ORBIT CONTROL AT THE ADVANCED PHOTON SOURCE*

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Abstract

The Advanced Photon Source (APS) began operation in 1995 with the objective of providing ultra-stable high-brightness hard x-rays to its user community. This paper will be a review of the instrumentation and software presently in use for orbit stabilization. Broad-band and narrow-band rf beam position monitors as well as x-ray beam position monitors supporting bending magnet and insertion device source points are used in an integrated system. Status and upgrade plans for the system will be discussed.

1 INTRODUCTION

Since the commissioning of the APS, there has been significant progress in the understanding of beam stabilization, with the result that a first round of hardware upgrades is near completion. The goal is ultimately to achieve better than 1 micron rms beam stability at all x-ray source points in a frequency band up to 30 Hz and extending at the low frequency end to 24 hours or longer, and to be able to prove it.

2 HARDWARE DESCRIPTION

The APS beam position monitor (BPM) systems consist of approximately 360 stations employing broad-band (monopulse) rf receivers [1], 48 narrow-band receivers [2] distributed among the 24 insertion device vacuum chambers, and 86 front-end x-ray BPMs [3,4].

Data from each of these BPM systems are provided to a distributed array of digital signal processors (DSPs) that have real-time (1.534 kHz) connections to as many as 317 combined function horizontal/vertical steering corrector magnet power supplies. For normal operation, this real-time feedback system [5] employs 160 broad-band rf BPMs and uses a singular value decomposition (SVD) algorithm to compute set points for writing to 38 corrector magnet power supplies.

The 38 corrector magnets employed by the real-time feedback system are mounted at spool piece locations and thus have faster response times than the other 279 units, which are mounted at locations with thick aluminum vacuum chamber walls that are subject to large eddy current effects. Each corrector is powered by an identical pulse-width-modulated power supply, which is interfaced both to the Experimental Physics and Industrial Control System (EPICS) network and the real-time feedback dedicated network. EPICS also reads the BPMs at up to a -Hz rate, after de-aliasing, for use in a separate DC correction algorithm.

3 SYSTEMATIC EFFECTS

Virtually all of the orbit correction technique can be reduced to the study and compensation of systematic effects of one form or another. While space does not allow a detailed study of the many known effects, a listing of them should give some idea of the depth of this area. With regard to orbit correction, there are both intrinsic and extrinsic systematic effects. The extrinsic effects are those for which the BPM system was built to correct in the first place. The challenge in putting together an effective orbit correction strategy is to reduce the size of the intrinsic systematic effects to such a degree that the extrinsic perturbations can be reduced to an acceptable level.

3.1 Rf BPM systematic effects

- Timing/trigger stability
- Intensity dependence
- Bunch pattern dependence
- The “rogue” microwave chamber modes [6]
- Electronics thermal drift

3.2 X-ray BPM systematic effects

- Stray radiation striking X-BPM blade pickups [7]
- X-BPM blade misalignment
- Electronics thermal drift
- Gap-dependent effects (e.g., sensitivity, steering)

3.3 Extrinsic systematic effects (noise sources)

- Magnet power supply noise/ripple
- Rf system high-voltage power supply ripple
- Mechanical vibration
- Thermal effects (tunnel air/water temperature)
- Earth tides
- Insertion device gap changes

Each of these systematic effects has its own spectrum, ranging from long-term drift effects of hours to days, up to motions of several kHz. Ultimately, one can speak of stabilizing turn-by-turn motions using rf frequency broad-band feedback systems, however this can be considered to impact beam size for most x-ray experiments that average over many turns, and is beyond the scope of the present

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discussion. Ultimately, however, the goal is to stabilize the flux striking the user's sample, and plans are being made to correct for multipole-induced beam size changes associated with insertion device gap changes using feed forward.

4 SOFTWARE DESCRIPTION

The EPICS control system provides a convenient and reliable framework upon which all orbit correction algorithms are based. The EPICS low-level "engineering screens" allow access to individual "process variables" for troubleshooting purposes. A higher level library of programs known as the self-describing data set (SDDS) toolkit [8] allows the development of very high-level scripts and graphical user interfaces, which typically use the tool command language (Tcl) scripting environment.

In addition to the real-time orbit feedback system, workstation-based (DC) orbit correction [9] takes place nominally with a 2.5-second update period. A Tcl application is used for orbit correction configuration and allows the generation of response matrices, which are inverted using singular value decomposition (SVD). Any combination of rf and x-ray BPMs together with the selection of any of the 317 corrector magnets in each plane is allowed.

Additionally, the weighting of BPMs provides the possibility of building quasi-local bumps. For example, the x-ray BPMs are considered to be more reliable than the rf BPMs for the determination of angles due to their lever arm advantage gained from their being located further from the x-ray source points. A popular algorithm is to use two upstream and two downstream corrector magnets, with all rf BPMs having weight 1 and one of the two x-ray BPMs associated with that source point having a weight of 5. Thus the source position is held stable by the best-fit line through several rf BPMs straddling the source point, while the source angle is fixed by the single x-ray BPM. The second x-ray BPM is used as a check on the performance of the first unit.

Because the new x-ray BPM data acquisition system is just recently coming online, primarily only rf BPMs have been used to date during normal user beam operation. The configuration found most robust has been to use as many rf BPMs as possible (i.e., functioning units), with two corrector magnets per sector-a total of eighty in each plane. This provides a smooth fit and minimizes the effects of unit-to-unit variation among the different BPMs. Quasi-local control as described above has been used in a few cases during machine operation, in one case vertically in a bending magnet beamline, and in both planes at fixed gap on three separate insertion device beamlines. The local control is integrated together with the two-corrector-per-sector pattern into a single response matrix.

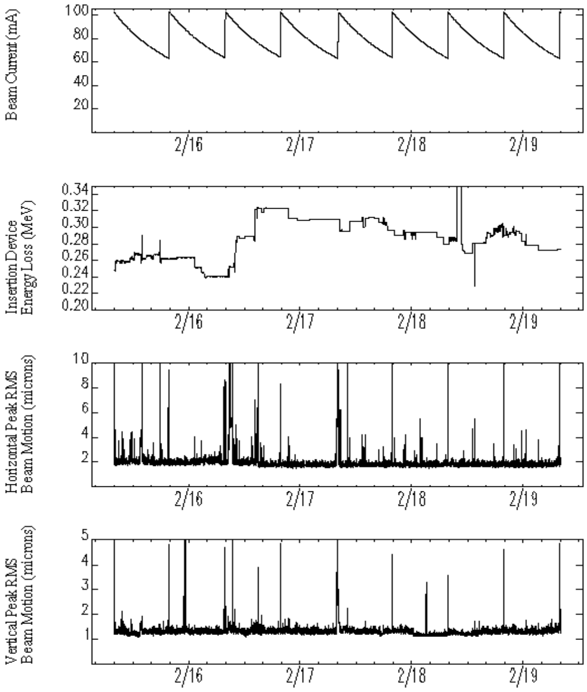

Figure 1: APS beam stability over a 96-hour period.

5 STATUS AND PLANS

Figure 1 is a representative data set showing beam stability in the frequency band from 0.1 Hz up to 30 Hz. The top frame shows stored beam current as a function of time over a four-day period during February of 2001. The second frame shows the total radiative energy loss resulting from insertion device radiation and thus indicates individual gap changes anywhere around the ring as steps in the data. The two bottom frames show the "peak rms" beam motion averaged over approximately 80 beam position monitors located near the insertion device source points. This data is computed by the real-time feedback system.

At 1.5 kHz, data for each BPM has a 0.01 Hz input high-pass digital filter applied to reject DC, followed by a

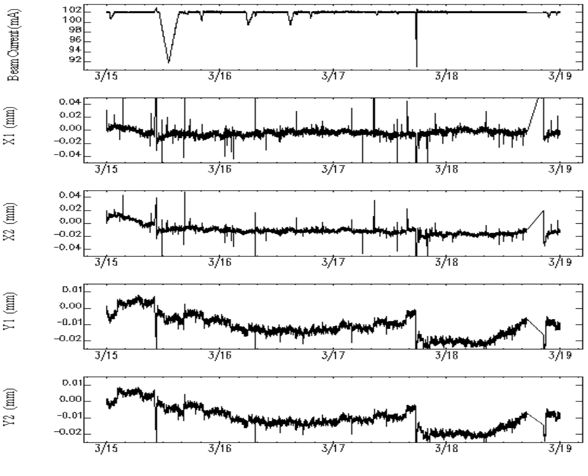

Figure 2: X-BPM drift over a 96-hour period.

30 Hz low-pass filter, squaring, exponential averaging, and finally a square root operation, resulting in a de-aliased “noise” signal. Noise data from approximately 80 BPMs is averaged, with a 0.1 Hz low-pass filter applied to the result. Since the data logger collects data every 60 seconds, this signal is peak detected over a 60-second buffer period in order that the logger not “miss” any orbit transients, nor de-emphasise them by averaging. Thus the data of Figure 1 is robust, i.e., unforgiving, and provides an unadulterated view of the beam stability in this band.

Generally speaking, the stability sits near 1.3 microns rms vertically and 2.0 microns in the horizontal from 0.1 to 30 Hz. Most of the transients seen vertically are correlated with injection. Many of the remaining transients, especially horizontally, are correlated with insertion device gap changes, which are controlled by users. An aggressive effort is taking place to reduce these 5-to-15 micron rms transients by using feed forward algorithms in the real-time feedback system processors. Please note that the beam size at insertion device source points is 300 microns rms horizontally and approximately 20 microns rms vertically.

Shown in Figure 2 are horizontal (X1, X2) and vertical (Y1, Y2) X-BPM data from insertion device beamline 34-ID with a fixed, 20-mm gap, over a four-day period during top-up operation mode. Top-up entails injection of a single injector shot every two minutes with x-ray user shutters open to maintain a constant 102 mA [10]. The data of Figure 2 is digitally filtered with a 20-second time constant and is logged every two minutes.

The detectors represented in Figure 2 are located 16 and 20 meters, respectively, downstream from the insertion device source point and are sensitive primarily to source angle, e.g., 20 microns corresponds to about 1 micro-radian. Neither detector was included in the DC or real-time orbit-correction algorithm. So these data indicate our performance to date without X-BPM feedback. The common mode signal where two detectors in the same front end agree with one another is an indication of the “true” beam motion and gives some idea of the level of improvement that can be expected once these systems are folded into the correction algorithm.

As can be seen from the figures, the immediate improvements needed toward the goal of submicron beam stability are feed forward on insertion device gap changes plus the incorporation of the recently upgraded X-BPMs into the DC correction algorithm. Additionally, the recently completed upgrade to the timing/triggering of the monopulse BPMs from beam-derived to low-level-rf-derived will reduce intensity dependence to 10 microns or less while allowing closer bunch spacing. New software has been tested that integrates the DC and real-time correction, reducing a “dead band,” and this will be commissioned soon. Integration of X-BPM data into the real-time system is a further planned upgrade.

6 CONCLUSIONS

Orbit correction techniques at the APS have matured significantly during its five-year operating history. The latest round of hardware and software upgrades should lead the way toward true submicron rms beam stability. Robert Lill, Om Singh, John Carwardine, Frank Lenkszus, John Galayda, Michael Borland, and Louis Emery have all been instrumental in the success of this effort.

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