DIGITAL TRANSVERSE BUNCH-BY-BUNCH FEEDBACK SYSTEM FOR HLS

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Abstract

HLS (Hefei Light Source) is an 800 MeV storage ring with the bunch rate of 204 MHz, the harmonics of 45, and the circumference of 66 meters. HLS injection works at 200 MeV, where the beam is easily affected by transverse instabilities and, previously, the octupole magnet was used to suppress the transverse coupled bunch instabilities during injection. However, the octupole magnet itself limits further current increase and we developed a digital transverse bunch-by-bunch feedback system to suppress the transverse instability during injection. For this, we employ the SPring-8 FPGA based feedback processor, which can operate 500 MS/s with six ADCs and two 20-tap FIR filters. Such performance is two times more than that for one-dimensional feedback for HLS: sampling rate of 204 MS/s with three ADCs and one FIR filter. Then the FPGA code of the processor was modified by NSRL/USTC to process horizontal and vertical oscillation signal, independently and simultaneously by one single processor. The design of the digital feedback system and primary experiment results are presented in this paper. Further improving of the feedback system and investigating of the characteristics of the feedback loop are the future work.

INTRODUCION

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

Table 1.Parameters of the HLS storage ring

Injection energy	200 MeV
Operation energy	800 MeV
Circumference	66.13 m
Current	~250 mA
RF frequency	204.016 MHz
Harmonic number	45
Revolution frequency	4.534 MHz
Tunes ($\nu_H/\nu_V/\nu_S$)	~3.54/2.59/0.008

Coupled bunch instabilities occurred during injection and operation. The octupole magnet was implemented to cure the transverse instabilities during injection. The beam current usually cannot exceed 120 mA without octupole magnet. With octupole magnet, the storage ring can store the beam current 200~250 mA. However, the octupole magnet limits injection efficiency and further increase of beam current. With octupole magnet, the beam usually lost when beam current was over 250 mA. A digital bunch-by-bunch feedback system was developed to suppress the transverse instabilities during injection and operation, and to improve injection efficiency and to increase beam current during injection.

THE TRANSVERSE FEEDBACK SYSTEM

The scheme of the HLS digital 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, RF amplifiers and a kicker. The processor operates with 1/3 RF frequency LVDS signal which is produced by a clock generator offered by NSRRC Taiwan.

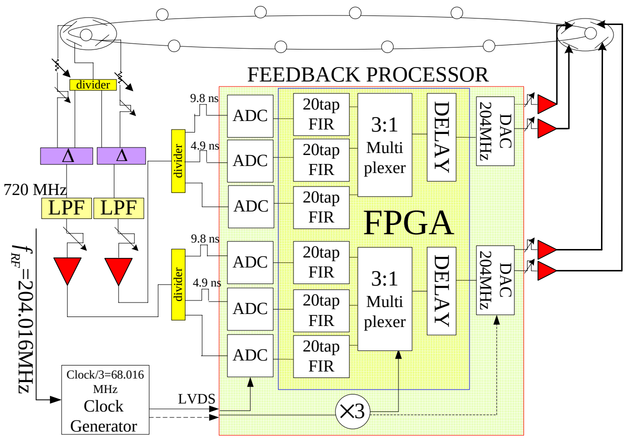


Figure 1: Overview of the HLS digital transverse Bunch-by-Bunch feedback system

RF Direct Sampling

RF direct sampling scheme is used for the HLS digital bunch-by-bunch system. The RF signal from the BPM is directly sampled by ADCs without down-conversion circuit, which makes the system simple and easy to adjust [1].

The bipolar signals from electrodes of a BPM are sent to two 180-degree hybrids to produce the difference signals which represent horizontal oscillation and vertical oscillation. These bipolar oscillation signals are sampled directly by ADCs of the feedback processor. Each oscillation signal is divided to 3 parallel ways and is sampled by 3 ADCs because HLS operates with harmonics 45, which can be divided by 3. Each ADC samples 15 bunches of one turn and the six ADCs of the processor process the horizontal oscillation and the vertical oscillation signals independently and simultaneously. The analog bandwidth of ADCs is

750MHz which covers frequency band of the beam motion from 102MHz (1/2 f_{RF}) to 714 MHz (7/2 f_{RF}).

Feedback Processor

The feedback processor [2] is composed of a Xilinx Virtex-II PRO FPGA, six 12-bit 125MSPS ADCs (AD9433), and five 12-bit 1.2 GSPS (AD9735) DACs. Oscillation signals are sampled by ADCs and sent to FPGA. The oscillation signal is processed by FIR filter in the FPGA and sent to the DACs to drive the kicker. Because the horizontal tune and vertical tune of HLS are too close each other to apply the single-loop two-dimensional feedback scheme, we need two independent loops for horizontal and for vertical. The FPGA program of the processor was modified by NSRL/USTC to meet the request of processing horizontal and vertical oscillation signal by one processor with two independent sets of 20-tap FIR filters implemented in FPGA. The 12-bit resolution of ADC is necessary to enhance dynamic range of the feedback system because the orbit of beam of HLS changes during injection and it brings big DC-offset to the front-end. Five DACs and their complementary outputs introduce the flexibility of polarity of output and beam diagnostics. 32 sets of FIR filter coefficients can be stored in internal register of FPGA and we can switch these with software control via USB or with external logic signal. The switching speed of FIR filter coefficient is several tens nano seconds that makes the system flexible to meet dynamic change of ring parameters especially during injection.

Time domain least square fitting method, developed by T. Nakamura, was applied to the configuration of 20-tap FIR filter to compensate the phase advance between the BPM and the kicker. Two independent sets of FIR filter which process horizontal oscillation and vertical oscillation are shown is Fig 2.

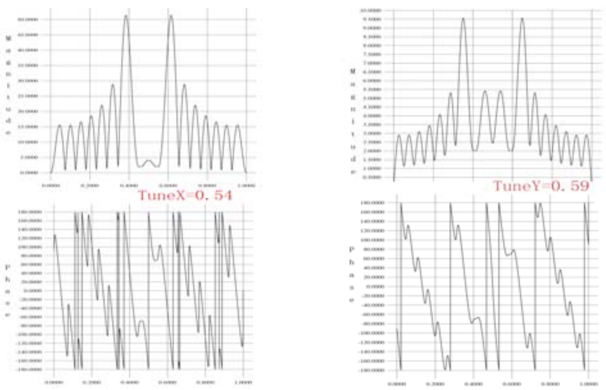


Figure 2: 20-tap FIR filter frequency response. Fractional tune of horizontal (left) and vertical (right) are 0.54 and 0.59 respectively.

COMMISSIONING RESULTS

The transverse feedback system was commissioned during June and July in 2008.

The HLS tune measurement system was used to excite the forced oscillation of the beam and to observe the shape of the tune peaks on the spectrum of the oscillation. The damping effect of the feedback reduces the peak height and broadens the peak width. The tune measurement system is composed of a BPM, a 180-degree hybrid, a mixer, a spectrum analyzer with a sweep signal generator, a power amplifier and an excitation electrode, as shown in Fig. 3.

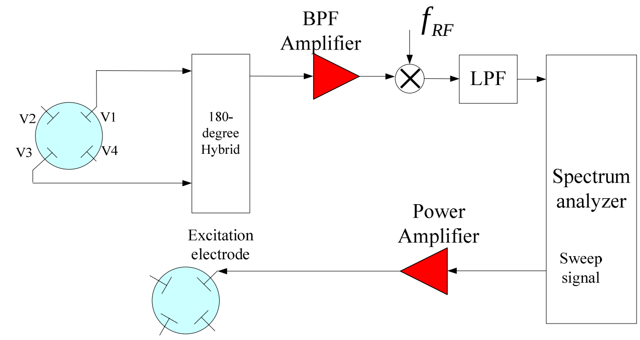
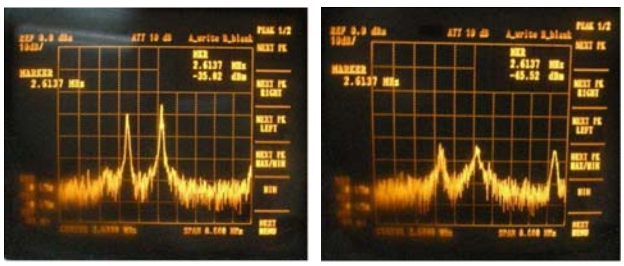


Figure 3: Functional block diagram of the HLS tune measurement system.

The feedback system was tested during single bunch operation. The spectrum of the force oscillation with feedback off is shown in Fig. 4 (a). The bandwidth is 0.6 MHz and center frequency 2.6 MHz. The left peak in the spectrum is of ν_H and the right peak is of ν_V . With feedback on, the peak height was suppressed by the feedback system, as shown in Fig. 4 (b).



(a) Feedback off (b) Feedback

Single bunch test

Figure 4: spectrum of single bunch excited by the tune measurement system. With feedback on, the forced oscillation was suppressed by the feedback system.

The feedback system was also tested during multi-bunch operation. The spectrum with feedback off is shown in Fig. 5 (a). With feedback on, the suppression of the peak height was also observed as shown in Fig. 5 (b), however, was smaller than that in the case of single bunch.

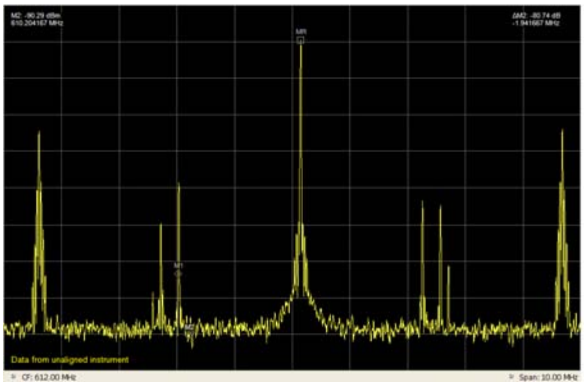
According to these tests, the damping effect of the feedback system could be clearly observed during single bunch operation. However, the damping effect was not as clear as during single bunch operation. One possible reason is that the phase shift between the beam signal and the RF reference signal produced by beam loading degraded the feedback system as in the case at the injection as mentioned later.

(a) Feedback off (b) Feedback on

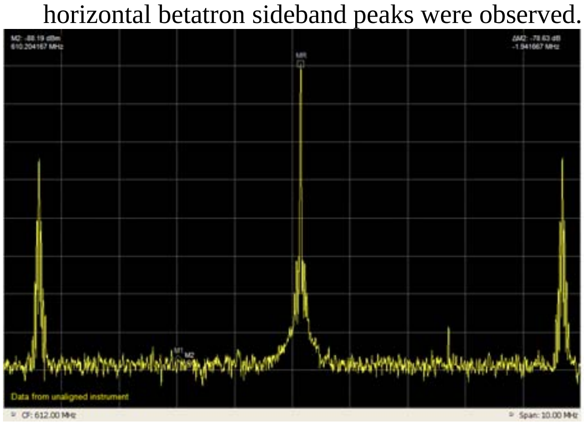
Multi-bunch test

Figure 5: spectrum of multi-bunch excited by the tune measurement system. With feedback on, the forced oscillation was suppressed by the feedback system.

The transverse feedback system was commissioned during normal 800 MeV operation with multi-bunch. In the spectrum of the beam motion, horizontal betatron sideband peaks produced by transverse instabilities were observed at the beam current of 210 mA, as shown in Fig. 5 (a). With feedback on, the peaks were fully suppressed by the feedback system, as shown in Fig 5. (b).



(a) Feedback off, transverse instabilities happened and horizontal betatron sideband peaks were observed.



(b) Feedback on, the instabilities were fully suppressed

Figure 6: spectrum of beam during 800MeV operation with 210 mA current.

The feedback system was also tested during injection. However, the feedback system cannot increase the current during injection as the octupole magnet did. The phase shift between the beam and RF reference signal was produced by the beam loading during injection. The phase shift was about 40 degrees in 204 MHz or 0.5 ns at 200 mA, and ADCs sampled less beam signal voltage as shown in Fig. 7, which degraded the gain and SNR of the feedback system.

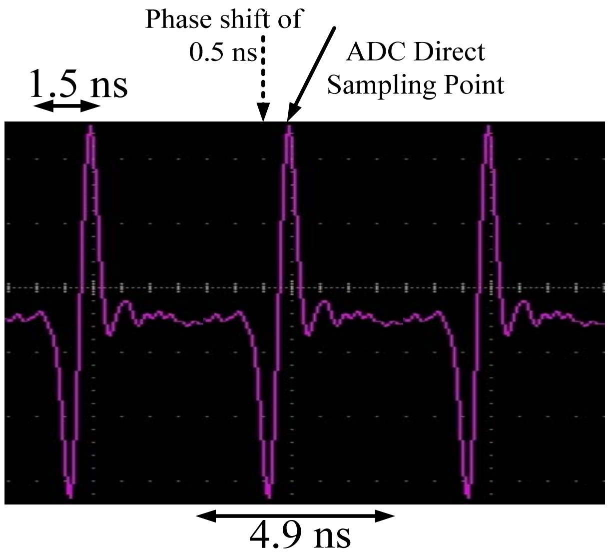


Figure 7: Phase shift during injection affected ADCs sampling

SUMMARY

We developed a transverse bunch-by-bunch feedback system of HLS with RF direct sampling. The FPGA code was modified to meet the request of processing horizontal oscillation and vertical oscillation simultaneously by one processor. The feedback system could suppress the forced oscillation excited by the tune measurement system. During 800 MeV operation, the transverse instabilities were observed and were fully suppressed by the feedback system. However, further study is necessary to increase the beam current at the injection.

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