COMMISSIONING OF THE DIGITAL TRANSVERSE BUNCH-BY-BUNCH FEEDBACK SYSTEM FOR THE HLS*

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Abstract

Hefei Light Source (HLS) is an 800MeV storage ring with bunch rate of 204 MHz, the harmonics of 45, and circumference of 66 meters. HLS injection works at 200MeV, where the multi-bunch instabilities limit the maximum stored current. A digital transverse bunch-by-bunch feedback system has recently been commissioned at HLS to suppress the multi-bunch instabilities during injection. We employ the SPring-8 FPGA based feedback processor [1] and modified it at NSRL to process horizontal and vertical oscillation signals, independently and simultaneously by one single processor. The design of the digital transverse feedback system and the experiment results are presented in this paper.

INTRODUCION

HLS is a synchrotron light source, consisting of a 200MeV linac and a storage ring. Injection of HLS works at 200MeV with 45 bunches and operation works at 800MeV. Table 1 gives the specification of HLS storage ring.

Table 1: Parameters of the HLS storage ring

Injection energy	200MeV
Operation energy	800MeV
Circumference	66.13 m
Current	~250mA
RF frequency	204.048 MHz
Harmonic number	45
Revolution frequency	4.534 MHz
Tunes ($\nu_x / \nu_y / \nu_s$)	~3.525/2.57/0.008

Coupled bunch instabilities occur during injection and operation and could be suppressed by the digital transverse bunch-by-bunch feedback system. The octupole magnet was implemented to cure the transverse instabilities during injection. The beam current usually cannot exceed 120mA without octupole magnet. With octupole magnet, the storage ring could store the beam current 200~250mA during the experiment. However, the octupole magnet itself limits injection efficiency and further increase of beam current. Therefore we use the digital transverse feedback system to improve injection to store more beam current. With digital feedback system and octupole magnet, the injection beam current could be stored more than 350mA.

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THE TRANSVERSE FEEDBACK SYSTEM

The scheme of HLS digital transverse bunch-by-bunch feedback system is shown in Fig. 1. The system consists of a beam position monitor (BPM), a RF direct sampling front-end, a feedback processor, a clock generator, power amplifiers and a kicker. The processor operates with 1/3 RF frequency low voltage differential signal (LVDS), which is produced by a clock generator offered by NSRRC Taiwan.

Horizontal and vertical position signals are made from BPM signals by direct sampling front-end, and are captured and processed by the feedback processor. The feedback signals after DAC are sent to hybrid to get combined signals before power amplifiers. The power amplifiers provide feedback gain to drive the kicker.

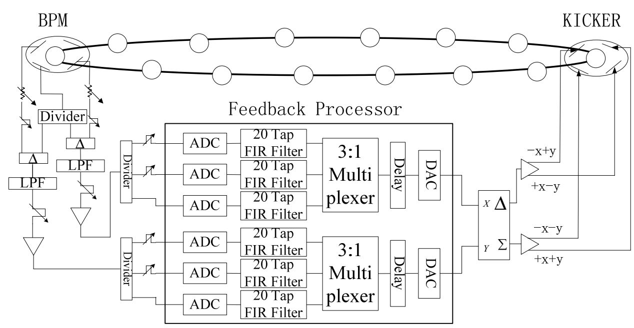


Figure 1: Overview of the HLS digital transverse Bunch-by-Bunch feedback system.

RF Direct Sampling

RF direct sampling scheme is used for the HLS digital bunch-by-bunch system. The bipolar RF signals from the BPM are directly sampled by ADCs without down-conversion circuit, which makes the system simple and easy to adjust [2].

Because ν_x and ν_y of HLS are close to each other (table 1), single-loop two-dimensional feedback scheme [3] is hard to be implemented in HLS. The horizontal and vertical beam oscillations are processed separately in the front-end and also in the feedback processor. The RF acceleration frequency of HLS is 204.048MHz, and we use 3 ADCs to achieve this sampling rate. The analog bandwidth of ADC in feedback processor is 750MHz which covers frequency band of the beam motion from 1/2 f_{RF} to 7/2 f_{RF}. ADC could sample the peak voltage of the bipolar signal from BPM, eliminating the conventional down-conversion stage.

Two Independent Loops in Feedback Processor

The feedback processor has 6 125MSPS ADCs, and operates at 4-ADC mode or 6-ADC mode. The harmonics 45 of HLS cannot be divided by 4 or 6. Running the processor at 6-ADC mode with sampling rate 408MHz, twice of the RF frequency, is one possible solution: every two ADCs sample the same bunches. However, in the view of cost performance, it can handle only one feedback loop and, the one-loop two-dimensional feedback cannot be implemented in HLS because of the close tunes (table 1). Therefore, we modify the FPGA program of the feedback processor to apply two independent loops in one single feedback processor.

One loop contains 3 ADCs, and every ADC processes 15 bunches in one turn (harmonics 45). 6 ADCs of the feedback processor are assigned to two independent loops (Fig.1): one for horizontal feedback and the other for vertical feedback. Each loop has a 20-tap FIR filter and two DACs. Time domain least square fitting method, developed by T. Nakamura, is applied to the configuration of FIR filter to compensate the phase advance between the BPM and the kicker.

Optimization of Filter Design

The FIR filter needs to suppress the DC component produced by reflection noise in the cables and close orbit drift, and to eliminate the signal brought by synchrotron oscillation. Required gain and phase shift at target tune is also generated by FIR filter. Suitable tap number of FIR filter needs to be considered because shorter taps makes wider tune variation acceptance at target tune, and longer taps makes smaller gain not at target tune. The horizontal tune of HLS is 0.5234, close to 0.5, and needs more taps to generate FIR filter. A 20-tap FIR filter is generated for horizontal feedback (Fig.2). For vertical case, ν_y is 0.5788, and 10-tap FIR filter is a good compromise for wider tune variation acceptance and low gain of noise.

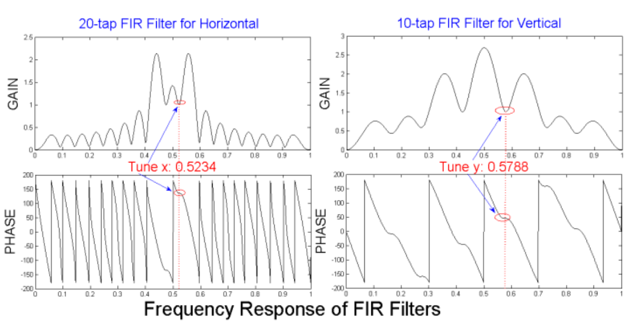
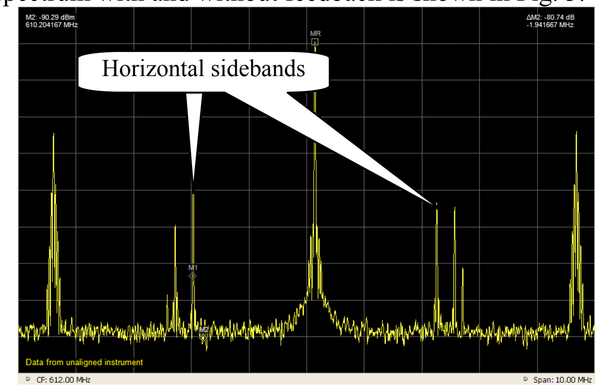


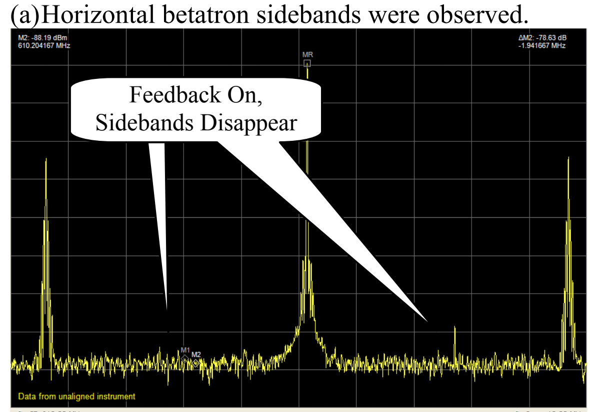
Figure 2: Frequency response of FIR filters for horizontal and vertical feedback.

COMMISSIONING RESULTS

The digital transverse feedback system was commissioned in June 2008. At 800MeV operation with beam current 210mA [4], horizontal betatron sidebands were observed and suppressed by feedback system. The spectrum with and without feedback is shown in Fig. 3.



(a)Horizontal betatron sidebands were observed.

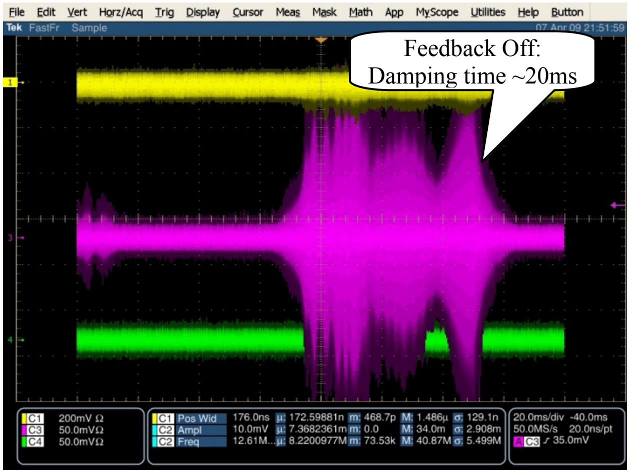


(b) With feedback on, the sidebands were suppressed.

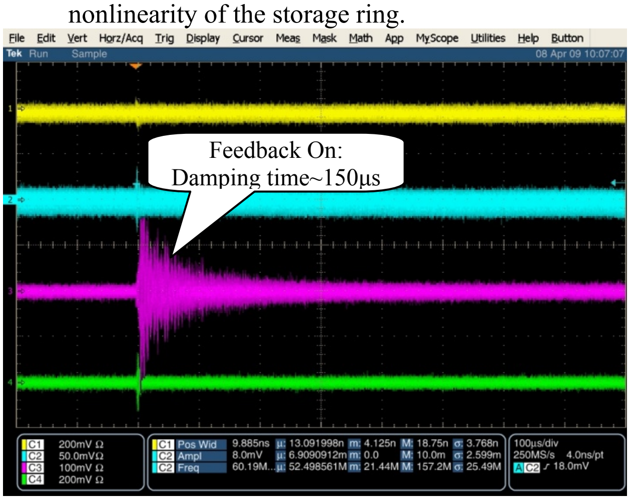
Figure 3: Spectrum of beam during 800MeV operation with 210mA current in June 2008.

The digital transverse feedback was commissioned in 200MeV injection in April 2009. The damping time due to injection bump excitation could be decreased to about 150µs by feedback system (Fig.4（b）). Without feedback and octupole magnet, the instabilities caused big amplitude oscillation (Fig.4 (a)) and were suppressed by the nonlinearity of the storage ring itself with damping time ~20ms.

The transverse feedback system could improve injection to store more beam current. Without octupole magnet and feedback system, the beam became unstable (Fig.4 (a)) and beam loss happened when beam current was over 70mA, and the beam current could not exceed 100mA. With octupole magnet on only, the beam current could be stored up to about 250mA. And with feedback on only, the beam current could be stored up to 300~320mA. The 358mA peak current was stored when the feedback and octupole magnet were both turned on as shown in Fig.5.



(a) Damping time was about 20ms due to the nonlinearity of the storage ring.



(b) Damping time was decreased to about 150µs by feedback system.

Figure 4: The damping time was decreased by feedback system.

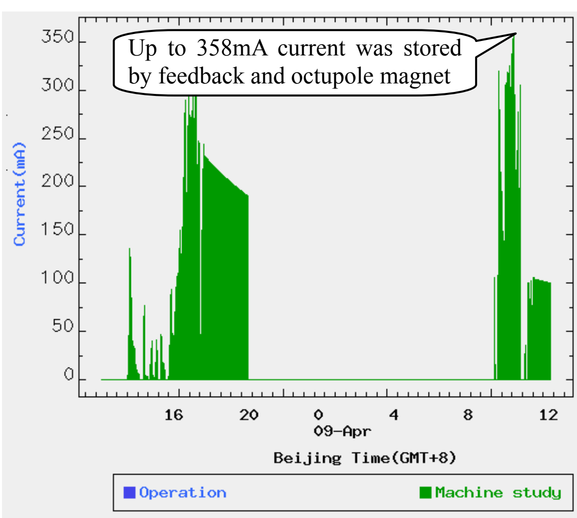


Figure 5: Feedback system improved the injection to store more beam current.

The beam loss happened during ramping from 200MeV to 800MeV. For ramping, ν_x changed from 0.525 to 0.55 and ν_y changed from 0.57 to 0.61 due to the unstable magnet and magnet power supplies.

The feedback system also excited the beam when the gain of feedback was increased. Because ν_x is close to 0.5, the gain at 0.5 is high (Fig. 2), and the half integer of revolution frequency could be excited by feedback. And we need more taps of FIR filter to eliminate the gain at half integer of revolution frequency.

SUMMARY

We developed a digital transverse bunch-by-bunch feedback system of HLS with RF direct sampling font-end. The FPGA code was modified to meet the request of processing horizontal feedback and vertical feedback independently and simultaneously by one single processor. The feedback system could suppress transverse instabilities which occurred during injection and operation. And the feedback system could decrease the damping time to about 150µs and improve the injection to store more beam current. The feedback itself could excite the half integer of revolution frequency and lost the beam. More taps of FIR filter are needed to eliminate the gain at 0.5 f_{rev} and upgrade of magnet system of HLS is needed to lessen the tune variation during ramping.

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