RECENT PROGRESS OF THE BUNCH-BY-BUNCH FEEDBACK SYSTEM AT THE ADVANCED PHOTON SOURCE*

C.-Y. Yao#, V. Sajaev, N. Di Monte
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

A bunch-by-bunch feedback system was installed at the APS in 2008. Close-loop tests were conducted and improvements have been made to the system, including two 500-watt amplifiers, a new location for the horizontal drive stripline, a two-blade new horizontal stripline, and upgrade of front-end electronics. With these improvements we are able to stabilize beam with a reduced chromaticity of 4 in both the horizontal and vertical planes for the 24-singlet bunch pattern. Beam lifetime has increased from about 8 hours to 15 hours. We did not observe any obvious increase in the effective beam emittance and rms beam motion. Studies on the single-bunch beam accumulation limit showed a 1- to 6-mA increase for the same chromaticity settings. The variation depends mainly on the chromaticity values. The result can improve beam performance of the hybrids fill pattern, which has a 16-mA leading bunch. We report the system improvements and the results of our tests.

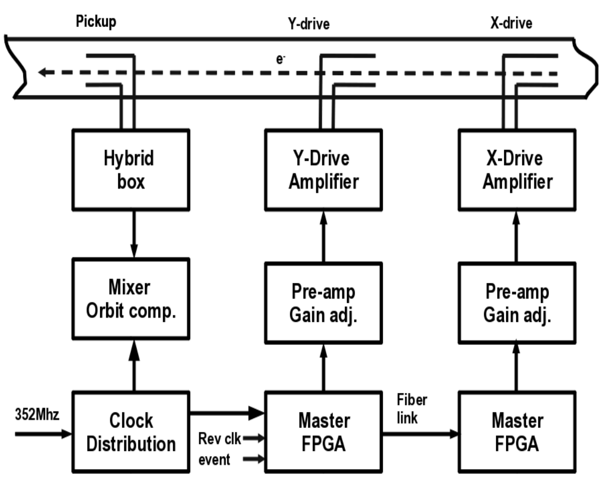

Figure 1: Block diagram of the feedback system.

SYSTEM IMPROVEMENTS

The system is described in detail in [1]. Figure 1 is a diagram of the most recent system configuration. The processor board has been upgraded to two Stratix II-GX PCI development boards [2]; one serves as master and the other as slave. This is necessary in order to relocate the horizontal stripline to a high beta-x location about 200 m away from the mail feedback system rack. The slave system only receives processed output data for the x-plane from the master processor and sends them to the DAC to drive the beam. Transmission of the data is through a PCI-Express fiber link at a rate of 2.36 Gb/s.

Programmable attenuators and rf switches are added to an orbit-component-compensation circuit so adjustment can be made remotely when beam orbit changes.

In order to increase drive strength in the horizontal plane two 500-W amplifiers were purchased and installed. The horizontal drive stripline was relocated to a high beta-x point in the ring. We also reconfigured the vertical drive with combiners and four amplifiers so each blade receives about 250 W of power. The bandwidth of both plane is 0.01 to 250 MHz. The kick angles for both planes are around 0.25 μRad.

A new two-blade, 34-cm-long stripline was developed for the horizontal plane. This was necessary because the original 4-blade stripline only has a length of 16.7 cm, and driving with four diagonal blades is not as cost effective as the 2-blade configuration. Figure 2 shows a photo of the stripline assembly. The device has just been tested, leak checked, and installed. It will be commissioned in the coming runing period. The kick strength is estimated 0.5 μrad.

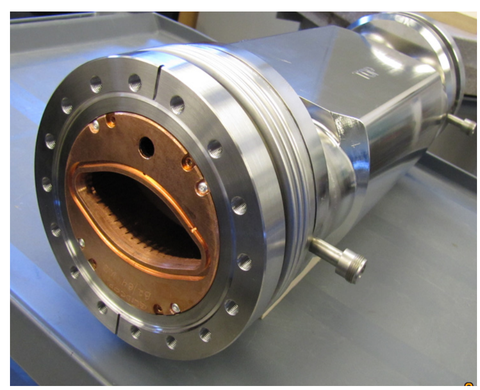

Figure 2: A new 2-blade stripline assembly.

DAMPING TIME MEASUREMENT

Damping time measurement is essential in evaluating system performance and initial setup. We tried both the kicking method and the gain-polarity-reversing method reported by other researchers [3,4]. Figure 3 shows the results of damping measurements for different gains of both x and y planes. A 0.5-kV kick is applied to an injection kicker for horizontal excitation and the same is applied to a vertical pinger for vertical excitation.

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#cyao@aps.anl.gov

Damping times of centroid motion, estimated from these data, are 0.47 ms and 0.05 ms in x and y planes, respectively.

The gain-reversing method did not produce the expected damping waveform. This is most likely due to the high nonlinearity of the APS lattice and short decoherence time.

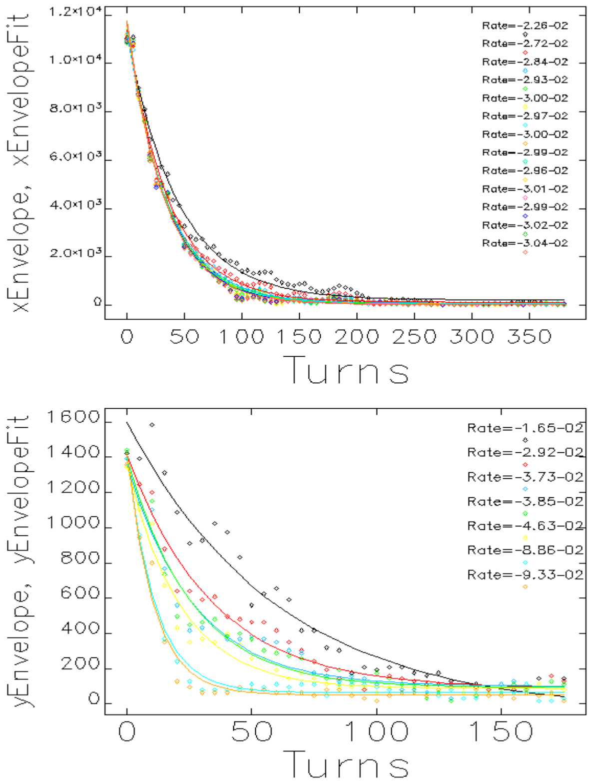

Figure 3: A plot of damping test results.

For system routine tuning purposes we perform a tune-gain-scan. In this case an HP network analyzer and a stripline that is independent of the feedback system are used to excite beam and measure tunes. Figure 4 shows the results of a scan in each plane.

We observe that in the horizontal plane we can use a filter with up to 13 taps while maintaining loop stability. On the vertical plane the loop easily becomes unstable at a tap number higher than 4. This may be due to higher sensitivity of phase response o tune shift at high tap number.

TEST RESULTS WITH NORMAL CHARGE MULTIBUNCH BEAM

In order to measure the effect on beam quality when loops are closed, we filled the storage ring with our standard 24-singlet pattern with a total current of 102 mA and the chromaticity of the x/y planes reduced from 7/6 to 3/2, respectively. Table 1 lists a comparison of the case with feedback system loops closed and open.

The effect on beam lifetime is clear. We saw small changes in x and y beam emittances. Low-frequency rms noise was also similar for both cases. The horizontal full-bandwith rms beam motion, which was measured from many BPMs, increased by 10%.

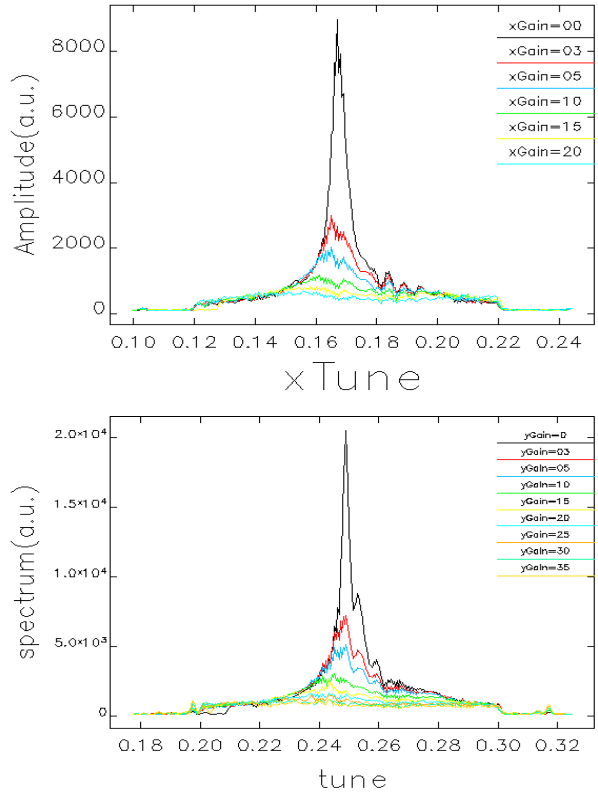

Figure 4: A plot of gain scan results in the horizontal plane.

Table 1: Comparison of Beam Emittance and rms Motions of Closed and Open Loop.

	Loops closed	Loops open
chromaticity(ξ_x, ξ_y)	7/6	3/2
x-emittance ε_x (nm)	2,450	2,5
y-emittance ε_y (nm)	0,054	0,06
Coupling (%)	2,210	2,22
xRMS-30Hz (μm)	2,730	2,45
xRMS-full (μm)	8,720	6,05
yRMS-30Hz (μm)	1,240	0,75
yRMS-full (μm)	2,960	3,17
Beam life τ (min.)	443,0	878,0

TEST RESULT OF SINGLE-BUNCH ACCUMULATION LIMIT

To measure the effect of running the feedback system on the single-bunch charge beam accumulation limit, we scanned the horizontal and vertical chromaticity from 5 to 11 and recorded beam stability and accumulation limits when the feedback system loop was closed and open.

Figure 5 shows the accumulated data of several of such scans. At chromaticity of 0 to 3.0 we observed both horizontal and vertical instability with different thresholds. The vertical instability disappears above chromaticity 3.0. The horizontal instability disappears around chromaticity 9.0. Above that we only observe an accumulation threshold, where a large portion of the beam is lost instantly. At very high chromaticity the benefit of running the feedback system is minimal, which is expected due to lack of detectable centroid beam motion.

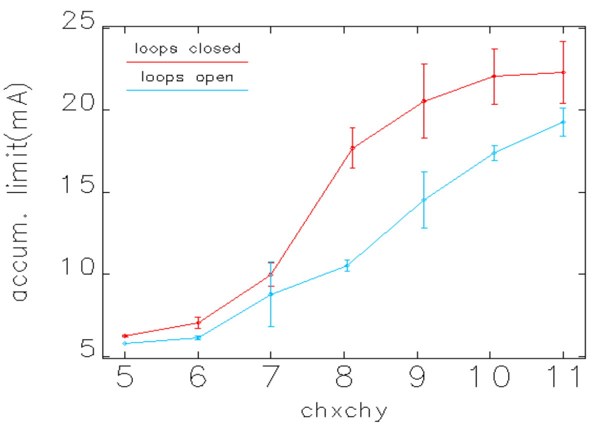

Figure 5: Beam accumulation limit with normal chromaticity feedback loops open and with reduced chromaticity feedback loops closed.

COMPENSATION FOR BEAM ORBIT AT PICKUP AND NOISE REDUCTION

We found the orbit-component compensation circuit is effective in reducing the saturation effect of beam orbit at the pickup stripline. Large beam orbit offset at the pickup stripline produces high orbit component in the beam signal that not only saturates the front-end circuits but also enhances noises due to jitter in both the LO signal of the mixer circuits and the sample clock. However, this is only applicable when beam orbit at the pickup stripline is stable and its changes are infrequent. This is true during APS user operations, and we only need to adjust the attenuation of the sum compensation after a lattice switching or fill pattern change. In order to make this process totally transparent, it is necessary to develop a procedure that adjusts the compensation based on beam position monitor readings. A new orbit correction configuration that includes the pickup stripline location as the correction target would also help.

The noise spectrum in the sampled data contributes to beam emittance and beam motion when the feedback loop is closed. Reducing noise from all sources is essential to the performance of a feedback system. We have identified and eliminated some of these noise spectra, including a 1-MHz sideband in the LO signal of the mixer, and a 40-kHz ripple from the faster correctors of the storage ring fast-orbit feedback system. There are some noise spectra that are still unidentified; further investigation will continue.

FUTURE DEVELOPMENT PLANS

We are in the process of finalizing system components and operating procedures. A test user run period has been planned.

The APS upgrade plans demand significantly higher single-bunch beam charge than the current operation values. The required chromatic correction makes the lattice design challenging [5]. Application of a transverse feedback system is included in the design to reduce the required chromatic correction and thus improve nonlinear effects.

The current version of hardware limits the sample rate to 117 MHz, or sampling every third storage bucket. We plan to upgrade the system to a sample rate of 352 MHz so it can feedback on arbitrary fill patterns. This will require a faster ADC and processor board, and may also call for a shorter pickup stripline.

Because the current system only applies to high charge bunches, gain adjustment for individual bunches is not employed. We plan to add this in the future upgrade.

CONCLUSIONS

The bunch-by-bunch transverse feedback system is effective in stabilizing beam instability and reducing the required chromatic correction of the storage ring lattice. This is particularly beneficial for low-emittance lattice development. We observed the effect of the system on beam accumulation limit for different chromaticity corrections.

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