COMMISSIONING RESULTS OF SLOW ORBIT FEEDBACK USING PID CONTROLLER METHOD FOR SIAM PHOTON SOURCE

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Abstract

A slow orbit feedback (SOFB) system has been developed to improve the orbit stability of the Siam Photon Source (SPS) storage ring. The SOFB uses a PID controller method utilizing LabVIEW channel to access 20 BPMs and 28 correctors of the ring. The first phase implementation of the feedback loops based on this method was operated at 0.05Hz sampling frequency, which reduces the fluctuation of both horizontal and vertical positions of the orbit from ~100-200 microns down to ~15-30 microns. The commissioning results indicate that further work and hardware upgrade are required. A higher sampling frequency up to 30-50Hz is strongly necessary for PID controller implementation. Upgrading of the existing 12-bit resolution corrector power supplies is also needed. The basic principle of PID algorithms, hardware, software and commissioning results of the current SOFB system, as well as future development plans, will be presented.

INTRODUCTION

The Siam Photon Source (SPS) is a synchrotron light source operated by the Synchrotron Light Research Institute (SLRI), and is located in Nakhon Ratchasima, Thailand. The first light was achieved in December 2001. Afterwards, a number of machine problems originated from operating such an old machine were encountered by the machine group. Most of these problems were caused by the degradation of various electrical and electronic components. The efforts to improve and upgrade the machine performance have been continually carried out [1, 2]. Rather serious machine problems that needed to be addressed were: storage ring RF problems, low injection efficiency, inaccuracy of the storage ring BPM system, and problem with beam position stability in the ring. We have spent almost one and a half years to overcome the critical parts of the problems, whereas the rest of those are currently being investigated.

With increasing user demand for improved beam position stability, an orbit feedback system is absolutely a necessity. In this report, we propose a new orbit feedback architecture, as well as a novel design approach for control algorithms, along with the hardware and software configuration for SPS storage ring. We then present the orbit feedback implementation and commissioning results. Finally, we will discuss beam stabilizing limitations based on existing hardware components and the ways to improve the feedback performance.

ORBIT FEEDBACK AND ORBIT STABILITY

It is well known that beam orbit stability is one of the quality criteria in synchrotron facilities around the world. Several detrimental effects lead to beam orbit variation, which include thermal effects, ground vibration, and mechanical vibration of accelerator components, among others. At SPS, for example, during eight hours of user beamtime period, the fluctuation of the photon beam monitored with a photon BPM (PBPM) is about 100 and 200 μm in horizontal and vertical directions, respectively (see Fig.1).

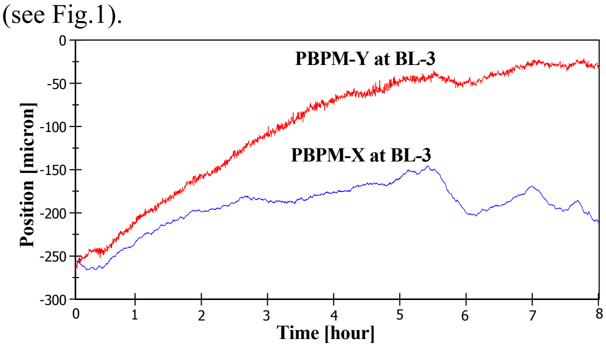

Figure 1: Horizontal and vertical orbit movement measured by the photon BPM at BL-3.

The machine group has made considerable effort to improve the beam orbit stability during the past few years. Iimprovements of cooling water and air conditioning temperature stabilization, improvement of the electron BPM and photon BPM accuracy and precision, and improvement of the electrical grounding system, for example, had been carried out.

The improvement of storage ring BPMs in October 2011[3] has made it possible to employ a reliable orbit correction system at SPS. A slow orbit feedback system (SOFB) was designed and implemented in the SPS storage ring in December of the same year. The goal for the first implementation of feedback system is to stabilize the slow orbit drift (as measured by photon BPMs) to within 20 μm in both horizontal and vertical directions.
The theoretical foundations of orbit feedback system including the PID controller design and model based compensator concept will be given in following section.

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CONTROL ALGORITHMS

In this section, we will briefly describe the algorithms governing the operation of the SPS storage ring SOFB system. The SOFB is designed based on the combination of on-line conventional PID control and adaptive compensator, constituting a robust control for unknown input disturbance and modelling uncertainty [5].

PID Controller

A typical structure of feedback system is shown in Fig.2 (yellow box). A mathematical description of a continuous time PID controller (u_{PID}) is:

$$u_{PID}(t) = K_P e(t) + K_I \int edt(t) + K_D \frac{de(t)}{dt} \qquad (1)$$

where K_p , K_i and K_d are the proportional , integral , and derivative gains, respectively. These gains are chosen to achieve control goals (reference values) and minimize error change (e). It is important to note that the use of the PID algorithm for control does not guarantee optimal control of the dynamical system or system stability [4]. However the PID controller proved to be the best control mechanism in this situation.

Model Based Compensator

The model based compensator methodology has been widely adopted in control system design in recent years, especially in the areas of vehicle and aerospace control. In our case, the modified strategy of model based compensator [5] was applied to the SPS feedback control framework.

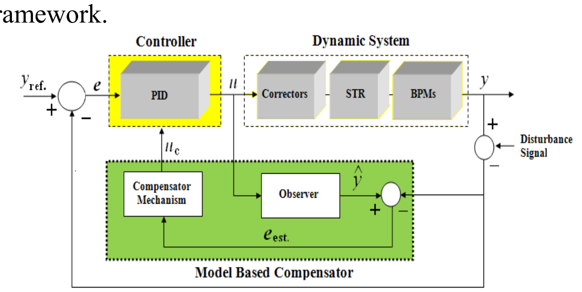

Figure 2: The proposed feedback system architecture.

Basically, the observer will estimate the system output ($\hat{y}$) and then form a part of compensator-controller structure using the estimated error ($e_{est.}$) signal information. The compensator mechanism computes the compensated controller (u_C) signal to minimize the difference between measured and estimated system output. The u_C compensates not only an unknown input disturbance signal (noise) but also the modelling error arising from nonlinear behavior in system identification. In this case, the modelling error means the discrepancy between the optics given by the on-line model and the actual machine lattice during the SOFB operation.

The underlying concept and goal behind the feedback system in Fig.2 is to combine the PID controller (u_{PID}) in Eq. 1 (yellow box) with compensated controller (u_C) (green box) into one system structure. Therefore, the *total* feedback controller (u) is given by:

$$u(t) = u_{PID}(t) + u_C(t) \qquad (2)$$

In next section, we will present an experimental setup for developing and evaluating this designed feedback scheme based on the PID and compensated control algorithms.

EXPERIMENTAL SETUP

In the first commissioning, a feedback algorithm outlined above operates on a host PC in the control room. In order to study various effects on the orbit feedback performance, the combination of LabVIEW and MATLAB scripts are developed. It utilizes all of the 20 BPMs, 16 horizontal and 12 vertical correctors.

The feedback processing algorithms are implemented in a MATLAB code, and communicate with BPM hardware components and correctors via an Ethernet communication link using LabVIEW's built-in data socket transfer protocol. The SOFB Graphical User Interface (GUI) is shown in Fig.3.

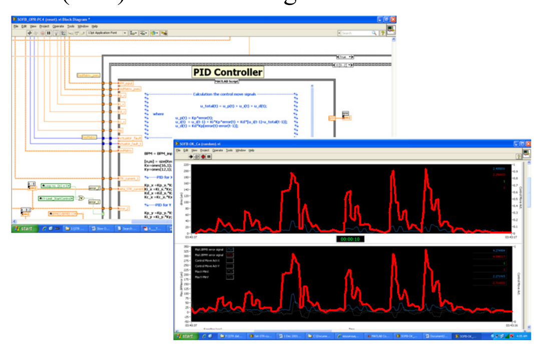

Figure 3: GUI for SPS slow orbit feedback system.

The optimal PID parameters, frequency response of feedback control loop, control performance, and orbit response characteristic against input disturbance will be described in the following section.

FEEDBACK TEST RESULTS

The SOFB was tested during the machine study period in December 2011. The tests were dedicated to exploring an optimal operation mode of the feedback system, including the choices of *(i)* the PID gains, and *(ii)* the sampling frequency of close loop system. The commissioning results are as followed.

PID Tuning

Optimizations of the PID gains were done by varying the beam orbit with an external disturbance. We opted to adjust the four air-cored correctors located upstream and downstream of our U60 undulator. These four correctors are not included in the 28 correctors forming the feedback system.

Fig.4 shows an example of the feedback reaction for current variation in the correctors. Here, only PID parameters tuning in the vertical plane will be presented. The PID tuning results show that every time the current is changed, the (vertical) beam orbit return quickly to it reference value without any reconfiguration required.

This demonstrates the effectiveness and the excellent performance of the designed SOFB. However, it is important to note that the PID gains are at the moment not yet optimized. It should be modified later together with an appropriate bandwidth of feedback control loop. The current PID parameters are $K_p = 0.25$, $K_i = 0.45$, $K_d = 0$, and the sampling frequency is 0.05 Hz.

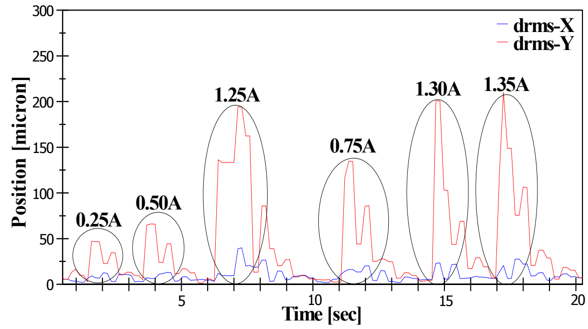

Figure 4: PID tuning and orbit response.

SOFB Implementation

Fig.5 shows the vertical orbit motion, measured by PBPMs at BL-3, and BL-6, in 2 four-hour periods (separated by a beam injection) with and without the orbit feedback.

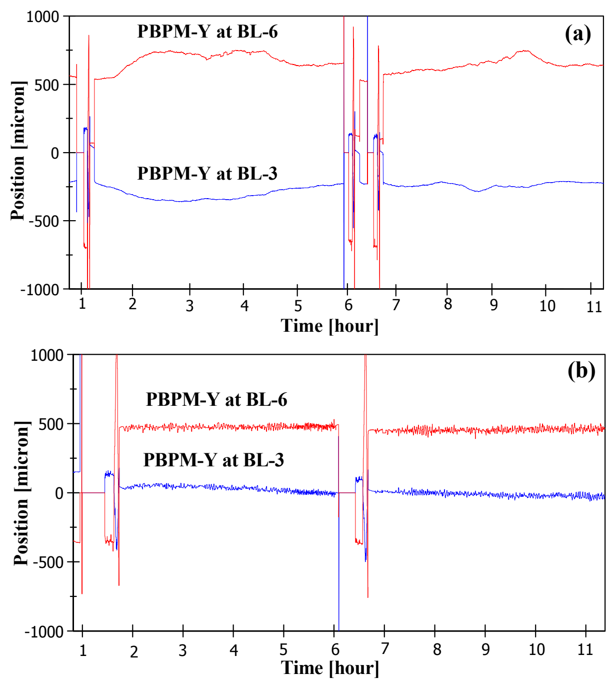

Figure 5: The vertical PBPM data with and without the orbit feedback.

Without the orbit feedback (Fig.5a), the vertical orbit movement is more than 150 µm. When the feedback is on (Fig.5b), the vertical orbit variation is restricted to below 20 µm with respect to the referenced golden orbit.

Fig.5b also shows a small unwanted residual variation of orbit with feedback. From a control point of view, this is due to a constrained optimization control problem caused by an insufficient bit resolution of the corrector power supplies, and a signal processing network problem against increasing frequency in feedback loop.

Fig.6 shows the horizontal and vertical orbit motion when the feedback system operated for about four hours, maintaining both horizontal and vertical orbit fluctuation to less than 20 μm (RMS).

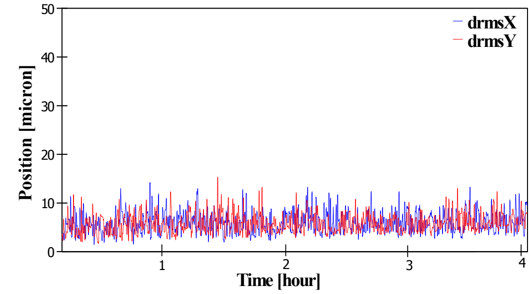

Figure 6: Horizontal and vertical orbit variation when the slow feedback is on.

CONSLUSION

The SOFB system with the proposed control algorithms were successfully tested and found to work well in its first commissioning. The variation of the photon beam position has been suppressed down to less than 20 µm, and less than 15 µm in the case of the electron beam, in both horizontal and vertical directions. However, we decided not to implement the feedback system on a permanent basis until the problems associated with limited resolution of the existing corrector power supplies, and low sampling frequency in the loop are overcome.

In the meantime we will continue to improve the performance of the feedback system. The future improvements will include on-line implementation of high precision I/O loop measurements with higher frequency. New power supplies for corrector magnets with higher resolution (16-bit) were ordered and will be installed, replacing the current 12-bit ones, by the end of 2012. It is expected that performance of the feedback system, and in turn the beam orbit stability, will improve significantly.

ACKNOWLEDGMENT

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