COMPARATIVE STUDIES OF RF BEAM POSITION MONITOR TECHNOLOGIES FOR NSLS II*

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Abstract

Sub-micron beam stability is a necessary performance requirement for the NSLS II light source, a substantial challenge testing the limits for currently available RF beam position monitoring methods. Direct performance comparisons between commercially available BPMs and Advanced Photon Source in-house developed BPM were made at the APS storage ring. Noise floor, fill pattern dependence, and intensity dependence were investigated and correlated with photon diagnostics at the beam diagnostic beamline at APS sector 35. Key results are presented.

INTRODUCTION

The comparative tests of different BPM receivers were performed at APS. The key features of the experimental arrangement are shown in Figure 1. The Libera Brilliance receiver [1] was connected to the S36A:P0 BPM station in the diagnostics straight. An in-house built APS FPGA-based BPM receiver [2] was connected to the S35B:P0 BPM station. Both stations use 4-mm diameter pick-up electrodes mounted on an 8-mm high vacuum chamber of a diagnostics undulator. Horizontal separation of the buttons is 9.6 mm center-to-center. Separation between 35B:P0 and 36A:P0 is about 4 meters. Bergoz electronics [3] was used for S35B:P1 and S36A:P1 equipped with 10-mm buttons mounted on the approximately 4x8 cm elliptical vacuum chamber.

At a distance of 30.045 meters from the center of the ID straight is a vertically moveable horizontal slit, and at 29.5 meters is a horizontally moveable vertical slit. Both the slit size and center are adjustable with high accuracy using stepper motors. The beamline uses an hourglass-shaped beryllium window to separate the ring vacuum from the beamline vacuum. By using this shape, heat is more efficiently removed, albeit at the expense of transmogrifying the transverse profile of any transmitted photon beam.

The slit assemblies are accessible and their motion can easily be calibrated against a reference dial indicator to quantify mechanical motion. Preliminary measurements indicate backlash at the level of 20 microns, although there are indications that repeatability is significantly better than this, below 5 microns.

Both horizontal and vertical calibrations were performed at 35-ID. The main idea was to independently determine the absolute calibration of S35B:P1 and S36A:P1 from the slit/flux monitor combination, and compare the results with the lattice model.

Because S35B:P0 and S36A:P0 used experimental electronics, they have not been calibrated against the ring model. Instead, the local bump scans provide absolute calibration data for these electronics, in addition to supplying absolute calibration data for the front-end photon BPMs.

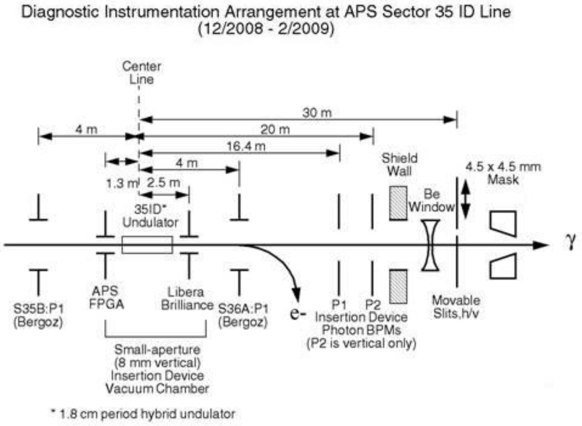

Figure 1: Diagnostics arrangement for 35-ID source point. Distances are approximate.

OBSERVING NOISE SPECTRUM OF CIRCULATING BEAM

During studies the Libera Brilliance signal level was manually set and direct measurement (no switching) was selected. The APS FPGA-based BPM receivers were in routine configuration. 262144 data points at a revolution frequency of 271.6 kHz were collected for both devices and the observed horizontal beam motion spectra are shown in Fig. 2.

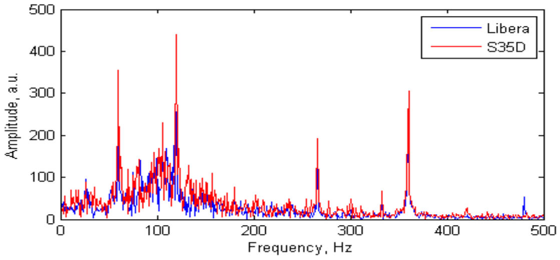

Figure 2: Overlaid spectra of beam motion in the horizontal plane. The data are from both Libera Brilliance and FPGA based receiver.

Excellent agreement of the two sets of data was found. The finest details are a perfect fit (see Fig. 2-4).

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As can be seen from Figures 3 and 4, Libera Brilliance has less noise than the APS FPGA-based receiver.

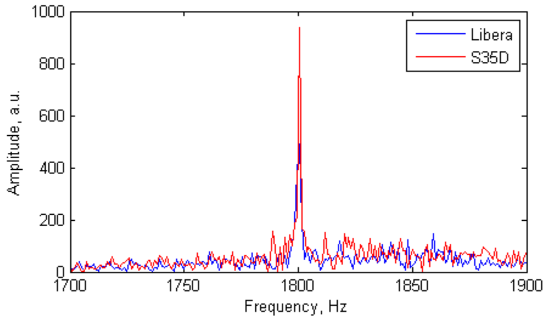

Figure 3: Synchrotron motion line observed by Libera Brilliance and FPGA-based receivers.

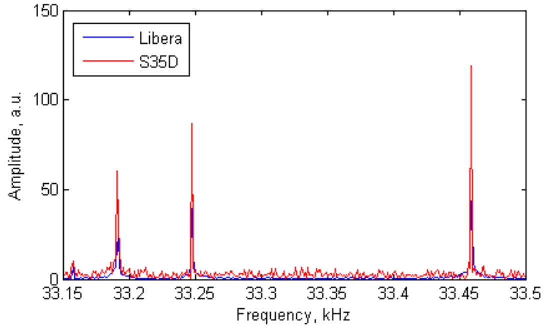

Figure 4: Details of horizontal beam motion in 30 kHz region observed by Libera Brilliance and FPGA-based BPM receivers.

INJECTION TRANSIENT STUDIES

The injection trigger signal was split and used to start simultaneous data acquisition for both the APS FPGA-based BPM receiver and Libera Brilliance. Final fine alignment on the time axis was done during post processing. The relative delay was the same for both planes. The transients are shown in Fig. 5 and Fig. 6.

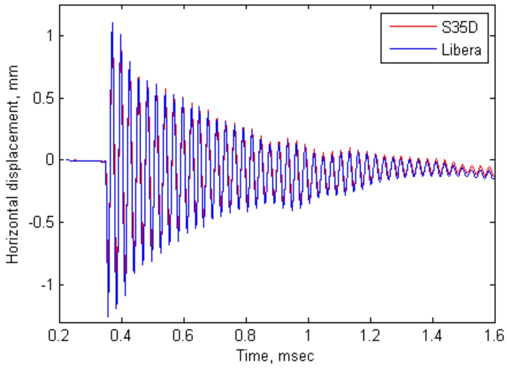

Fig. 5: Horizontal transient caused by the injection kickers. There is remarkable agreement in the two curves except for a small offset observed towards the end of the transient.

The vertical transient has good agreement but not as good as for the horizontal plane.

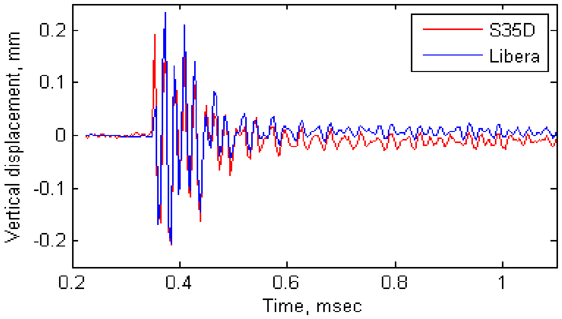

Figure 6: Vertical transient caused by injection kickers.

FILL PATTERN DEPENDENCE

Fill pattern dependence was considered as a perceptible intensity dependence seen when a gap in the 324 bunch fill pattern is present while maintaining constant total circulating charge. A single button was attached to a four-way splitter at the input to the Libera Brilliance module. Intensity dependence was simulated by large horizontal steering. For the uniform fill of 90 mA beam in 324 bunches was used.

The beam was refilled to 102 mA and then with a mismatched kicker (IK2 had 9 kV instead of normal 6 kV), part of the beam was blown away. 270 bunches had full charge and 10-15 bunches on each side had reduced charge. Again dependences of beam position and measurement noise on signal intensity were found. The process of refill and cleaning followed by measurements was repeated to obtain a fill pattern with 75 mA and a larger hole.

For the more direct study of the dependence of position and noise on signal intensity, all readbacks associated with a certain level were averaged and the standard deviation was found. The peak-to-peak position variations did not exceed 80 nm for both planes (see Fig. 8). The noise levels are shown in Fig. 7.

With a high level signal for all three patterns the noise was around 5 nm in the horizontal plane and 10 nm in the vertical plane (due to the difference in the programmed sensitivities). Reduction of the signal level increased noise in both planes by a factor of 3. In the medium range, change of the beam position readback with fill pattern was about 80 nm for both planes.

For the Bergoz BPM receivers in similar conditions, drift was 50 nm in the horizontal plane and 170 nm in the vertical plane. For the APS FPGA-based receivers, drift was 240 nm in the horizontal plane and 680 nm in the vertical plane. So, the Bergoz and Libera Brilliance had comparable performance, while the APS FPGA-based module was a factor of 3 worse.

Table 1 shows results from data logged for 24 hours while top-up was running with the 24-bunch (154 ns spacing) fill pattern. A single button was connected to a 4-way splitter and then into the Bergoz inputs, and a second button was sent into a second splitter and routed to the Libera Brilliance. For both receivers the simulated electron beam was on center (i.e., after splitter signals were directly connected to inputs). The Libera data rate is 9.82 Hz with 2 Hz low-pass filtering. The Bergoz is one sample per minute, with a 20-second time constant filtering. In general, the variation in the vertical plane is larger due to the calibration factor difference for the unrotated button geometry (for Libera K_x/K_y=0.407).

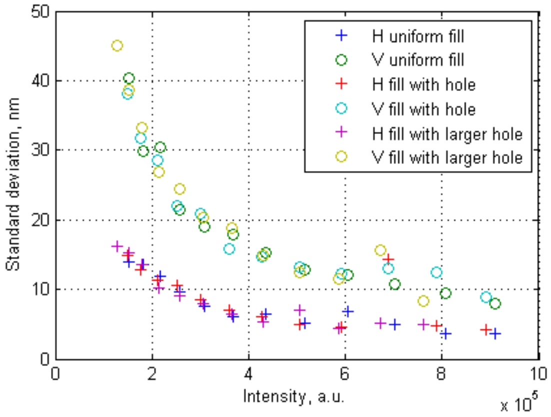

Figure 7: Libera Brilliance beam position measurement noise dependence on intensity for different fills.

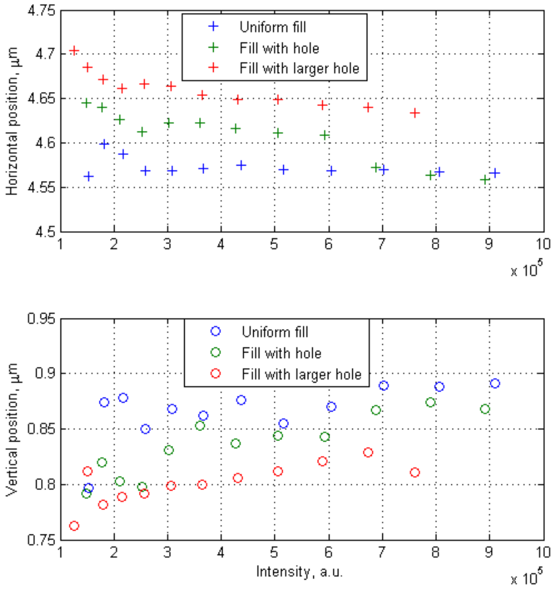

Figure 8: Beam position measured by Libera Brilliance vs. intensity for different fills.

The performance was also verified for beam with a simulated “offset” by the installation of a 4 dB attenuator into one of the four inputs for both receivers.

The drift performance of the Bergoz unit is somewhat better than the first data set; perhaps the rack temperature was more stable. The Libera Brilliance rms values seem to have increased by about 70% for the horizontal plane, and 33% for the vertical plane and now their ratio is more in line with the ratio of calibration factors. The summarized data are shown in Table 1. As mentioned before, the signal bandwidth was different for the two units. To make comparison more direct, the position signals from the Libera Brilliance were averaged using a 20 sec Hanning window: the corresponding noise is shown in parentheses.

Table 1. Summarized data for BPM receivers drifts during 24 hours of top-up operation.

	Bergoz		Libera Brilliance	
	X, nm	Y, nm	X, nm	Y, nm
Rms motion for centered beam	54.0	90.6	7.6 (4.1)	27.1 (22.1)
Rms motion for beam with offset	44.0	49.5	12.8 (6.1)	36.6 (25.2)

BPM CALIBRATION USING SLIT

The flux monitor installation was completed in December, 2008 and first measurements with beam were conducted on December 22. Local steering of the undulator beam across a slit provides a very clean profile measurement. By displacing the slit by a known calibrated amount and repeating the local bump scan of the particle beam, the measured profile is displaced. Determination of the amount of displacement by extrapolation from the source RF BPMs provides a cross-calibration relating measured electron beam position to slit position. For each of the data sets, a straight line fit was made. For the FPGA BPM receivers, the residuals to the fits of the data are ±1 micron out of a full-scale range of about half a mm, or ±0.2% nonlinearity. It was found that calibration factors for FPGA electronics were 16.6% off in the vertical plane and 22.9% in the horizontal plane.

For the Libera Brilliance, the loaded internal calibration factors were K_x = 2778000 nm and K_y = 6831000 nm. It was found that vertical calibration factors should be decreased by 3.9% for the vertical plane and by 2.1% for the horizontal plane.

CONCLUSION

There is excellent agreement between observations of beam motion with a Libera Brilliance and APS FPGA-based receiver, with the Libera Brilliance unit having less noise in the high-frequency part of spectrum. For fill pattern dependence, Libera Brilliance outperformed both the APS FPGA-based unit and the Bergoz BPM receiver.

Calibration factors for Libera Brilliance found from the numerical calculations are in good agreement with photon slit scans, while FPGA receivers are off by as much as 20%.

REFERENCES

[1] http://www.i-tech.si

[2] G. Decker et al., “Performance of FPGA-Based Data Acquisition for the APS Broad Band Beam Position Monitor System,” Proc. of BIW’08, pp.155-160.

[3] http://www.bergoz.com