OPERATION EXPERIENCES OF THE BUNCH-BY-BUNCH FEEDBACK SYSTEM FOR TLS

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Abstract

Severe multi-bunch instabilities have deteriorated the performance of Taiwan Light Source (TLS) during the operation since SRF system upgrade in 2004. FPGA-based bunch-by-bunch feedback system was commissioning during late 2005 and early 2006. Multi-bunch instabilities in both transverse and longitudinal are damped effectively. Delivery up to 400 mA stored beam was demonstrated. Transverse feedback system makes low chromaticity operation possible; this is very helpful to improve injection efficiency which is essential for routine top-up operation. Operation experiences of the bunch-by-bunch feedback system will be summarized in this report.

INTRODUCTION

A FPGA based bunch-by-bunch feedback system to suppress of transverse and longitudinal instabilities was deployed in November 2005 and February 2006. The Taiwan Light Source (TLS) at NSRRC is composed of a 1.5 GeV storage ring. Two major upgrades of TLS have been completed - the superconducting RF cavity (SRF) upgrade in late 2004 and the top-up operation in late 2005. Both upgrades were intended to increase the stored beam current from 200 mA to over 400 mA, to eliminate strong instability that is caused by the high-order modes (HOM) with conventional RF cavities, and thereby continue to provide a constant heat load for high-quality photon beams. The threshold current of transverse multi-bunch instability is slightly less than 40 mA. The longitudinal instability is also a problem when the stored beam current exceeds 150 mA. The major sources of the transverse instability are the resistive wall and the ion effects. The cavity-like structure of the vacuum duct is assumed to contribute in the source of longitudinal instability. These instabilities can be effectively controlled by the transverse feedback system and the longitudinal feedback system. This report will present the status of instability suppression at TLS.

BUNCH-BY-BUNCH FEEDBACK SYSTEM

FPGA-based bunch-by-bunch feedback applications are extensively adopted in numerous laboratories. The SLAC/LNF-INFN/KEK collaboration G-board project and Libera Bunch-by-Bunch projects for ESRF broadband feedback system are typical examples. The feedback processor in TLS was originally developed for the SPring-8 [1]. A highly flexible feedback processor

design led to easy adoption for TLS applications. Figure 1 presents the block diagram of a bunch-by-bunch feedback system [2]. The system consists of a beam position monitor (BPM), an analog front-end (analog de-multiplexer for transverse feedback and phase detector for longitudinal feedback), a feedback processor, an SSB or QPSK modulator for a longitudinal feedback system, power amplifiers and kickers. The beam signals measured by the BPM are processed by an analog de-multiplexer or a phase detector into baseband signals and fed to the digital feedback processor, and converted the position or phase oscillation signal of each bunch into digital forms which are filtered using the FIR filters. The filtered error signal drives the kicker to dampen the bunch motion. The latency of the system should be one or two periods of revolution of the storage ring plus the bunch propagation delay between the BPM and the kicker in the transverse feedback loop.
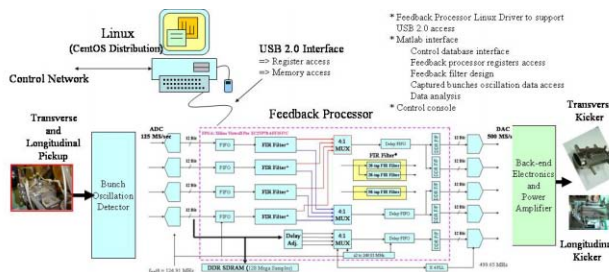

Figure 1: Block diagram of bunch-by-bunch feedback system. The feedback processor is shown in the center of this figure. The FIR filter inside the feedback FPGA consists of two 20-tap FIR filters in the transverse feedback and a 50-tap FIR filter in the longitudinal feedback.

Up to 32 sets of FIR filter coefficients can be stored in an internal register of FPGA and are selectable via a USB 2.0 interface or an external logic input control. The switching speed is about 10 ns in the latter case. This function makes the system very flexible for use in the grow-damp experiments. Up to 256 historic mega-samples of ADC can be recorded for further analysis. The latency time of the feedback processor is about 300 ns. A favorable frequency response of the FIR filter can be easily achieved using a two-turn delay (800 ns) in the transverse feedback loop. The frequency multiplier supplies a DAC clock at the RF frequency with a cycle-to-cycle jitter of 50ps from the ADC clock. The processor with five DACs - four for the multiplexed FIR filter output and one for multiplexed raw ADC data - is used in diagnostics and tuning. The latency of the multiplexed FIR filter output can be controlled by

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adjusting the internal delay. Each DAC has complementary outputs. These functions are very useful in the system tuning. For instance, the delay time and polarity of the individual kicker must be tuned when several kicker electrodes are used for feedback. A compact Flash (CF) card is used as a FPGA store and booting device. The USB2.0 interface is provided to control the processor and transfer captured data by Linux computers. The Matlab control software with device driver was developed in the TLS to provide a convenient and integrated environment of the interface of the feedback processor. These scripts are compatible with the existing accelerator Matlab control interfaces; the environment effectively satisfies various demands in routine operation and accelerator studies.

The feedback processor has four parallel channels. Each channel has a 12-bit ADC and a FIR filter. The RF frequency f_{RF} is 499.654 MHz and the harmonic number is 200. In the four-ADC mode, the feedback processor and ADCs are operated with a clock frequency of $f_{RF}/4$.

Transverse feedback system

The SRF upgrade reduces the bunch volume by increasing the RF gap voltage. Severe transverse instability cannot be controlled by the compensation of chromaticity in a manner that is convenient in routine operation. The resistive wall and ion-related effects may contribute to such instability. The old analog transverse feedback system is very sensitive to the tuning [3]. The new FPGA based on a two-dimensional transverse feedback system with a single loop scheme, is proposed by Nakamura. This feedback loop comprises one pick-up and one kicker. The 20 taps FIR filter is linearly combined with vertical and horizontal responses. Bunch oscillation signals are multiplexed into four parallel channels in an analog manner. Delay lines align the four consecutive bunches in parallel. The differential output of the DACs drives two power amplifiers.

Longitudinal feedback system

TLS has suffered from severe longitudinal instabilities during the last decade. The HOM of two conventional RF cavities are the main sources of these instabilities. A second tuner has been introduced to adjust the HOM frequency and thus reduced the strength of instability. RF gap voltage modulation was adopted to eliminate the remaining instability at the cost of increased energy spread. Following the SRF upgrade, some residual longitudinal mode remained, possibly because of the impedance of beam ducts or some unknown sources. Extensive studies were performed during the operation of SRF in 2005. However, the aforementioned instabilities were not identified.

Because of limited space, the longitudinal kicker based on the SLS design was modified by fitting a beam tube into the TLS vacuum chamber, conserving space for a taper. The kicker was installed to the storage ring in January 2006. The preliminary longitudinal feedback system was commissioned in early February 2006 after a long shutdown.

The BPM sum signals are fed into the I-Tech RF front-end detector, which is used as a bunch-by-bunch phase detector at three times f_{RF} (1.5 GHz). The baseband output is split into four channels with a suitable delay to align four consecutive bunches signals into four parallel channels at a data rate of 125 MHz. These signals are subsequently fed into the feedback processor. The digitized signals are filtered through 50-tap FIR filters. The corrected output is sent to the SSB modulator. The lower sideband is sent to the beam excitation amplifier and the kicker.

OPERATION STATUS

Both transverse feedback and longitudinal feedback are supported for routine operation. Up to 400 mA of current was tested to demonstrate an adequate damping of both feedback loops. Figure 2 shows the beam profile of various conditions for transverse and longitudinal feedback loop on and off during the data taken as the operation current is around 300 mA. When both feedback loops open, huge beam blow up was observed as shown in Fig. 2 (a). When transverse feedback loops closed, transverse instabilities are suppressed, beam size shrinks to a–small size as shown in Fig. 2 (b). Since the source point of synchrotron radiation monitor is located in the dispersion region ($\eta \approx 0.108$ m), the energy oscillation contributes significantly to the horizontal beam size. After the longitudinal feedback loop is turned on, the horizontal beam size is markedly reduced as shown in Fig. 2 (c).
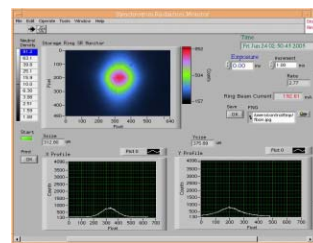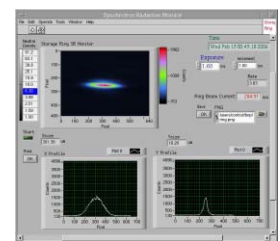
(a) TFB OFF, LFB OF   (b) TFB ON, LFB OFF
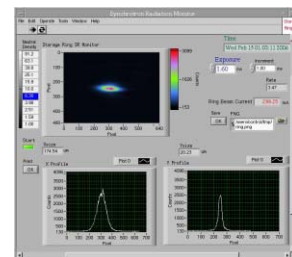
(c) TFB ON, LFB ON

Figure 2: Measured synchrotron profile for different operation conditions of the bunch-by-bunch feedback loops. (a) Shown both feedback loops are open. (b) TFB is ON and the LFB is OFF. (c) Both feedback loops are ON.

Modal analysis is useful to extract growth and damping time of the instabilities modes. Figure 3 (a) and (b) show the results of model analysis of the typical vertical

grow/damp data measurements, and corresponding modal analysis. A damping time of less than 1 ms and an operating current of 300 mA were obtained of all modes in the vertical plane. Figure 3 (c) and (d) show the growing/damping evolution of the envelopes and the mode pattern in the longitudinal feedback system. Only two modes dominate. Data of horizontal plane is not shown in here.
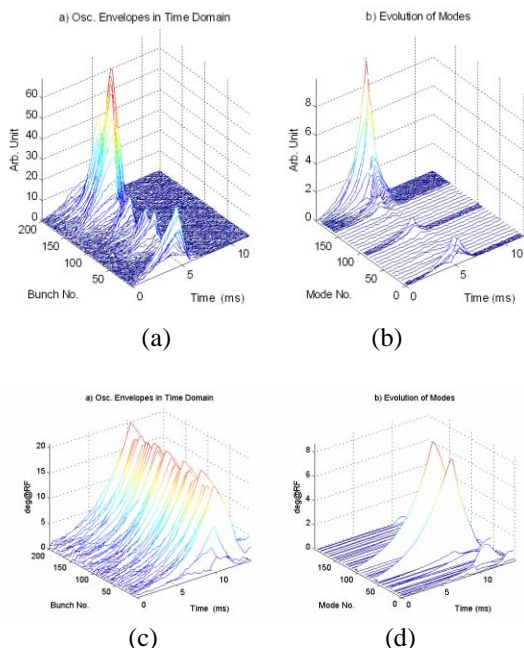

Figure 3:   Typical grow/damp results. (a) The evolution of vertical oscillation envelops in transverse grow/damp experiments. (b) Evolution of vertical oscillation modes. (c) Evolution of longitudinal oscillation envelop of bunches. (d) Evolution of longitudinal modes.

OPERATION EXPERIENCES

Injection efficiency

Strong transverse instabilities can be controlled by over compensated of chromaticity with cost of low dynamic aperture, its mean low injection efficiency. Transverse feedback system suppressing these instabilities to make near zero chromaticity operation is possible. Double of injection efficiency is achieved when the storage ring operated near zero chromaticity. This high injection efficiency is essential for the top-up operation.

Saturation of RF front-end of transverse feedback due to large closed orbit excursion at the pickups of transverse feedback

Large orbit excursion of the beam position at the site of the transverse feedback pickup will saturate the feedback electronics and lead the malfunction of the feedback loop during some machine conditions in machine study. This is not a problem for routine operation, since the orbit is kept at the same. The RF front-end can be optimized at this point.

Residue instabilities

Residue instabilities remain to be required further study. Identification of the noise source of the feedback system is under way.

Reliability

The digital transverse and longitudinal feedback loops are operated since 18 and 16 months ago respectively. Both feedback loops work well. Transverse feedback loop malfunction in several occasions due to orbit mis-steering are observed. It recovered after the orbit return of the original or fine tune of the RF front-end. The longitudinal feedback loop had failed several times after adjustment of the RF low level RF system. However, after fine tune of the RF phase of the bunch phase detector, the system back into service soon. The reliability of the feedback system is excellent from operation of view.

Access of the feedback system from control system

Access of all system components of the bunch-by-bunch feedback system is on-going constituted. Control of the power amplifier will be done soon. Since the reliability of the system is no bad, the priority and schedule will be done when resources are available later.

SUMMARY

This report summarizes the operation experience in the last year of the transverse and longitudinal feedback systems. Both feedback loops are working well. The transverse feedback system not only eliminates instability but also increases the injection efficiency because it supports low chromaticity operation, which is essential to the top-up injection. Longitudinal feedback increases the brilliance of the light source. The system performance and reliability of both feedback loops are constantly being improved. The functionality of the feedback system is no bad.

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06 Instrumentation, Controls, Feedback & Operational Aspects

T05 Beam Feedback Systems