BEAM STABILITY AT THE ADVANCED PHOTON SOURCE*

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Abstract

The Advanced Photon Source has been in operation since 1996. Since that time, extensive incremental improvements to orbit stabilization systems have been made. This includes the addition of 80 channels of narrowband rf beam position monitors (BPMs), 44 channels of bending magnet photon BPMs, and most recently the inclusion of 16 insertion device photon BPMs into the orbit correction response matrix. In addition, considerable improvements have been made in the area of power supply regulation, both for the main multipole magnets and the steering corrector magnets. The present status of overall performance will be discussed, including long-term pointing stability, reproducibility, and AC beam motion.

INTRODUCTION

Beam stability requirements have grown tighter in the last five years at the Advanced Photon Source due to improvements in storage ring brightness. Table 1 shows the steady reduction in allowable beam motion since 1995 [1]. The most stringent stability requirement, based on particle beam dimensions, is the vertical divergence of 0.15 µrad. However, this requirement can be relaxed to 0.22 µrad when the photon angular divergence is included in quadrature.

Table 1: APS SR Beam Stability Requirement Evolution

Parameter	Units	RMS Beam Size and ***stability requirement*** (5 % of beam dimensions) at IDs in year		
		1995	2001	2005
σ_x ***x***	µm	334 ***16.7***	352 ***17.6***	280 ***14***
$\sigma_{x'}$ ***x'***	µrad	24 ***1.2***	22 ***1.1***	11.6 ***0.58***
σ_y ***y***	µm	89 ***4.45***	18.4 ***0.92***	9.1 ***0.45***
$\sigma_{y'}$ ***y'***	µrad	8.9 ***0.45***	4.2 ***0.21***	3.0 ***0.15***
ε_{eff}	nm-rad	8	7.7	3.2
Coupling	%	10.0	1.0	0.9

Beam stabilization efforts at APS have undergone a continuing process of evolution in order to meet the stability requirement challenge and are summarized here.

RECENT UPGRADES AND STATUS

The strategy for achieving true sub-micron orbit stability has been to study and compensate for multiple systematic effects and noise sources, enhance orbit correction feedback systems, and employ feedforward methodology where applicable [2,3]. Figure 1 shows a layout of beam position monitors (BPMs) and magnets in one sector.

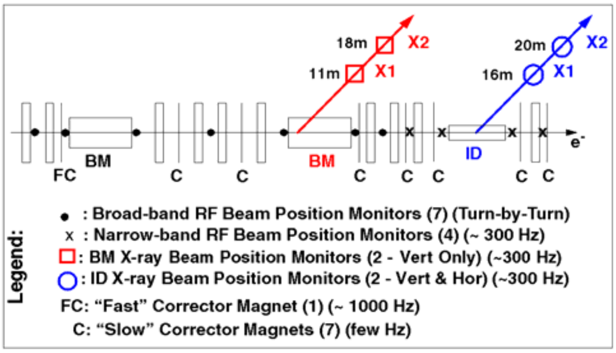

Figure 1: Beam position monitors/magnets in one sector.

Broadband rf BPMs' performance has been optimized in the past by improving pickup electrode signal strength and trigger stability [4,5]. Recently, a "cogging" technique where turn-by-turn data is collected by sequencing through different target bunches every turn and then averaging, has reduced bunch-pattern-dependent systematic errors. This technique has turned out to be crucial for top-up. The "rogue" microwave vacuum chamber modes [6] and aging turn-to-turn electronic hardware are still problematic. An upgrade to the data acquisition system [7] is in progress that employs fast digitizers coupled with field-programmable gate arrays and embedded signal processing, enabling the collection of up to 256 samples of data on every turn, compared to only one sample per turn at the present time.

Narrowband rf BPMs, straddling the insertion device source points, have shown quite small systematic errors associated with intensity, bunch pattern, and thermal drifts, and have been very effective when used in DC orbit control for orbit reproducibility [8]. Encouraged with this result and given the need to upgrade the beam missteering interlock, a second set of narrowband electronics were recently commissioned, replacing broadband electronics at elliptical vacuum chamber pickup electrodes located near the insertion devices. Studies are in progress to include narrowband BPMs in the fast feedback system.

Photon BPMs in the bending magnet (BM) beamlines have been the workhorse for vertical beam stabilization and alignment, and are used routinely in DC orbit correction [9,10]. Lattice modification efforts to reduce background radiation for insertion device (ID) photon BPMs have been completed at all beamlines [11]. Also, before ID photon BPMs could be used in orbit correction, compensation for ID gap-dependent systematic errors was

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*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

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0-7803-8859-3/05/$20.00 ©2005 IEEE

required. The photon BPM readback varies with ID gap as a result of mechanical fabrication errors, surface photoemission characteristic variations, space charge, and residual stray radiation sources. Further, since the magnetic field decreases exponentially as the ID gap is opened, the beam position signal noise increases in a similar fashion. To overcome this, the readbacks are artificially forced to zero for gaps larger than 31 mm. A set of feedforward (FF) lookup tables are used to subtract predetermined offsets from the photon BPM readings as the gap varies. The FF data is determined during machine studies periods prior to the start of user operation by simultaneously scanning the gaps while locking down the orbit using rf BPMs. The resulting photon BPM readback variations provide the desired offsets for subtraction by the FF algorithm. Figure 2 shows a typical set of raw and FF data for sector 7 ID horizontal position.

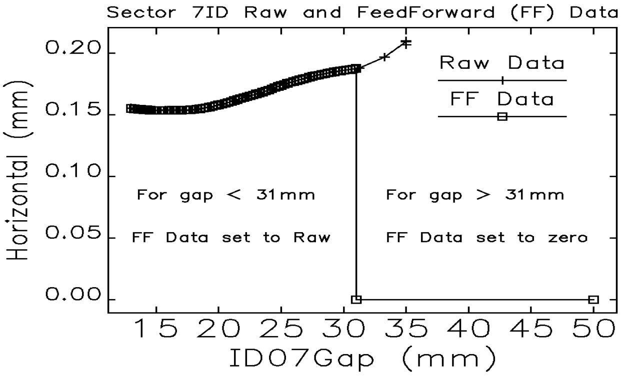

Figure 2: ID X-BPM raw and feedforward data.

Corrector magnet power supply current regulators were upgraded [12], eliminating the regulation instabilities at zero current crossover. With the new design, converters can now operate smoothly in the full range ±150 A. The new design also meets tighter specifications in terms of ripple current and dynamic response. While all corrector power supplies and magnets have fast open-loop response (~ 1 pole at 1450 Hz, with 0.2-ms delay), only one corrector magnet per sector, which is mounted on a vacuum spool piece, produces an overall fast response. Eddy currents from the aluminum vacuum chambers limit the bandwidth on all other units.

DC orbit correction operation on an EPICS input/output controller (IOC) has been commissioned, increasing the correction rate by a factor of 25 in comparison to the original workstation-based algorithm, from 0.4 to 10 Hz. This virtually eliminates orbit motions caused by insertion device gap changes [13]. This system makes use of the same hardware utilized by the fast orbit correction system (at 1.53 kHz rate) [14]. Plans are underway to increase the DC correction rate up to 100 Hz, which should exploit the full bandwidth (BW) available from the slow corrector system (few Hz).

OVERALL PERFORMANCE STATUS

The long-term (>48 hrs) drift performance is generally good vertically for bending magnet (BM) source points where horizontal positioning relies on the broadband rf BPM system. Figure 3 shows that vertical pointing stability falls within 2 µrad p-p for the majority of beamlines, exceeding the pointing stability requirement, which amounts to 5% of the 73 µrad photon beam angular divergence.

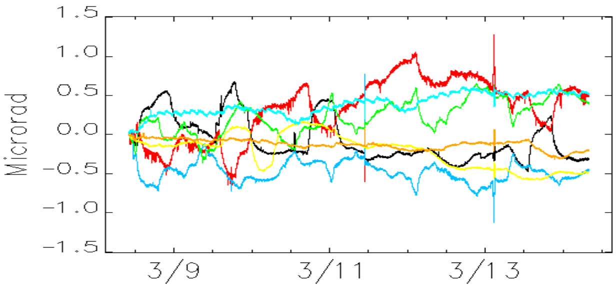

Figure 3: Long-term BM vertical pointing stability shows < 2 µrad p-p drift in six days.

Figure 4 shows that both horizontal and vertical pointing stability variations in ID8 beamline are correlated with the local tunnel air temperature variation. Clearly, the improvement of temperature regulation will improve long-term drifts considerably, and efforts are progressing in this area.

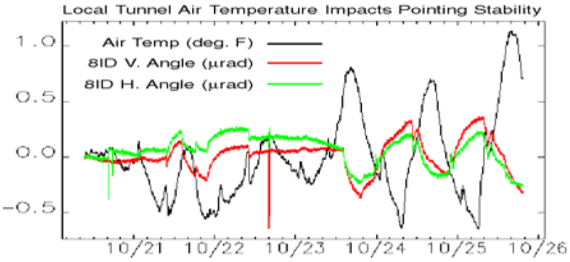

Figure 4: Long-term ID pointing stability correlation with the local tunnel air temperature variation.

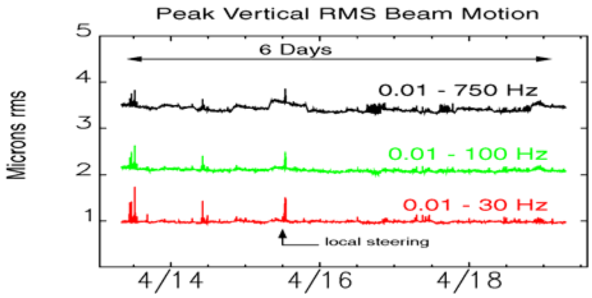

Figure 5: Steady-state vertical AC orbit stability in three frequency bands.

The steady-state AC orbit stability measured by BPMs straddling insertion devices is shown in Figure 5, indicating vertical rms beam motion in three frequency bands. The horizontal rms beam motion, not shown, is about 50% higher. The inclusion of ID photon BPMs in AC orbit correction should give significant improvement.

FUTURE IMPROVEMENTS-DISCUSSION

The rms beam stability requirements have been met in the horizontal plane, but further improvements are necessary to do the same in vertical plane. The vertical position stability of 0.45 micron rms requires an improvement on the order of two or four depending on the frequency band of 30 or 100 Hz, as observed in Figure 5.

As discussed earlier, there are four flavors of BPMs but each flavor has some restriction on their use in DC or AC orbit correction systems. A list of all available BPMs and their orbit correction (OC) application is shown in Table 2.

Table 2: Comprehensive List of All Available and In-use DC/AC Orbit Correction BPMs in the Storage Ring

Type	Available BPMs	In-use orbit configuration BPMs			
		dc-h	dc-v	ac-h	ac-v
Broadband	280	214	9	152	77
Narrowband	142	131	129	0	75
BM x-ray	44	NA	32	NA	0
ID X-ray	62	13	16	0	0
Total	528	358	186	152	152

Only a small number of broadband BPMs are used in vertical DC OC due to the "rogue" microwave modes. The upgrade of the broadband BPM data acquisition system [7] is in progress and will replace the aging turn-to-turn electronics hardware. When fully implemented, this will hopefully reduce the effects of "rogue" microwave as well. The use of narrowband and photon BPMs in AC OC is presently limited due to large phase shifts caused by 6-pole anti-aliasing filters. Modified anti-aliasing filters are planned so that most of the narrowband and photon BPMs can be included in AC OC.

As discussed earlier, the improvement in the tunnel temperature regulation will provide significant improvement in long-term pointing stability. There seems to be a potential for improvement on a one-to-one basis i.e., a factor of two reduction in temperature variation would cut the drift in half.

The long-range goal is to eliminate the need for local steering requests and any uncertainty regarding the position of the white beam as it strikes the first x-ray beamline optical element. An insertion device "gold standard" white BPM is being investigated for this purpose. This monitor will be sensitive only to hard x-rays, approximately 9 keV, and should be insensitive to the large number of soft stray radiation that adversely affects the present photoemission-type photon BPMs This effort will hopefully reduce long-term drift and week-to-week repeatability to well below 500 nrad peak-to-peak.

Simulations show that adding a second fast corrector to every sector will reduce AC orbit motion by a factor of ~ 2 in the frequency band up to 50 Hz. However, this may involve significant costs since many other accelerator components will have to be relocated or removed. Additional cost-performance analyses are being done.

Presently the AC orbit correction rate is limited to 1.53 kHz due to digital signal processing speed limitations, and the orbit correction BW is limited to ~ 50 Hz. Simulations shows that this correction BW can be increased to approximately 200 Hz by increasing the orbit correction rate by an order of magnitude, up to about 10 kHz. Preliminary investigations are in progress to evaluate the cost involved in upgrading the AC OC infrastructure using readily available fast digital signal processors and/or field programmable gate arrays.

CONCLUSIONS

In the last few years, there have been improvements to the orbit correction hardware and system, and a significant level of orbit stability has been achieved. But more needs to be done in order to meet a beam stability of 5% of the beam size. As usual, this work is the result of collaborations between several groups within APS.

REFERENCES

[1] Y.-C. Chae and G. Decker, Proc. of PAC 1995, Dallas, TX, p. 3409 (1996), http://www.jacow.org.

[2] G. Decker, O. Singh, Proc. of PAC 2001, Chicago, IL, p. 390 (2001), http://www.jacow.org.

[3] G. Decker, Proc. of DIPAC 2001, ESRF, Grenoble, France, p. 177 (2001), http://www.jacow.org.

[4] E. Kahana, Proc. of the 3rd Beam Instrumentation Workshop, AIP Conference Proceedings 252 (1992) 235.

[5] F. Lenkszus et al., Proc. of PAC 2001, Chicago, IL, p. 767 (2001), http://www.jacow.org.

[6] Y. Kang, G. Decker, J. Song, Proc. of PAC 1999, New York, NY, p. 3092 (1999), http://www.jacow.org.

[7] R. Lill et al., "Design of the APS RF BPM Data Acquisition Upgrade," these proceedings.

[8] O. Singh et al., Proc. of PAC 1999, New York, NY, p. 2093 (1999), http://www.jacow.org.

[9] D. Shu et al., Nucl. Instrum. Methods A 319 (1992) 56.

[10] O. Singh et al., Beam Instrumentation Workshop 2000, AIP Conference Proceedings 546 (2000) 594.

[11] G. Decker and O. Singh, Phys. Rev. STAB 2 (1999) 112801.

[12] J. Wang, Proc. of EPAC 2004, Lucerne, Switzerland, p. 1768 (2004), http://www.jacow.org.

[13] F. Lenkszus et al., Proc. of PAC 2003, Portland, OR, p. 283 (2003), http://www.jacow.org.

[14] J. Carwardine, F. Lenkszus, 1998 Beam Instrumentation Workshop, AIP Conference Proceedings 451 (1998) 125.