STRATEGY FOR ACHIEVING TRUE SUB-MICRON ORBIT STABILIZATION AT THE ADVANCED PHOTON SOURCE*

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Abstract

The Advanced Photon Source was commissioned in March 1995 to provide high-brightness ultrastable x-ray photon beams to its user community. The original beam stability specifications were that the source points not move more than 4.5 microns rms vertically and 17 microns rms horizontally. Reductions in coupling, together with planned reductions in emittance and increasing beamline user sophistication, are pushing the envelope of presently achievable beam stabilization methods. While beam stability below the 2-micron rms level is achieved routinely in the band from .016 Hz to 30 Hz in both the vertical and horizontal planes, much remains to be done to reduce this level below 1 micron rms. An additional challenge is to maintain the beam stability for longer time periods, i.e., days to weeks. This paper discusses progress to date on these issues and suggests methodologies for further improvements.

1 INTRODUCTION

Orbit control at the Advanced Photon Source is performed using two independent frequency-band-separated systems that have access to data from 357 monopulse rf beam position monitors (BPMs), 48 narrow-band BPMs, and up to 48 insertion device (ID) and 38 bending magnet (BM) x-ray BPMs. Correction is accomplished using different configurations of 317 combined-function horizontal/vertical corrector magnets and power supplies. A subset of 38 corrector magnets are located at vacuum spool piece locations and have significantly higher bandwidth (200 Hz) than most correctors whose bandwidth is limited to a few Hz by eddy current effects associated with the thick-walled aluminum vacuum chamber.

Two independent systems perform orbit correction. A weighted singular value decomposition (SVD) algorithm operates on a workstation in the main control room and has access to all BPMs and all correctors [1]. This system typically uses 80 correctors (two per sector) and as many rf BPMs as possible, and it updates the corrector settings every 4 s. x-ray BPMs have just recently undergone an upgrade in their data acquisition section and they are integrated, with the rf BPMs, into a single orbit correction configuration tool used to set up the SVD algorithm. The choice of correction configuration, i.e. selection of correctors, BPMs and BPM weights, is a critical factor in reducing long-term drift with this system.

In parallel with the workstation-based algorithm is a real-time [RT] feedback system [2]. This system has access to all rf and x-ray BPMs and is being upgraded to have RT communication of setpoints to all corrector power supplies. The typical configuration of this system is to operate at a sample rate of 1.53 kHz and use the 38 broadband corrector magnets and 4 out of 11 rf BPMs per storage ring sector. A singular value decomposition algorithm is used, which employs all 38 eigenvalues. The RT feedback system presently employs a high-pass filter such that the correction bandwidth extends down to approximately 0.1 Hz. Below this frequency, the workstation-based algorithm takes effect. Configuration of the RT feedback system sets the limit on the achievable beam motion in the band from 0.1 Hz up to about 60 Hz.

2 PRESENT STATUS

2.1 AC Beam Stability

One important measure of beam stability at the APS is the rms beam motion in the frequency range from 0.1 Hz to 30 Hz, averaged over up to 80 rf BPMs located near ID source points. This algorithm is evaluated for both the horizontal and vertical planes by a digital signal processor (DSP) embedded within the RT feedback system.

Shown in Fig. 1 are data collected at 1-min intervals over a 24-h period. The top frame shows the stored beam current. The second and third frames show the vertical and horizontal rms beam motion, respectively. The fourth frame shows the total calculated energy loss from ID synchrotron radiation, indicating when gap changes occur, and the bottom frame shows the machine coupling as derived from an x-ray pinhole camera image. Note that the raw rms beam motion data have a 10-s time constant associated with a 0.1-Hz low-pass digital filter, so the data displayed have been peak-detected over a 60-s period, commensurate with the 1-min sampling interval. In this manner, all orbit glitches are properly logged.

These data demonstrate that AC beam motion up to 30 Hz is kept below 2 microns for a large fraction of the time, with the exception of a small number of orbit transients, which can be as large as 15 to 20 microns rms. Comparison of frames 4 and 3 show that most of these transients are associated with ID gap changes. The IDs were constructed to ensure that the first and second field integrals were tightly constrained as the gap was varied. The residual variation, however, is not insignificant down at the few-micron scale. Worse, these transients fall in a “deadband” between the bands covered by the RT and workstation-based control algorithms.

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Ultimately, when discussing beam stability at these insanely small scales, not only the beam centroid motion, but small beam size or shape variations also become important, because users are concerned primarily with the flux striking their samples. As the bottom frame of Fig. 1 illustrates, the vertical beam size shows a strong correlation with ID gap changes.

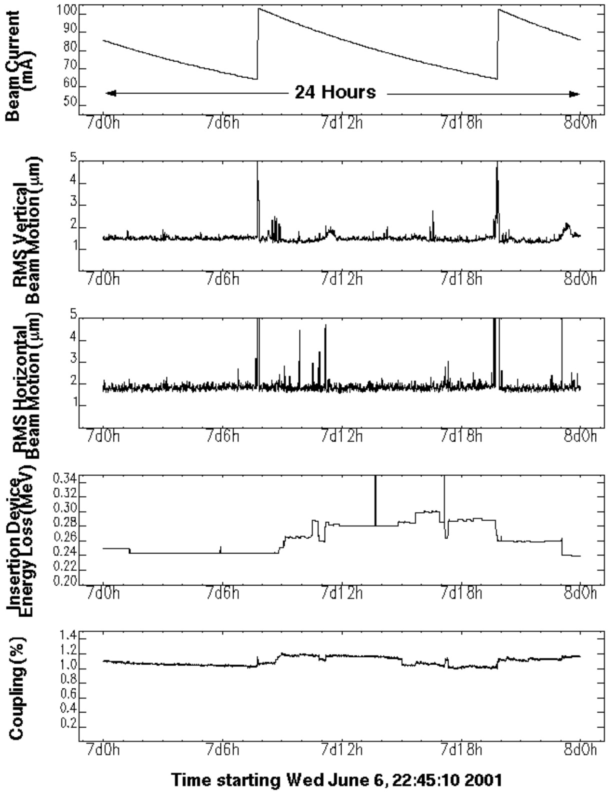

Figure 1: AC beam stability and beam size data.

In addition to constraining the first and second field integrals, specifications were given to limit multipole variations within the device. Even with this limitation, the IDs are affecting the vertical beam size, which is nominally about 20 microns rms at the ID source points.

2.2 DC Beam Stability

Shown in Fig. 2 are X-BPM data indicating vertical positioning stability over a recent 8-day period for a selected bending magnet beamline (8-BM). The x-ray BPMs consist of metal-coated chemical vapor deposition (CVD) diamond wafers placed edge-on to the x-ray beam, symmetrically above and below the accelerator midplane [3]. Each X-BPM blade assembly is mounted on a moveable translation stage, which in turn is mounted on a thermally insulated, vibration-dampened support. A number of blade geometries are used for BM, undulator, and wiggler sources.

As a result of an upgrade to the X-BPM data acquisition and processing electronics in May 2001, these units provide clean, anti-aliased signals for inclusion in orbit control algorithms [4, 5]. Each beamline has two X-BPMs in the front-end area, located 11 and 18 m, respectively, downstream of the source point for bending magnet beamlines, and 16 and 20 m for the two ID X-BPMs. Thus, all things being equal, the X-BPMs have superior angular resolution in comparison to any of the rf BPMs. The 40 micron peak-to-peak variation seen in Fig. 2 amounts to only 2.2 μrad of angular drift over the one-week period. This amount of angular motion would result in only 4 microns of peak-to-peak drift as seen by the rf BPMs straddling the dipole source point, which have 4-m separation.

During an 8-h machine studies period on June 12, the downstream X-BPM in beamline 8-BM was added to the SVD algorithm, along with four vertical corrector magnets straddling the source point. The upstream unit, not included in the algorithm, shows the improvement achieved by this change in configuration. The peak-to-peak motion is reduced to nearly 5 microns, a factor of almost 4 improvement; 0.5 μrad peak-to-peak in comparison to over 2 μrad before (divide by about 3 to get rms).

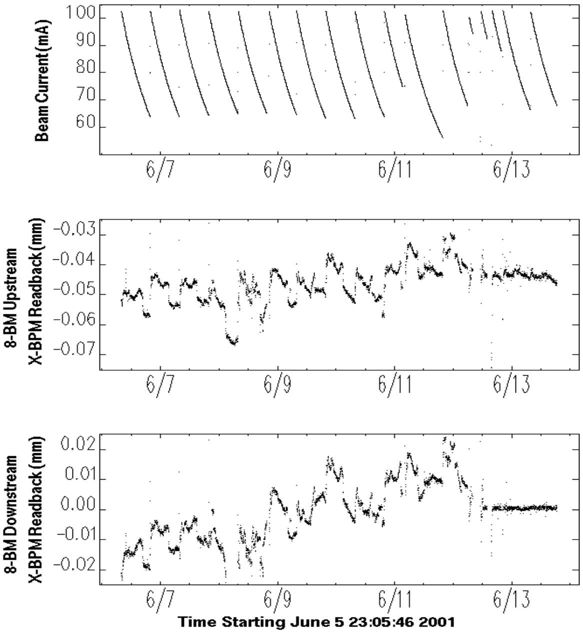

Figure 2: Long-term X-BPM drift data.

3 UPGRADE STRATEGY

Much has been done already in terms of hardware upgrades, including new data acquisition and processing for the X-BPMs and narrow-band rf BPMs and a new timing system for the monopulse rf BPMs. These upgrades have been done in such a way that the RT feedback system potentially has access to all BPMs and will soon have access to all correctors, at up to 1.53 kHz. While additional hardware upgrades are likely warranted, it is clear that much can be gained immediately by the refinement of correction algorithms and methodologies.

3.1 Feed-Forward

One obvious avenue of attack is the addition of feed-forward (FF) algorithms to reduce open-loop ID gap change steering effects. The effectiveness of this change has been demonstrated with a reduction (by a factor of 2) in the measured disturbance for the standard variable-gap undulator design using two correctors straddling the device. It has been implemented during machine operation for the electromagnetic wiggler, which changes polarity every 45 s, resulting in a 15-micron horizontal orbit transient without FF and less than 1 micron with FF.

The difficulty with FF for the majority of IDs is that the effects being measured are generally at the 10-micron rms scale, while the measurement to determine the compensation-corrector settings requires tens of minutes. Correcting the orbit between gap changes must be done using the workstation-based feedback down to the 1-micron scale and must be repeated several times to assure that no tiny orbit glitches have corrupted the data. Because all data are now available to the RT system, one idea is to extend this system's range down to DC and perform the same measurement in a much shorter time to minimize the likelihood of uncorrelated orbit glitches corrupting the data set. Once the FF lookup tables are complete, execution of FF by the RT system, which also has access to ID gap information, would assure minimization of ID gap-induced orbit transients. These lookup tables will be used for FF from the workstation as a first step.

The issue of FF on ID gap can get quite involved when one considers that the particle beam trajectory internal to the device can deviate considerably from the straight-line fit between adjacent rf BPM stations as the gap is changed. This implies that the x-ray centroid varies in a way that is unobservable by the rf BPMs. All FF performed to date concerns itself with reducing the effects of a gap change on other users. This effect implies that a second level of FF is required to stabilize the users' own x-ray beam as their gap is varied. Definition of this algorithm will be very difficult and presently places a fundamental limit of several μrad on DC pointing stability. If the ID X-BPM systematic effects that depend on ID gap could be resolved at the sub-micron scale [5], this problem could be eliminated.

3.2 System Configuration

It seems clear that the choice to separate the RT and workstation-based correction algorithms by frequency band is placing limits on our ability to correct the orbit in the critical deadband near 0.1 Hz. While it is possible to extend the RT range down to DC, this puts the two systems into contention because they share BPMs and correctors. Furthermore, the RT system is not as flexible owing to strict limitations of DSP speed and access to high-speed correctors. The problem of integrating slow and fast correctors into a unified RT algorithm has proven difficult; the only viable solution is to slow down the fast units to match the slow units, reducing the closed loop bandwidth. This was one of the motivating factors behind going to the two band-separated systems. A FF-type algorithm has been put into operation whereby the RT system is informed of workstation-based corrections in a synchronous fashion, with some success [6].

An alternative to frequency band separation of RT and workstation-based feedback is to orthogonalize the two systems spatially rather than temporally. A configuration with four-element local bumps tied to X-BPMs could be run in parallel with RT feedback where all rf BPMs used by the RT system are outside the local bumps, and no BPMs or correctors are shared. The local bump coefficients will need to be determined with high accuracy, maybe by using the RT system (upgraded to communicate with all correctors). This would permit both systems to operate down to DC and eliminate the deadband while allowing the degrees of freedom necessary to steer adjacent beamlines independently.

Addition of a second fast corrector in each sector — for a total of 78 compared to the present 38 — is a viable option, making use of a second vacuum spool piece. Simulations show that this approach could improve RT system noise suppression by a factor of 2. Investigations are underway to move the workstation-based algorithms to multiple local processors running at up to 100 Hz, which would solve many problems, especially if implemented in a fashion consistent with ref. [6]. Ultimately, a redesign of all orbit correction features into a unified RT system, while costly, may be required to achieve sub-micron stability.

Efforts continue to identify and eliminate noise sources (e.g., [7]), and BPM systematic errors [1]. Analysis of closed-loop system performance provides useful information on disturbance locations and spectra [2].

4 CONCLUSIONS

Beam stability at the APS is now reliable at the few-micron scale from 30 Hz down to a few hours, with occasional deadband transients. Immediate efforts will be to implement FF and investigate different system configurations and algorithms to achieve true sub-micron stability. This work should help focus further hardware upgrade efforts.

M. Borland and L. Emery have been instrumental in this work.

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