CONTROL OF THE MULTI-BUNCH INSTABILITIES AT TLS

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Abstract

The goals of the recent superconducting RF upgrade and top-up operation at the Taiwan Light Source (TLS) are to increase stored beam current and provide stable beams. Suppressing multi-bunch instabilities caused by the resistive wall of the vacuum chamber and cavity-like structures and suppressing ion-related instability are essential to exploiting these upgrades. FPGA-based transverse bunch-by-bunch and longitudinal feedback systems were adopted. Multi-bunch instabilities were successfully suppressed at stored beam currents of over 400 mA. Chromaticity can be reduced using a transverse feedback system, which is essential to increasing the injection efficiency in the top-up operation mode. The status of the feedback systems and an analysis of the behavior of multi-bunch instability are presented.

INTRODUCTION

The Taiwan Light Source (TLS) at NSRRC is a 1.5 GeV storage ring. Two major upgrades of TLS have been completed - the superconducting RF cavity (SRF) upgrade in the late 2004 and the top-up operation in the 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 source of the transverse instability is 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.

MULTI-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 [1] 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 [2, 3]. 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. 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 feedback processor is the key component of the feedback system, and is adapted from the SPring-8 design with minor modifications. 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 converts the position or phase oscillation signal of each bunch into digital form which is 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.

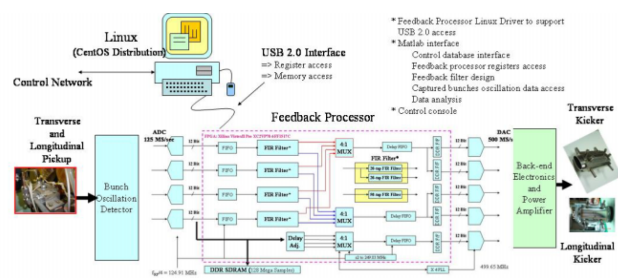


Figure 1: Block diagram of bunch-by-bunch feedback system. The feedback processor is shown in the center of the figure. The FIR filter inside the feedback FPGA consists of two 20-tap FIR filters in the transverse feedback and a 50-tap FIR filter in the longitudinal feedback.

Up to 32 sets of FIR filter coefficients can be stored in the 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 are stored in the DDR memory of the feedback processor. Therefore, up to 256 ms of data can be stored in the memory. (One sample is two bytes.) 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 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 an FPGA store and booting device. The USB2.0 interface is provided to control the processor and transfer captured data by Linux computer with kernel 2.4. The Matlab control software with this 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 meets various needs 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 OR conveniently during) 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 [4]. The new FPGA based 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

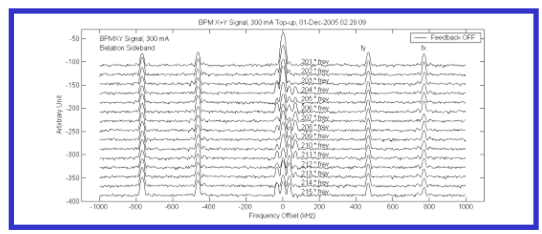
TLS has suffered from severe longitudinal instabilities in during the last decade. The HOM of two conventional RF cavities are the main source of these instabilities. A second tuner has been introduced to adjust the HOM frequency and thus reduce the strength of instability. RF gap voltage modulation 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, eliminating the request for a taper. The kicker was installed to storage ring in January 2006. The preliminary longitudinal feedback system was commissioned in early February 2006 after a long shutdown.

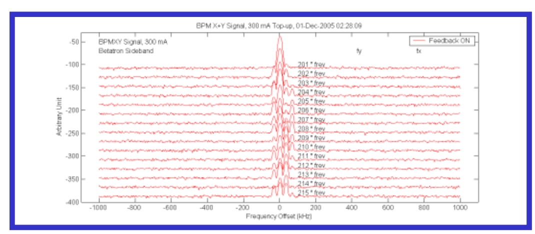
The BPM sum signals are fed into the I-Tech RF front-end detector [3], which is used as a bunch-by-bunch phase detector at three times f_{RF} (1.5 GHz). The baseband output is split into four channels with a suitable delay to align four consecutive bunches signals into four parallel channels at a data rate of 125 MHz. These signals are subsequently fed into feedback processor. The digitized signals are filtered through with 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.

STATUS OF INSTABILITY CONTROL

Figure 2(a) shows betatron sidebands without feedback. These betatron sidebands are completely suppressed when the feedback is on, as shown in Fig. 2(b). A damping time less than 1 ms at an operating current of 300 mA is achieved. Beam blowup is caused by transverse instability when feedback is off can be easily identified using the synchrotron radiation profile monitor, as presented in Fig. 3(a). After the feedback is turned on, the beam becomes stable, as presented in Fig. 3(b).

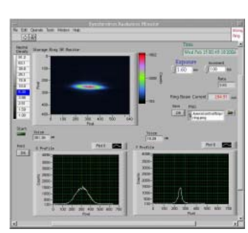


(a) Open feedback loop.

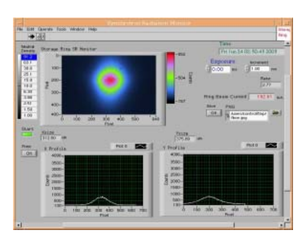


(b) Closed feedback loop.

Figure 2: Transverse spectrum from harmonic of revolution frequency 201 to 215 without longitudinal feedback. Strong synchrotron sidebands are observed near the harmonics of the revolution frequency.



(a) Feedback on.

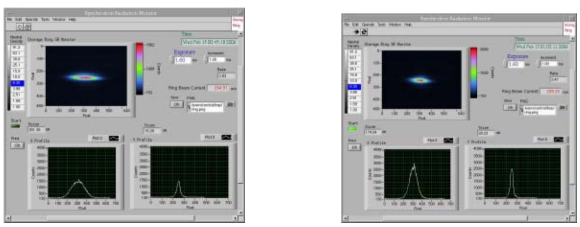


(b) Feedback off.

Figure 3**:** Measured transverse profiles of the synchrotron radiation monitor.

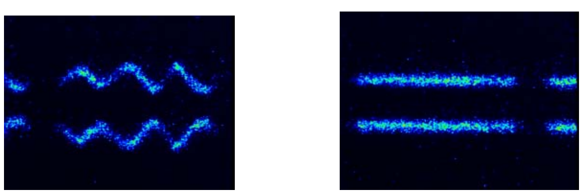
Figure 4 depicts the beam profile experiment between longitudinal feedback on and off. Since the synchrotron radiation monitor is located in the dispersion region, the energy oscillation contributes significantly to the horizontal beam size. After the feedback loop is turned on, the horizontal beam size is markedly reduced.

Figure 5 displays the image from a streak camera without and with feedback. A large oscillation is observed without feedback in (a). The energy oscillation is almost undetectable with feedback on in (b).



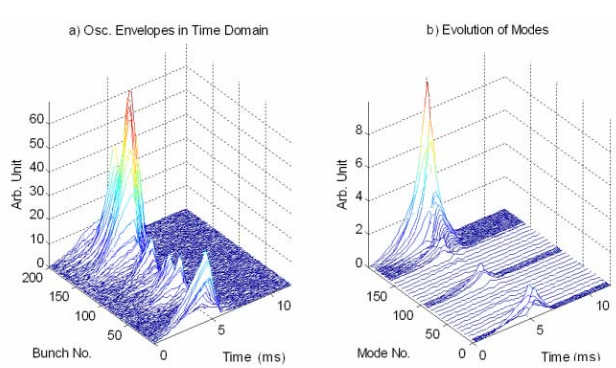
(a) Open Loop. (b) Closed Loop.

Figure 4: Transverse beam profile with and without longitudinal feedback. The source point of the synchrotron radiation is in the dispersion region ($\eta \approx 0.108$ m). The longitudinal feedback loop effectively reduces the horizontal beam size.



(a) Open loop (b) Closed loop

Figure 5: Snapshot of one-turn streak camera image. The vertical time span is 1.4 ns, and the horizontal time span is 500 ns in this dual scan configuration. The longitudinal feedback loop effectively suppresses the longitudinal motion.

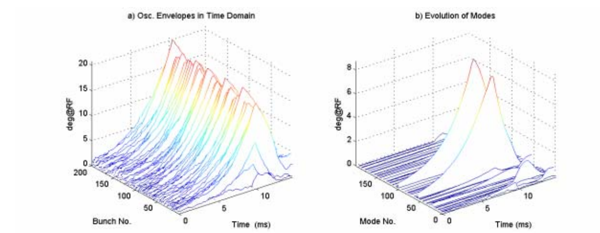


(a) (b)

Figure 6: The evolution of vertical oscillation envelops in transverse grow/damp experiments. (a) Evolution of oscillation envelope of bunches. (b) Evolution of modes.

Figure 6 shows the results of model analysis of the typical vertical grow/damp data measurements, and a corresponding modal analysis. A damping time of less than 1 ms and an operating current of 300 mA were obtained all modes in the vertical plane.

Figure 7 shows the growing/damping evolution of the envelopes and the mode pattern in the longitudinal feedback system. Only two modes dominate.



(a) (b)

Figure 7: Typical longitudinal grow/damp results. (a) Evolution of oscillation envelop of bunches. (b) Evolution of modes.

SUMMARY

This report summarizes the preliminary results of the newly commissioned transverse and longitudinal feedback systems. Both feedback loops are now in regular service. 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 machine. The system performance and reliability of both loops are constantly being improved. The functionality of the feedback system will be improved.

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