure 3 shows their step response respectively.

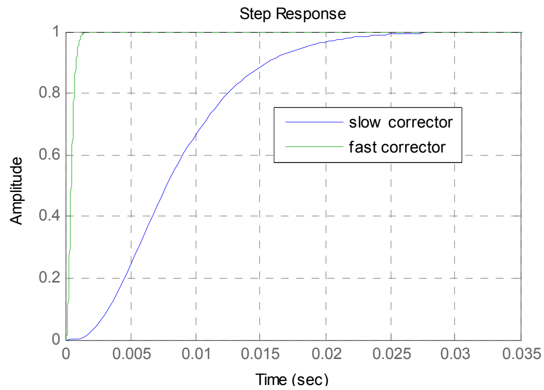

Figure 3: Step response for slow and fast correctors.

Controller for Slow and Fast Channel

To avoid saturation of fast correctors and counteraction of fast and slow loop, the different controllers would be applied for two loops respectively to separate the working frequency domain. Figure 4 shows the diagram of these control loops. It should be noticed that orbit data is shared for both loops and the corrections for both loops are also updated simultaneously.

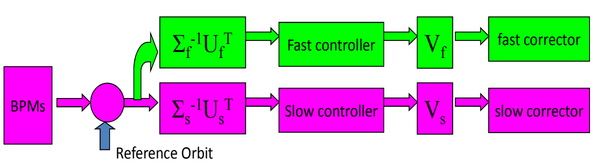

Figure 4: Feedback loop for slow and fast channel.

SIMULATION RESULTS

To obtain a stable solution, Tikhonov regularization is adopted where regularization parameter α is given one fifteenth of maximum of eigenvalue both for R_s and R_f. Figures 5 and 6 show the simulation results. One fast kick has related 5 μrad setting change with around 5 ms rising time and it results the vertical orbit is thus shifted with largest 3 μm displacement and soon suppressed by feedback system. Orbit deviation vanishes around in 6 ms. Figure 6 shows the corresponding fast and slow correctors change. It can be observed that at the time 2.5 ms, the correction of fast corrector was gradually transferred to the slow correctors. This demonstrates how the interaction of slow and fast corrections in the two loops.
From the figures, it is also seen that the corrections of fast correctors to compensate the kick change is almost less than plus/minus 0.05 μrad at final, which is smaller than correction of slow correctors.

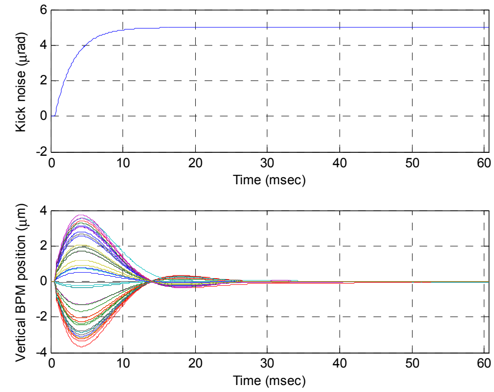

Figure 5: Response of the integrated orbit feedback system to the setting change of one fast kick.

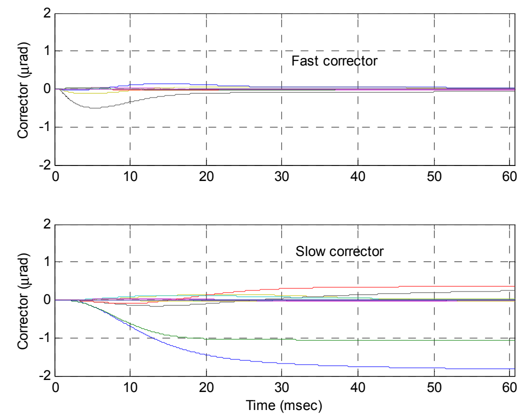

Figure 6: The strength of the fast correctors is gradually decreasing while in the same time the fast correctors take over the corrections.

Another condition is also simulated which one slower kick at the same position is applied a continuing change to the same strength 5 μrad. As Fig. 7 shown, the orbit displace can be less than an fifth compared to the above fast kick. The correction of fast correctors also gradually decreases at 38 ms when the kicker stops changing.

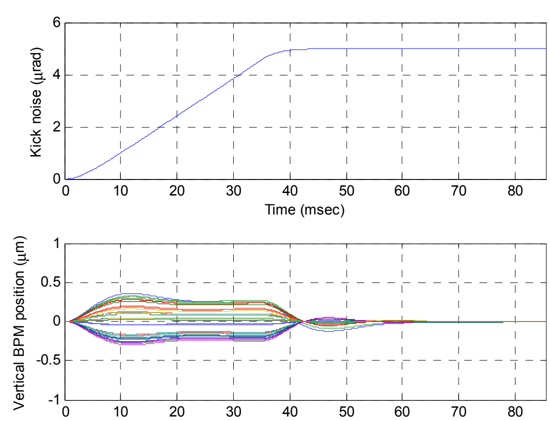

Figure 7: Response of the integrated orbit feedback system to the setting change of one slow kick.

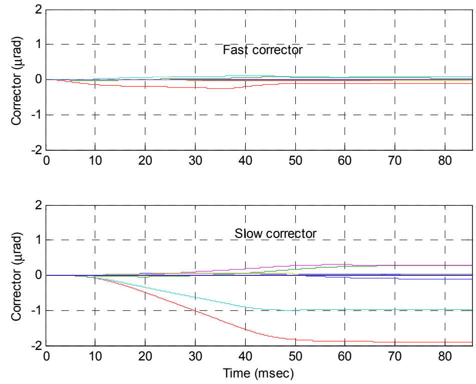

Figure 8: The slow and fast correction changes corresponding Fig. 7.

The bandwidth of the integrated orbit feedback system is initially designed around 500 Hz as the Fig. 9. The more precise number would be evaluated after prototypes of magnets and power supply come out.

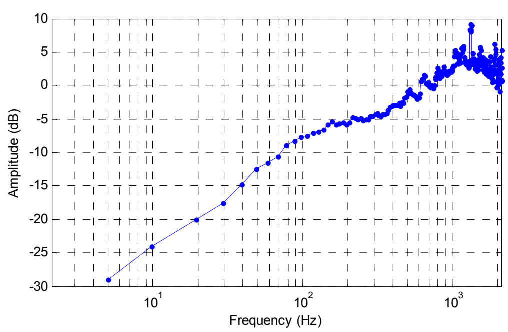

Figure 9: Simulated noise sensitivity function of the corrector VC014to bpm BPM011.

POSSIBLE ORBIT FEEDBACK SYSTEM INFRASTRUCTURE

There are several solutions of implementations and platforms which are look for. Advanced Telecom Computing Architecture was considered since the features of high throughput communication and high performance computing capabilities. Later, as the emergence of more diverse commercial products, MicroTCA is also selected another solution which has more IO supports as well as advantages of building a distributed system. Figure 10 shows the proposed structure of the integrated orbit feedback system using µTCA. Libera Brilliance is now the baseline design for the BPM electronics of TPS. Data distribution of all BPM values would be processed by FPGA inside Libera, which can be realized by Libera grouping or DLS Communication Controller. Another in-house or commercial FPGA card will be used to manage data acquisition and corrector calculation. The combination of the low latency aTCA/µTCA with FPGA/AMC will be our preliminary platform. Figure 11 shows one of possible solution using µTCA with AMC FPGA module. The corrector interface card would be designed for local remote control and the output will be sum with DC settings for COD correction to analogy power supply.

Additionally, the performance of aTCA/µTCA platform running real-time OS Monta Vista is also investigated whether it is capable of processing so demanding data acquisition/computation.

The orbit feedback system will be delivered at least four years later when we people hardly predict technical development or breakthrough. The later decision seems more beneficial. We will carefully evaluate the advantages and disadvantages of these options. The final solution would be decided after trade-off of the trend of technology, budget and manpower.

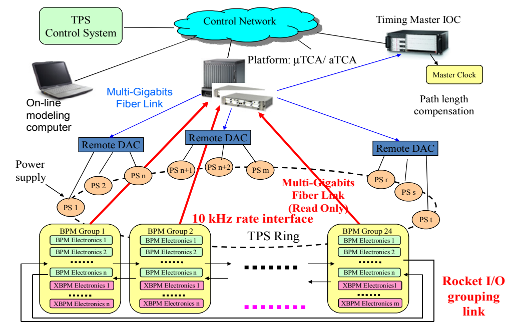

Figure 10: The infrastructure of the integrated orbit feedback system using µTCA.

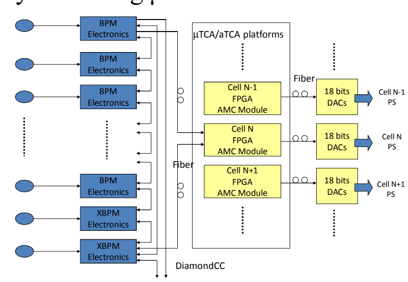

Figure 11: The µTCA using FPGA for the integrated orbit feedback system.

SUMMARY

The integrated orbit feedback system combined with slow and fast correctors of the TPS at the NSRRC is presented in this report. Simulations validate the integrated system fully utilizes the speed of fast correctors and can smoothly pass the strength of correction to slow correctors to avoid saturation of fast correctors. Possible platforms/architectures are also surveyed to implement the integrated feedback system.

REFERENCES

[1] L.H. Yu et al., “The Performance of a Fast closed orbit Feedback System with Combined Fast and Slow Correctors”, EPAC 08, Genoa, Italy.
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[4] TPS Design Book, v16, September 30, 2009.