EVALUATION OF A VARIETY OF PHOTON BEAM POSITION MONITOR DATA ACQUISITION METHODOLOGIES AT THE APS*

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Abstract

The APS has the largest installed base of closed-loop photon beam position monitors of any facility in the world; however, many portions of the orbit control systems use aging and near-obsolete components. Substantial improvements in beam stability are planned as part of the ongoing APS upgrade project. Among the planned improvements is a replacement of the present real-time feedback system using modern technology to increase the sample rate from 1.5 kHz to near 20 kHz. Because of this, new data acquisition options are being explored to support existing and new types of x-ray beam position monitors (XBPMs). Performance data collected from existing hardware, the APS-designed BSP-100 module and two commercial solutions, will be compared and contrasted.

INTRODUCTION

Figure 1 shows the pickup electrode (blade) arrangement for the P1 (insertion device) photon beam position monitor locations at the APS. The x-ray photon beam passes through the center of the blades; however, the beam halo strikes the blades and produces a photocurrent related to the proximity of the beam. This current is fed to a sensitive transimpedance amplifier (preamp) and converted to a voltage level, which is then digitized. From this information, the photon beam position can be calculated using the following relations:

$$\Delta X = (A + B) - (C + D) \quad (1)$$

$$\Delta Y = (A + C) - (B + D) \quad (2)$$

$$\Sigma = A + B + C + D \quad (3)$$

The photon beam position (X, Y) is then given by:

$$X = K_x(\Delta X/\Sigma), \quad Y = K_y(\Delta Y/\Sigma), \quad (4)$$

where K_x and K_y are calibration factors with values near 1 mm for APS XBPMS. The calculated beam position is sensitive to errors in the individual digital readings, since it relies on the difference of large signals. Beam position typically needs to be resolved to a few microns, and small errors in the individual A, B, C, and D blade readings can result in unacceptable errors in the calculated beam position. A significant source of these errors is in the ADC stage, manifested as DC errors (gain and offset drift) and AC noise.

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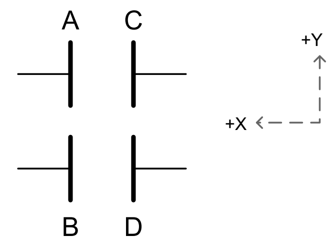

Figure 1: Typical photon beam position pickup electrode geometry. The beam direction is into the paper.

DATA ACQUISITION METHODS

The present APS XBPM data acquisition [1] makes use of the preamp stage with discrete gain settings covering 6 decades of signal intensity, from nanoamps to a milliamp. These are followed by a multiplexed 32-channel 16-bit VMI-VME 3122 digitizer operating at 1.534 kHz/channel. Typically the preamp gains are held fixed and varied only for machine studies. Individual blade signals are used to compute position data according to equation (4). While this system has been very reliable, the 1.5-kHz sample rate is not sufficient to support the planned real-time feedback rate near 20 kHz.

Four different new technologies have been tested at the APS. An in-house design known as the BSP-100 module is an 8-channel, 14-bit, 88-MHz digitizer with a built-in Altera Stratix II FPGA. This unit was developed for the APS broadband rf BPM upgrade, and its AC performance is excellent [2,3]. Another FPGA-based solution tested was the 4-channel 24-bit Libera Photon beam position processor, developed by Instrumentation Technologies. In addition, the National Instruments CompactRIO platform, which incorporates an FPGA and processor, was tested with two different digitizers: the 4-channel, 16-bit NI 9223, and the 4-channel, 24-bit NI 9239. A summary of the different systems is shown in Table 1.

LONG-TERM DRIFT STUDIES

To quantify long-term drift, the BSP-100 module was installed in a temperature-controlled environmental chamber maintained at 30 ± 0.5°C. All channels were provided with a 500-mV DC input. Shown in Fig. 2 are 7-day stability data indicating variation relative to the first data point. In the worst case, 400 microvolts p-p are observed, amounting to approximately 0.8 microns p-p according to equation (4).

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Table 1: Data Acquisition Module Details

Module	Vendor	ADC Configuration	Max. Sample Rate per Channel	Sample Rate as Tested	Additional Features
BSP100	APS	8 Ch. simultaneous, 14-bit	105 MS/s	88 MS/s	FPGA, embedded Linux, EPICS IOC
Libera Photon	Instrumentation Technologies	4 Ch. simultaneous, 24-bit	100 kS/s	10 kS/s	FPGA, embedded Linux, EPICS IOC
NI9223	National Instruments	4 Ch. simultaneous, 16-bit	1 MS/s	10 kS/s	FPGA, VXworks based EPICS IOC
NI9239	National Instruments	4 Ch. simultaneous, 24-bit Δ-Σ	50 kS/s	10 kS/s	
VMI-VME 3122	GE Fanuc Automation	32 Ch. (32-to-1 MUX) 16-bit	1.5 kS/s	1.5 kS/s	None

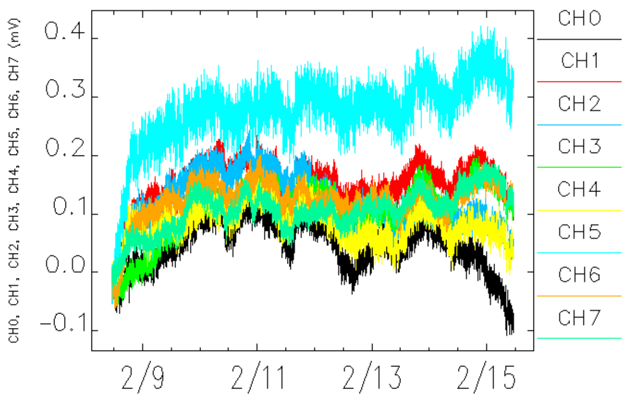

Figure 2: Seven-day stability data for the BSP100 module at constant temperature.

To investigate the impact of temperature variation, shown in Fig. 3 are data indicating sensitivity to deliberate oven temperature changes. A step change of 15°C and a slow ramp of 5°C over 24 hours are shown. BSP-100 readbacks vary proportional to temperature. In the worst case, 125 microvolts/°C is seen, with the smallest variation being about 75 microvolts/°C. It is the difference in slope that impacts position, i.e., 25 microvolts/°C is equivalent to about 50 nanometers/°C of position measurement error.

AC PERFORMANCE

APS beamline 35-ID has for years served as a test bed for new types of diagnostics including beam position monitoring. It uses a 1.8-cm-period undulator source with rf BPMs mounted on the 8-mm-aperture vacuum chamber, sporting the latest Instrumentation Technologies Libera Brilliance+ rf BPM electronics [3].

Located 16.35 meters downstream of the center of the insertion device straight section is the first photon beam position monitor with geometry as shown in Fig. 1, and for which Libera Photon, NI 9223, and NI 9239 electronics were tested. All tests were conducted at a fixed 15-mm undulator gap. This resulted in signal levels of a few volts. Calibration was determined using a local bump to scan the source angle and cross-referencing to the Libera Brilliance+ rf BPMs.

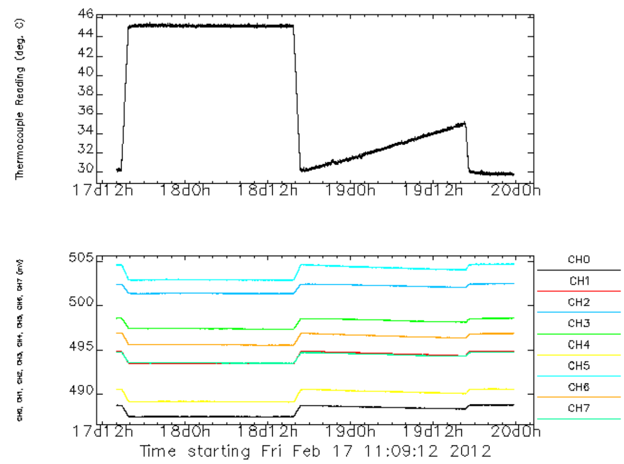

Figure 3: Temperature dependence of eight BSP100 ADC channels over a 15°C range.

Shown in Fig. 4 are data comparing the AC performance of the 16- and 24-bit National Instruments digitizers over five and a half decades of frequency. Plotted is the square root of the running integral of power spectral density, in both forward and reverse directions. This provides a quantitative measure of rms beam motion, accentuating low frequencies by integrating in the forward direction, while high frequency performance is easily discerned using the reverse integral. The sample rate used was 10 kHz, collected over a two-minute interval for each data set. These data were collected with orbit feedback operational, providing the lowest noise level presently achievable. It appears that the 16-bit digitizer is having trouble resolving small amounts of beam motion at both low and high frequencies.

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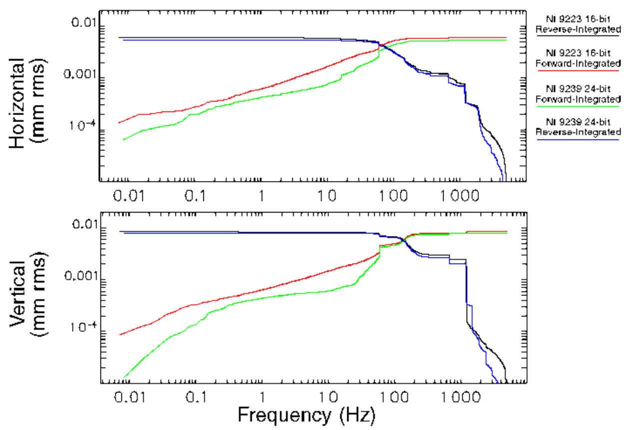

Figure 4: Comparison of NI 9223 (16 bits) and NI 9239 (24 bits) electronics with APS 35-ID photon BPM.

Shown in Fig. 5 is a comparison of the 24-bit NI 9239 with the Instrumentation Technologies 24-bit Libera Photon. In this case the data for the Libera Photon were collected in January, 2011, while the data for the two National Instruments devices from Fig. 4 were collected one year later on the same shift in January, 2012. For this reason, it is very likely that the spectrum of real beam motion is different, most clearly seen near the synchrotron tune at 2 kHz, which is larger for the Libera Photon. A 1.2-kHz spectral line was seen by both NI digitizers, but was not seen one year earlier. The most important spectral band is in the range from 1 to 200 Hz, where the planned APS real-time feedback system upgrade will operate; in this band the performance of both modules is comparable. Due to the necessarily brief testing periods, long-term trends similar to Fig. 2 were not available, but are clearly very important in the evaluation.

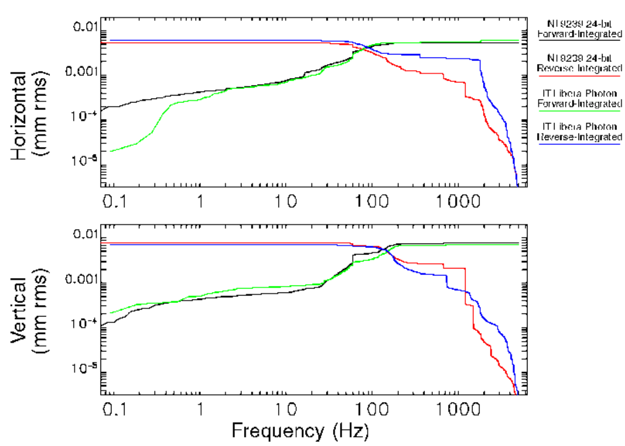

Figure 5: Comparison of NI 9239 (24-bit Libera Photon electronics) with APS beamline 35-ID photon BPM.

As a reference, the present APS photon BPM 1.5-kHz data acquisition system performance is shown in Fig. 6 for a bending magnet source (P1-Y) and for fixed input voltages varied over three decades of signal amplitude. This is a significant challenge for insertion device sources, where signal intensity can vary by four decades or more. For this reason, investigations have begun to explore the use of matched sets of logarithmic amplifiers to measure photoemission blade/photodiode signals in the range from fractions of a nA up to hundreds of microamps.

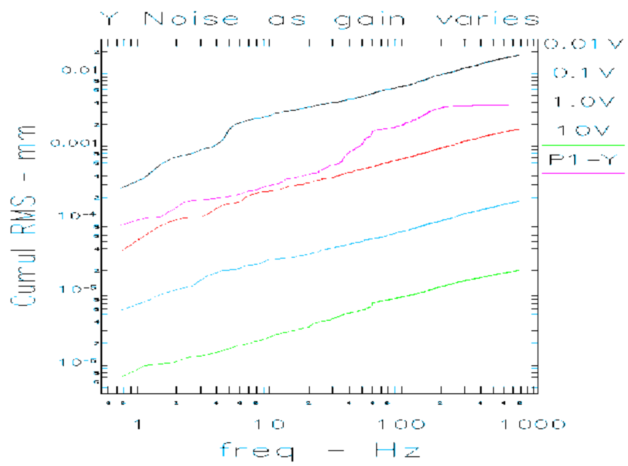

Figure 6: Performance of existing APS XBPM electronics.

CONCLUSION

A number of different types of data acquisition solutions for photon beam position monitoring at the Advanced Photon Source have been evaluated for long-term drift and AC performance. Although much work remains, a number of viable alternatives are available.

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