ADVANCED PHOTON SOURCE BOOSTER SYNCHROTRON BEAM POSITION MONITOR UPGRADE AND APPLICATIONS*

Nicholas S. Sereno, Frank Lenkszus, Robert M. Lill
Advanced Photon Source/ANL, Argonne, IL 60439, USA

Abstract

The Advanced Photon Source operates in top-up mode, which adds charge to the storage ring every two minutes to maintain the current at 102 ± 1.0 mA. This requires the booster synchrotron to operate efficiently and reliably. The booster BPM system was upgraded to overcome a severe performance limitation due to operation of the receiver at the low end of its input power range. The upgrade provided a 25-dB improvement in overall system gain. This improved dynamic range and resolution, and reduced other systematic errors. The booster BPMs have been used in studies including measurements of ring circumference, synchrotron and betatron tune, and orbit correction. Software feedback corrections of the energy and rf phase errors at injection have been implemented for routine operations using the BPM beam history/DSP-based synchrotron tune measurement. Transverse injection feedback is presently being commissioned. The latest experimental results using the upgraded BPMs will be presented.

INTRODUCTION

The APS booster BPM system is used to provide horizontal and vertical beam position, average beam position, and position history information over a user-selectable number of turns. This information can be obtained over the entire 225 ms it takes the beam to linearly ramp from 0.325 to 7 GeV at the 2-Hz booster cycle rate. Average position information is used to correct the orbit at various time points (energies) up the ramp. Average horizontal orbit position as a function of frequency was used to measure the orbit circumference and dispersion [1]. Orbit correction was used extensively when commissioning new low-emittance booster lattices [1].

Beam history position information is used for time and frequency domain processing to determine synchrotron and betatron tunes at any point up the ramp. The synchrotron tune measurement uses DSP techniques to process the first 256 turns after injection to determine the synchrotron tune for each pulse. The synchrotron tune is then used with feedback to correct the longitudinal phase-space mismatch (energy and phase deviation) that can occur due to rf phase errors and/or booster magnetic field errors. The same DSP techniques are presently being studied to determine betatron tunes as a function of time up the ramp.

BOOSTER BPM ELECTRONICS UPGRADE

The APS booster has a circumference of 368 m employing 80 BPMs installed every 4.6 m around the ring. The storage ring and booster both employ identical BPM electronics. The signal processing topology is a monopulse amplitude-to-phase (AM/PM) technique for measuring the beam position in the x and y axes. A logarithmic amplifier channel measures the beam intensity [2]. The signal level into the receiver with 1.0 nC of charge was typically –40 dBm during normal booster operation. This input power level is considered the low end of the receiver dynamic range (+5 to –45 dBm) and performance was severely limited. The booster has an operating range of 0.2 to 10 nC or 34 dB.

The BPM system upgrade block diagram shown in Figure 1 reduced the insertion loss of the original filter comparator as part of the upgrade. The filter comparator provides the sum and difference signals of the four button electrodes in a 10-MHz bandwidth centered at 352 MHz. The original filter comparator used attenuators on the inputs (6 dB) and between the hybrid bridge output and the bandpass filters (2 dB) to attenuate standing waves between components. This technique provided a broadband match at the cost of signal strength. The bandpass filter implemented in this design had an insertion loss of 3 dB.

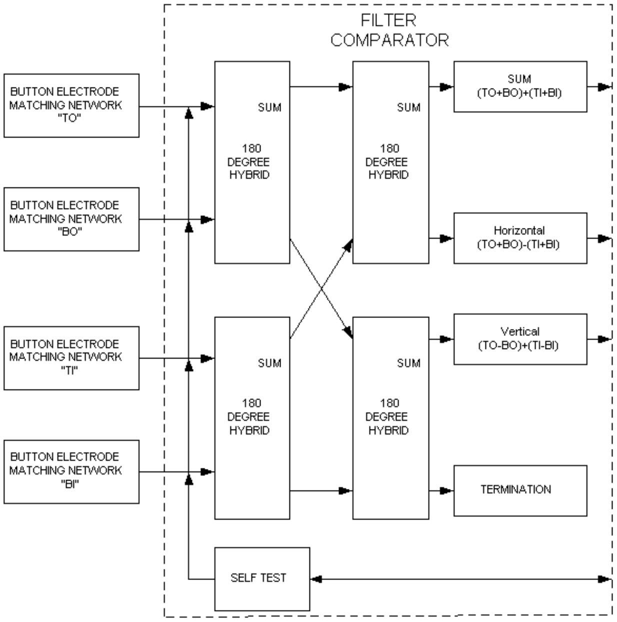

Figure 1: Upgrade block diagram showing schematically the new matching networks feeding signal to the filter comparator.

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The upgrade design eliminated the need for pads by carefully matching the components and button pick-up source. The source or button pick-up electrodes have a very poor return loss when measured from the feedthrough side, which results in reflecting 97% of the power. To match the button's impedance (0.25-75j ohm) into 50 ohms, an inductor is placed in parallel with the capacitive electrode. This effectively creates a parallel resonate circuit driven by the image current source. This technique of resonating the capacitive pickup provides a controllable response in a compact electrode design. A similar design was installed in the APS storage ring [3]. The upgrade also moved the critical filtering into the new matching network, which incorporates the 5-pf electrode capacitance into the filter design. When connected to the 10-mm button electrode, the matching network was designed to passively increase the signal power by 15 dB @ 352 MHz with a 20-dB return loss. The matching network has a bandwidth of 10 MHz @ -3 dB power point when connected to the capacitive button electrode. The matching network also provides 40 dB of filtering at the second harmonic (704 MHz). The modified filter comparator has an 11-dB reduction of insertion loss and the signal enhancement realized by the matching network (15 dB) equates to an overall system improvement of 26 dB.

BOOSTER LONGITUDINAL SYNCHROTRON MOTION MEASUREMENT AND CORRECTION

The booster BPM and beam history [4] are used to determine the synchrotron frequency and correct energy and phase (field) errors at injection. The BPM used in this application is located in a region of dispersion. This BPM is configured to provide only horizontal position data on each turn for 256 turns. Synchrotron oscillations can be observed on the beam history on each pulse depending on the level of phase and/or energy errors at injection.

The beam history time-domain data are processed (using DSP techniques) to filter out betatron motion. This filtering is accomplished by subtracting a shifted copy of the beam history waveform from itself. This procedure minimizes betatron oscillations on the processed waveform since the synchrotron oscillation is much slower than the betatron motion. The procedure also zeros the net waveform offset.

The processed time-domain waveform is Fourier transformed. The resulting real and imaginary parts are transformed into amplitude and phase. A peak search is done over a specified range to identify the synchrotron oscillation peak. The frequency, phase, amplitude, and real and imaginary parts at the peak are EPICS process variables that are used for feedback and to characterize the synchrotron oscillation. The real and imaginary components represent cosine- and sine-like synchrotron oscillations. In phase space an energy error (or equivalently a magnetic field error) at injection corresponds to the cosine-like synchrotron oscillation shown in Figure 2. Similarly, a phase error corresponds to a sine-like oscillation.

The real and imaginary values are used in a feedback loop to control general booster injection energy and phase errors. The actuators that control phase and energy errors in the booster are the rf phase setpoint and the timing of the dipole, quadrupole, and sextupole family ramps. The timing of the magnet family ramps controls the precise field the beam sees when it is injected. Standard feedback is performed based on the program sddscontrollaw [5], which uses an inverse response matrix with rf phase setpoint and magnet family ramp timing as actuators and the real and imaginary parts of the synchrotron oscillation as readbacks. The feedback is run continuously during normal booster operation.

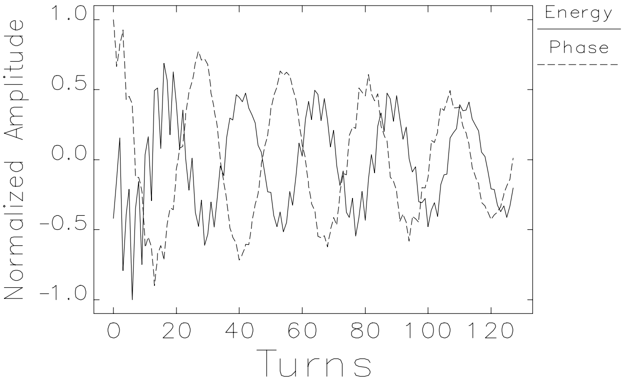

Figure 2: Horizontal BPM beam history data for pure energy and phase errors. One sees that the energy and phase oscillations are 90 degrees in phase apart. The fast ripple remaining on each waveform is residual betatron oscillation not completely removed by the DSP time-domain processing.

BOOSTER CIRCUMFERENCE AND DISPERSION MEASUREMENTS

Booster circumference and (horizontal) dispersion measurements were performed using the upgraded BPMs. The as-built booster circumference does not match precisely one-third of the storage ring (SR) circumference due to "distortion" of the SR lattice, which directs stray radiation away from the X-ray BPM blades [6]. The rf frequency is defined by the SR circumference, resulting in a beam that is horizontally off-axis in the booster at dispersion regions. The circumference measurement was performed by varying the rf drive frequency until the average horizontal orbit in the booster was zero. The difference between start frequency and the frequency where the average orbit is zero is proportional to the deviation of the actual circumference to the ideal circumference (proportionality factor is the known momentum compaction factor). Using this technique, the booster circumference was found to be 1.8 cm too large. This information will be used in the future to realign the booster magnets.

Similarly, the dispersion at the BPMs can be measured by varying the rf frequency and knowing the lattice momentum compaction. This measurement was done and is now a routine application (along with the chromaticity measurement). Figure 3 shows the results for the booster 132-, 109-, and 92-nm-radian lattices. The standard lattice (132 nm-radian) is seen to have zero dispersion in the straight sections. The two lower-emittance lattices show nonzero dispersion in the straight sections as is required since only for the horizontal tune for the standard lattice can there be no dispersion in the straight sections.

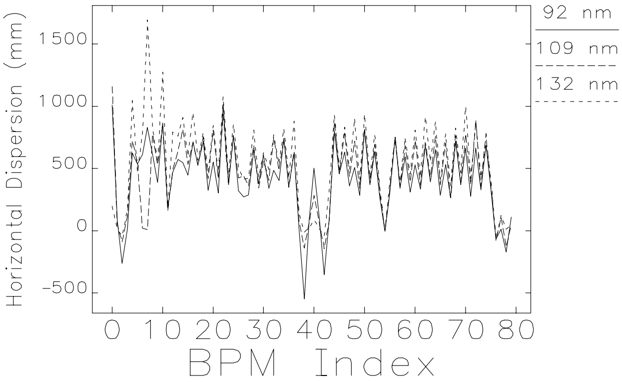

Figure 3: Measured dispersion function for 132-, 109-, and 92-nm-radian booster lattices. Some BPMs with obvious gain problems are observed. One can see that in the straight sections at BPM indexes 0, 40, and 80 the dispersion is (nearly) zero only for the standard, 132-nm-radian lattice. Comparison of the data with theory gives a measure of the BPM gain calibration for each of the different lattices.

CONCLUSION

A total of 80 BPM systems were upgraded in the APS booster. The upgrade was a cost-effective solution since the existing filter comparator was modified. The booster BPM upgrade presented improved single-shot resolution to 20 microns rms, which was an improvement of more than a factor of 50. The 26-dB gain was realized purely passively which saved the cost and complexity incurred with an active amplification solution. Further upgrades of the beam history modules will be investigated in the future.

The upgraded booster BPMs have been used extensively for orbit correction at various energies as the beam is ramped. In addition, the BPM beam histories have been used in an application to correct the phase and energy errors using feedback and a novel DSP-based measurement of the synchrotron oscillation at injection. The DSP processing of the beam history data will be used in the future to measure betatron oscillation as a function of time up the ramp. The BPMs have also been used to measure the booster circumference for realignment purposes and dispersion to characterize new low-emittance booster operating modes.

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