COMMISSIONING OF THE BUNCH-TO-BUNCH FEEDBACK SYSTEM AT THE ADVANCED PHOTON SOURCE*

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Abstract

The Advanced Photon Source storage ring has several bunch fill patterns for user operation. In some fill patterns single-bunch beam charge can be as high as 16 mA. We installed a bunch-to-bunch feedback system that aims to overcome high-charge beam instability and reduce the required chromatic correction. Recently we completed the system and started closed-loop testing. We present our preliminary results, some of the issues that we have experienced and resolved, and our plan to expand the system to the horizontal plane.

INTRODUCTION

The APS bunch-by-bunch transverse feedback system project is initiated as part of an effort to control beam instability and reduce the chromatic correction for the APS storage ring. We finished the development of the system components. Commissioning of the system started last December. We achieved the original goal of stabilizing standard 24-singlet-pattern beam with reduced chromaticity and observed the benefit of longer beam lifetime and better injection efficiency. We also explored the possibility of using the system to increase single-bunch current threshold during injection. We describe the experiment results, features and modification to the system, system limitations we experienced, and upgrade plans.

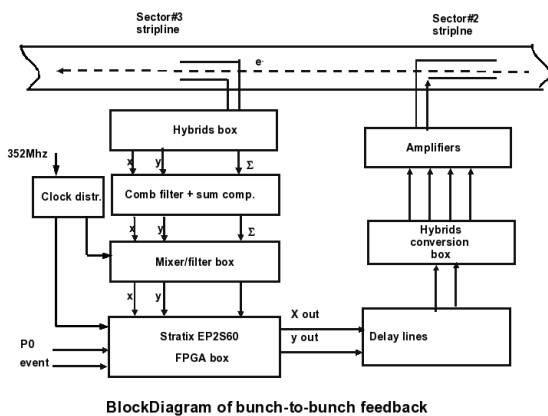**BlockDiagram of bunch-to-bunch feedback**

Figure 1: A block diagram of the feedback system.

SYSTEM DESCRIPTION

The bunch-to-bunch feedback system consists of a pick-up stripline, a front-end signal processing unit, a StratixII DSP processor unit, drive amplifiers, and a four-blade driver stripline. It has been described earlier [1]. Figure 1 shows a block diagram of the current system. At the core of the FPGA processor are the FIR filters. Our algorithm for the filter is based on the least square fitting method [2]. Our pickup and drive striplines are located in different locations of the ring. It is necessary to include tunes, β-functions, and betatron phase shifts into the calculation. A program is written to automatically generate FIRs from a lattice file. Figure 2 shows amplitude and phase responses of 9-tap filters for the APS low-emittance lattice.
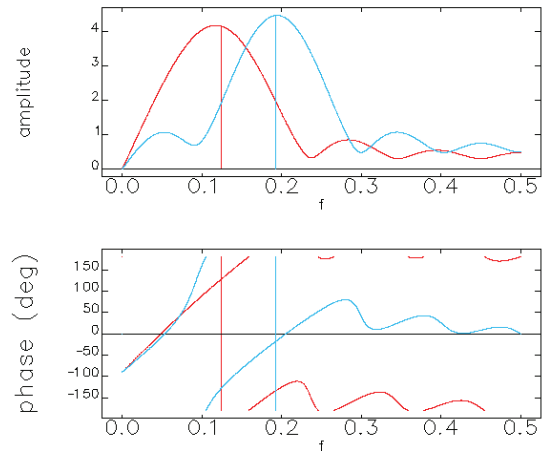

Figure 2: Amplitude and phase responses of a FIR filter for APS low emittance lattice (red: horizontal plane, blue: vertical plane).

SYSTEM IMPROVEMENTS

Based on our observations and test results, we have made significant changes in both the hardware and firmware.

A significant amount of effort was spent in improving the performance of the front-end unit. A 3-tap comb filter was added to make the down converted signal flatter at the peak. Replacing the mixers and amplifiers with ones of high power level increased the dynamic range of the system. Addition of a sum-signal compensation circuit reduced the orbit part of the input signal and thus avoided saturation at high beam charge.

The original clock source was derived from a 44-MHz timing distribution on the APS site, which was determined to contain too many sidebands and too much jitter. It was replaced by a 352-MHz clock source directly transmitted from the rf system master synthesizer. The new source was critical in suppressing jitter related noise.

A 48-position sample clock phase shifter was added to align the sample clock accurately on the crest of the beam signal and thus reduced the sample noise due to time jitter.

SOFTWARE IMPROVEMENTS

To facilitate system diagnostics and tuning we also added some firware features. Waveform process variables [3] of both input and DAC output were installed for diagnoistics.

For each data sample we defined a 3-bit control patterns as shown in table 1. These control functions are programmable for purposes such as timing alignment, AC coupling effect compensation of DAC output, and bandwidth matching for the amplifiers.

Gain control of individual sampled buckets was added to deal with non uniform bunch currents. We also added a DAC output delay adjustment with half sample clocks per step for each plane, which eliminated the need for additional analog delay devies.

High-level software was also developed to facilitate machine studies, such as a graphic interface for loading and saving DAC output control patterns; generating FIR filters from lattice files; saving, reviewing and loading FIR filters.

Table 1: DAC Output Control Bit Patterns

000	Zero out
001	Normal processed data
010	Negate processed data
011	Max. negative out
100	Max. positive out
101	Repeat last out
110	Negate last out
111	Future use

RESULTS FROM CLOSED-LOOP TESTS

We started closed-loop beam testing in last December. The first test was to stabilize medium-charged single- or multiple-bunch beam with reduced chromaticity. At the beam charge of 2 to 5 mA per bunch, beam instability develops into a steady, large-amplitude oscillation in both vertical and horizontal planes when chromaticity is reduced. By closing the feedback loops and optimizing the parameters of the feedback system we were able to stabilize beam with chromaticity reduction of -3 and -4 in x plane and y plane, respectively. With a 102-mA 24-singlet fill pattern beam we observed a beam lifetime increase from 420 minutes to 520 minutes with no

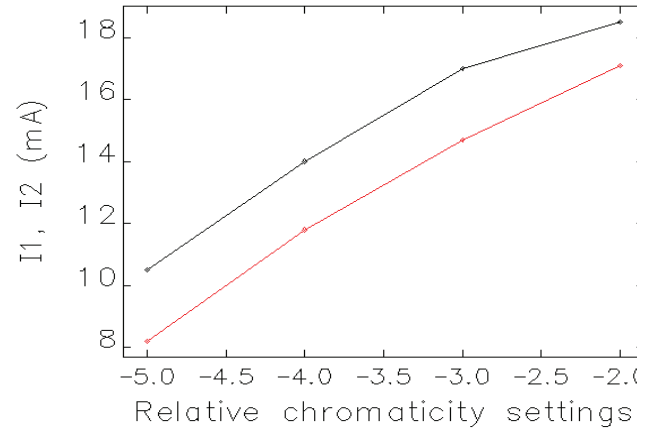significant deterioration in apparent emittance and rms beam motion.

Figure 3: Storage ring injection single bunch current threshold versus chromaticity with (black trace) and without (red trace) feedback loops closed.
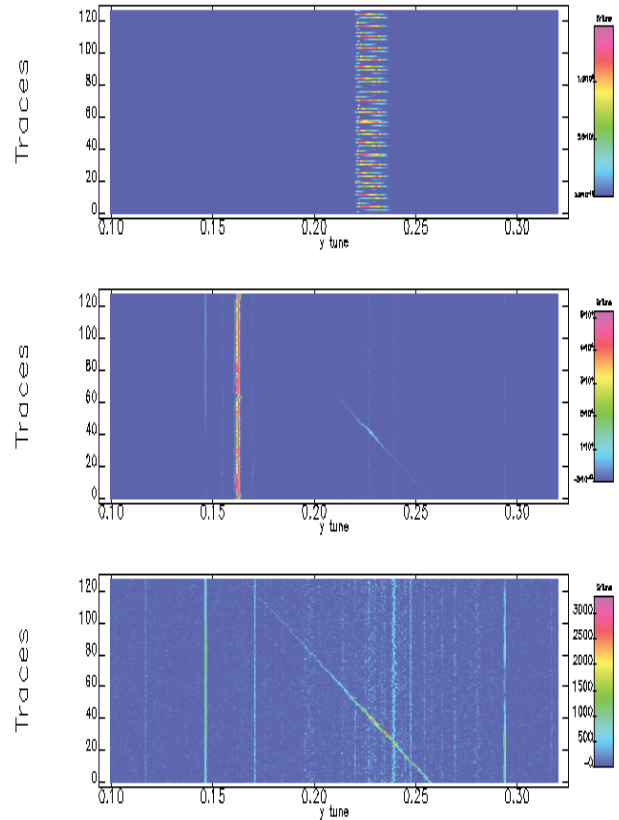

Figure 4: Beam spectrograph. Top: vertically unstable, middle: horizontal unstable, bottom: stabilized.

Our second test focused on improving stability of high-charge single-bunch beam. At 10 mA or more single-bunch charge, beam no longer develops sustained oscillations. The instability instead manifests as sudden beam loss during injection. The threshold current strongly depends on chromaticity. Figure 3 shows the measured single-bunch current threshold with and without feedback

loops closed. A reduction of 0.7 chromaticity in both planes are recorded. With both feedback loops closed we were able to inject and maintain a single-bunch beam at 17 to 18 mA level. Figure 4 shows a spectrograph of vertically unstable, horizontally unstable, and stabilized single bunch beam. The results are still very preliminary and not conclusive because we have not explored all the parameters.

SYSTEM LIMITATION AND UPGRADES

Our goal is to make the system sufficient for further studies and ready for normal operations. During the beam test we experienced some system limitations that need to address in order to improve the system performance.

The first limitation is insufficient horizontal drive and interference between the x and y planes. Our driver stripline has a four-blade diagonal geometry with a length of 0.17 cm. The measured kick angle is 0.26 µm with the 150-Watt amplifiers. It is installed at a location where the β-function is 27 m in plane y plane and only 5.4 m in the x plane. Our analysis showed that the main causes for insufficient kicking strength are the low β-function and short stripline. Due to its diagonal geometry, we need to drive the stripline blades though a hybrids circuit in order to achieve both x- and y-plane kicking. This single stripline configuration has the advantage of reducing the total space required. However, when the total power is limited there is interference between the two planes. We sometimes observe that turning on the second feedback loop makes an already stable loop unstable. This makes tuning difficult. We are building a two-blade dedicated horizontal stripline that will be installed in a high horizontal β-function section. Purchase of two more 500-W amplifiers are also planned.

In the APS storage ring, amplitude-dependent tune shift is high when operating in high chromaticity mode. With a tune acquisition sharing the same front-end beam signal with the feedback system, we were able to monitor the tune during the test. We observed up to 0.02 tune shift between low- to high-amplitude oscillations, as shown in the top plot of Figure 4. We had to reduce the number of taps of the FIR filter in order to maintain stability. This is equivalent to increasing the loop bandwidth. We are considering adding an adaptive algorithm to compensate for tune shift automatically.

The APS storage ring uses switching-type DC supplies for the correctors. These correctors generate 40-kHz ripples. Most of the ripples are filtered by the aluminum vacuum chambers. However, about 80 fast correctors used by the orbit feedback system have thin stainless vacuum chambers. The ripple signal drives beam that becomes a noise perturbation to the feedback system. The bottom contour plot of beam spectrum of Figure 4 shows a horizontal tune spectrum together with the ripple line. Its frequency is not far from the horizontal tune. We are working on upgrading the power supplies to suppress the ripples.

To accommodate the stripline upgrade we are also designing a new system that consists of master and slave FPGA units. The master performs all the essential functions of the system and the slave system serves as a remote DAC. Communication between the two is through a PCI-express fast-lane fiber link.

Figure 5 shows a designer drawing of the new stripline. It has been designed and is being fabricated.
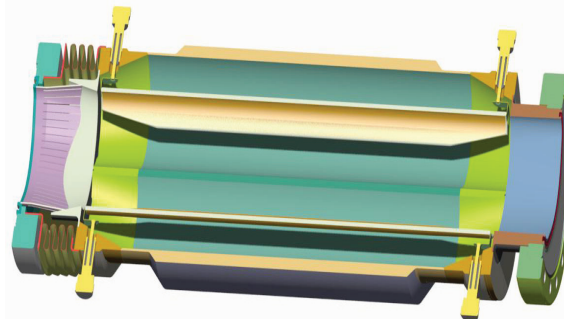

Figure 5: Designer drawing of the new two-blade stripline (courtesy of L. Morrison).

CONCLUSIONS

Our preliminary commissioning shows that the feedback system can stabilize normal current multi-bunch beam and reduce the required chromatic correction, which resulted in longer beam lifetime and better injection efficiency. The system also can be potentially beneficial for high single-bunch-charge beam operations. The limitations have been identified. Further upgrade to the system has been planned and is underway.

ACKNOWLEDGMENTS

REFERENCES

[1] C.-Y. Yao, et al., "An FPGA-based Bunch-to-bunch Feedback System at the Advanced Photon Source," Proc. of PAC07, 2007.

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