Studies of Beam Position Monitor Stability[1]

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Abstract. We present the results from two studies of the time stability between the mechanical center of a beam position monitor (BPM) and its electrical/electronic center. In the first study, a group of 93 BPM processors was calibrated via a test pulse generator once per hour, in order to measure the contribution of the readout electronics to offset drifts. In the second study, a triplet of stripline BPMs in the Final Focus Test Beam, separated only by drift spaces, was read out every six minutes during one week of beam operation. In both cases offset stability was observed to be on the order of microns over time spans ranging from hours to days, although during the beam study much worse performance was also observed. Implications for the BPM system of future linear collider systems are discussed.

INTRODUCTION

One of the most ubiquitous and critical tuning elements of future linear colliders is the beam position monitor system. The proposed NLC design, for example, calls for a BPM to be installed in the bore of each quadrupole, with a total of 3000 such units. Each "Q" BPM is expected to have a single-pulse resolution of 1 micron, an *ab initio* installation accuracy (magnetic to electrical center) of 200 microns, and a 24-hour stability of the electrical center of 1 micron [1,2].

Previous experiments have demonstrated the required BPM resolution for bunch charges comparable to the NLC's [3], and other experiences indicate that the installation accuracy required can also be achieved [4]. We report on two experiments which seek to quantify the time stability of state-of-the-art SLAC stripline BPMs, in order to assess the achievability of the NLC specification for electrical center drift.

CALIBRATION PULSER EXPERIMENT

High-resolution single-pulse BPM processing electronics are used at SLAC [5]. The signals from a pair of striplines (T/B or L/R) are amplified in a two-channel

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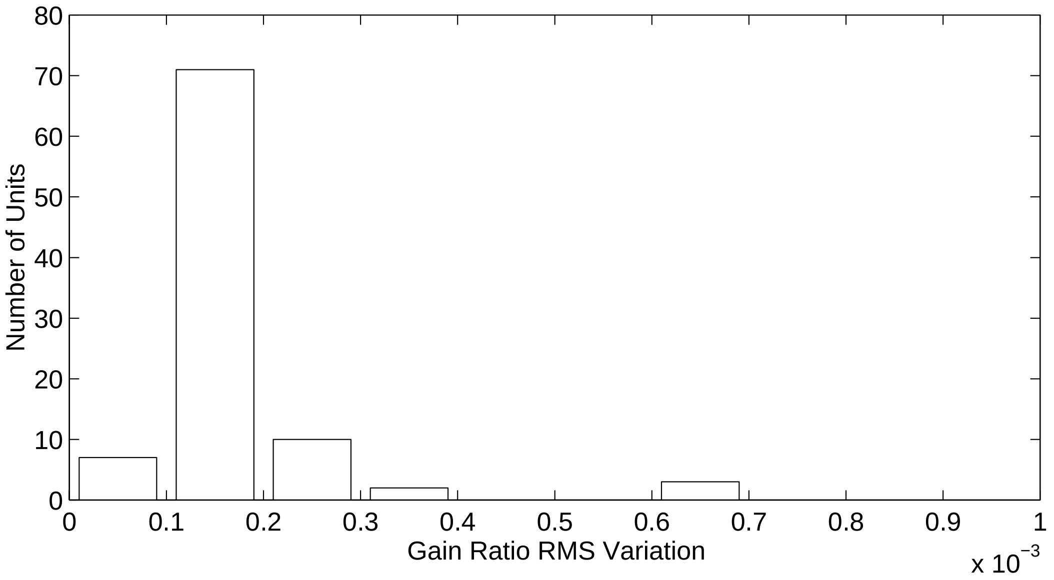

FIGURE 1. The rms gain ratio variations of 93 BPM processors when calibrated 30 times in a five-minute period.

amplifier, then digitized by a two-channel 16-bit track-and-hold (the "NiTnH"). The resulting digital words are then converted to position via the formula:

$$x, y = \frac{a}{2}\frac{(V_{R1} - P_1) - M(V_{R2} - P_2)}{(V_{R1} - P_1) + M(V_{R2} - P_2)}, \tag{1}$$

where a is the BPM radius, V_{R1} and V_{R2} are the two raw digital signals, P_1 and P_2 are the pedestals of channels 1 and 2, respectively, and M is the gain ratio between the two channels. The values of P_1, P_2, and M are determined via calibration. P_1 and P_2 are the digital words generated when the NiTnH is triggered in the absence of signal and M is measured by generating a test pulse and injecting it simultaneously into both channels of the head amplifier. By ramping the test pulse amplitude, the system gain as a function of input signal is measured for both channels and fit to a straight line for each channel. M is the ratio of the slopes.

Let us assume that after the calibration described above is performed, the pedestals and gain ratio change to $P_1 + S_1$, $P_2 + S_2$, and $M(1 + \epsilon)$, respectively, where $S_{1,2} \ll V_{R1,2} - P_{1,2}$ and $\epsilon \ll 1$. If a beam position is decoded from the raw signals using the old calibration, the error in the position determination to lowest order is:

$$dx, dy \approx \frac{a}{4}\left[\frac{MS_2 - S_1}{M(V_{R2} - P_2)} - \epsilon\right]. \tag{2}$$

The calibration described above was executed once per hour on a total of 93 BPM processors: 41 in the Next Linear Collider Test Accelerator (NLCTA) equipment area, and 52 in the Final Focus Test Beam (FFTB) instrumentation shacks.

The experiment lasted for one week, allowing long-term drifts to be assessed on a meaningfully large population of processors.

Resolution of the Method

In order to assess the resolution of the method, the calibration procedure was executed 30 times in rapid succession (less than five minutes was required). The rms drift of the gain ratio and the pedestals over five minutes gives an estimate of the resolution of the system.

Figure 1 shows the distribution of rms gain ratio variations measured in this procedure. Note that nearly all processor gain ratios were stable to within 2×10^{-4} in this procedure, which is taken to be the resolution of the system. Similarly, the pedestals were found to be stable to within one count, which is taken to be the resolution of the pedestal variations.

Results of the Calibration Pulser Experiment

Figure 2 shows the distribution in rms drifts of pedestals over one week. Typical units were stable at the level of two counts. Considering Equation 2, and assuming $M(V_{R2} - P_2) \approx 16,000$, a variation in pedestals of two counts would result in a shift in the measured BPM center of roughly 0.25 microns for a BPM with 6 mm radius.

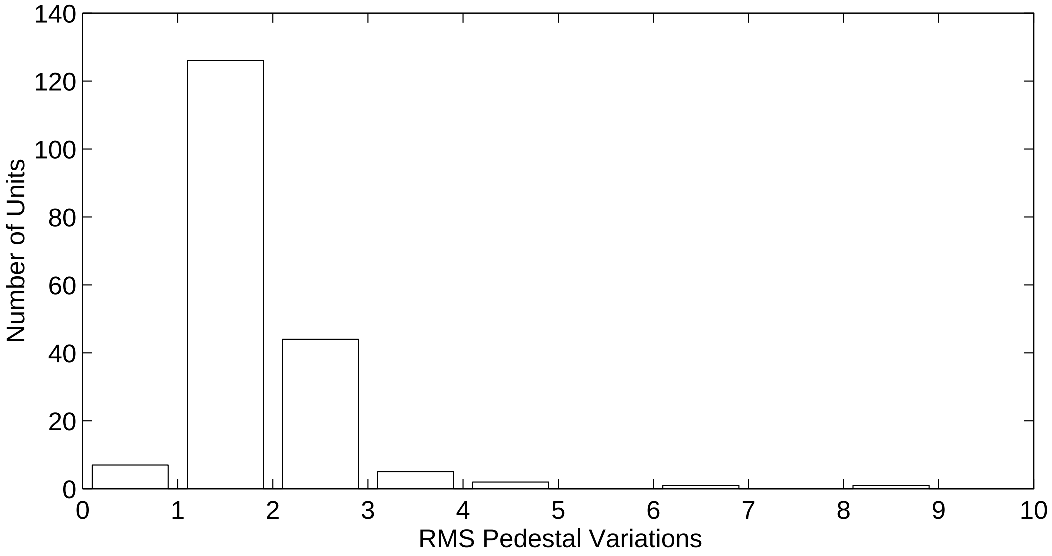

FIGURE 2. The rms pedestal variations of 93 BPM processors when calibrated once per hour over one week.

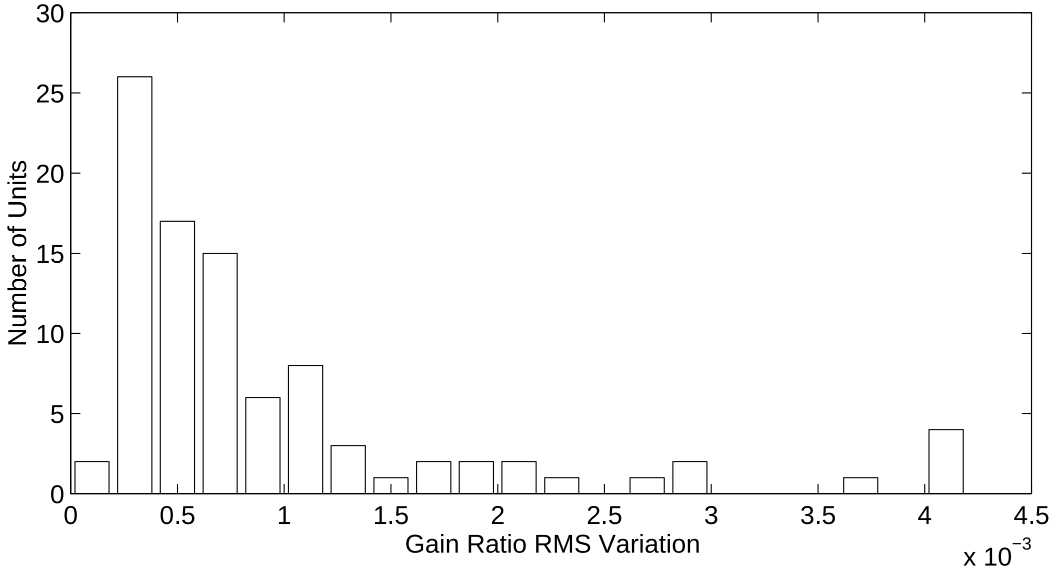

FIGURE 3. The rms gain ratio variations of 93 BPM processors when calibrated once per hour over one week.

Figure 3 shows the distribution in rms drifts of gain ratios over one week. Only 88 processors are represented; 5 of the 93 units displayed discontinuous “jumps” in gain ratio or other pathologies which indicated probable electronic failure of the processor, and were eliminated from the study. Most units were stable to within 1.2×10^{-3} of their mean values, equivalent to an rms offset drift of 1.8 microns for a BPM with 6 mm radius. Furthermore, the drifts were found to be highly correlated to the temperature of the crate containing the NiTnH (up to 85% correlation). When the temperature-correlated portion of the gain ratio drift is subtracted from each processor, the resulting distribution in rms gain ratios is as shown in Figure 4: 64 out of 88 units are stable to within 6×10^{-4} of their mean gain ratios, resulting in an offset drift of less than 1 micron. Note also that the tail of the distribution in Figure 4 is less extended than that in Figure 3. Typical values of the gain ratio/temperature slope were from from $-5.0 \times 10^{-4}/°\mathrm{C}$ to $+5.0 \times 10^{-4}/°\mathrm{C}$.

BEAM POSITION MONITOR TRIPLET EXPERIMENT

The Final Focus Test Beam [6] includes a diagnostic region in which three consecutive BPMs are separated by drift spaces. In this region, the betatron functions are relatively small, and therefore potential issues of beam scraping near the striplines are minimized. Let us consider a set of such BPMs in which the distance from the first to the second and from the first to the third are L_2 and L_3, respectively, and in which the offsets of the BPMs are d_1, d_2, d_3. If the measured BPM readings are given by x_1, x_2, x_3, then the relationship between the measured positions and the

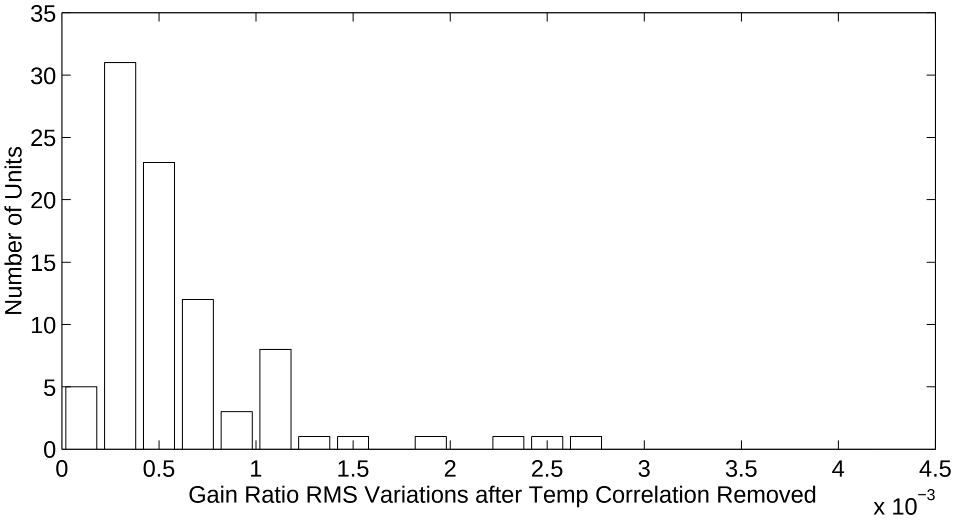

FIGURE 4. The rms gain ratio variations of 93 BPM processors after temperature-correlated drifts are subtracted off.

BPM offsets is given by:

$$x_3 - \frac{L_3}{L_2} x_2 + \left(\frac{L_3}{L_2} - 1 \right) x_1 = d_3 - \frac{L_3}{L_2} d_2 + \left(\frac{L_3}{L_2} - 1 \right) d_1. \tag{3}$$

If we define $X \equiv x_3 - \frac{L_3}{L_2} x_2 + \left(\frac{L_3}{L_2} - 1 \right) x_1$, and we assume that the BPM offsets in the three BPMs are varying incoherently with time with an RMS variation of σ_{BPM}, then we can expect that:

$$\sigma_{BPM} = \sigma_X \left[1 + (L_3/L_2)^2 + (L_3/L_2 - 1)^2 \right]^{-1/2}. \tag{4}$$

During the FFTB run of May 1997, the quantity X was read out and stored once every six minutes, for horizontal and vertical planes. For each stored value of X, four pulses were averaged; consequently the expected contribution to σ_{BPM} from BPM signal-to-noise limitation is 0.5 microns. While the calibration pulser experiment concentrated on the readout electronics, this experiment measures the contributions of all parts of the BPM system from the stripline to the main control computer.

Results of the BPM Triplet Experiment

Figure 5 shows the value of $Z \equiv X \left[1 + (L_3/L_2)^2 + (L_3/L_2 - 1)^2 \right]^{-1/2}$ in the horizontal plane as a function of time. Several “fliers” have been removed from the dataset, which are believed to result from massively mis-steered pulses from the linac producing copious spray in the FFTB apertures. The rms incoherent offset drift implied by Figure 5 is 17 microns. Note also that, due to data acquisition errors, the data in the first few days of the run was saved at a much lower frequency than the 10 measurements per hour desired.

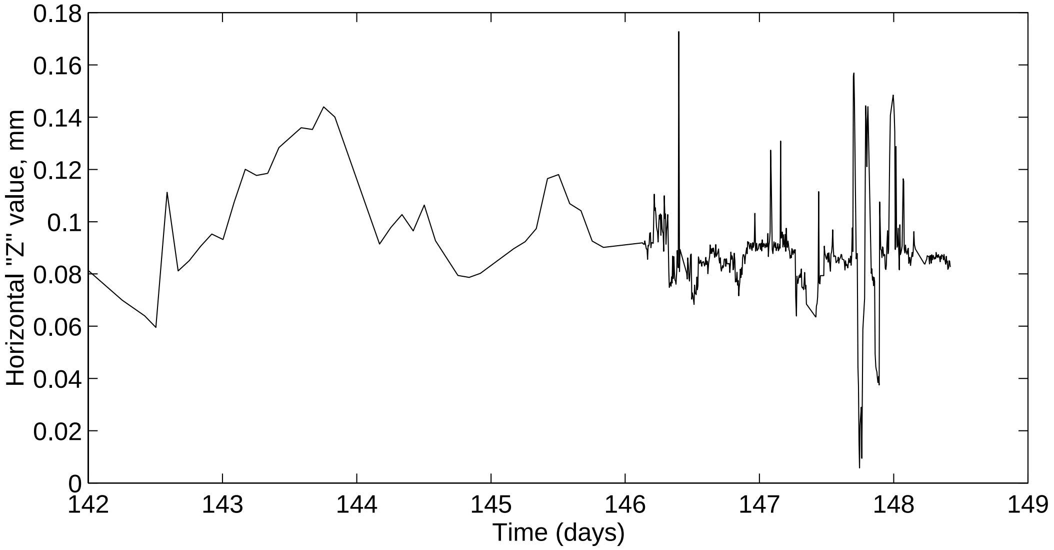

FIGURE 5. The value of Z for the horizontal plane during the May 1997 FFTB run. The implied rms offset drift per BPM is 17 microns.

Figure 6 shows the value of Z in the vertical plane, again with "fliers" suppressed. Here the implied rms drift is 4.2 microns, with several periods of extremely stable conditions during which drifts as small as 1.5 microns were observed for up to half a day. It is believed that the smaller drifts in the vertical plane result from the smaller vertical normalized emittance during the run (3.6 versus 36 mm/mrad), and also from the fact that the horizontal plane is the bend plane of the FFTB and thus synchrotron radiation and low-energy tails will primarily affect the horizontal measurements.

It is worth noting that the NLC beam position monitor has an aperture roughly half that of the FFTB unit (6 mm versus 11.5 mm in radius). If the drifts mentioned above are due primarily to effects in the cables and the feedthroughs, then the offset drifts for the NLC could be as small as 2 microns for a similar quality installation. Furthermore, there is no way to determine what fraction of the 4.2 microns measured in the vertical plane can be eliminated with further improvements in beam quality.

CONCLUSIONS

In both the experiment with the calibration pulser and the experiment with the BPM triplet, we see that BPM offset stability on the order of a few microns over

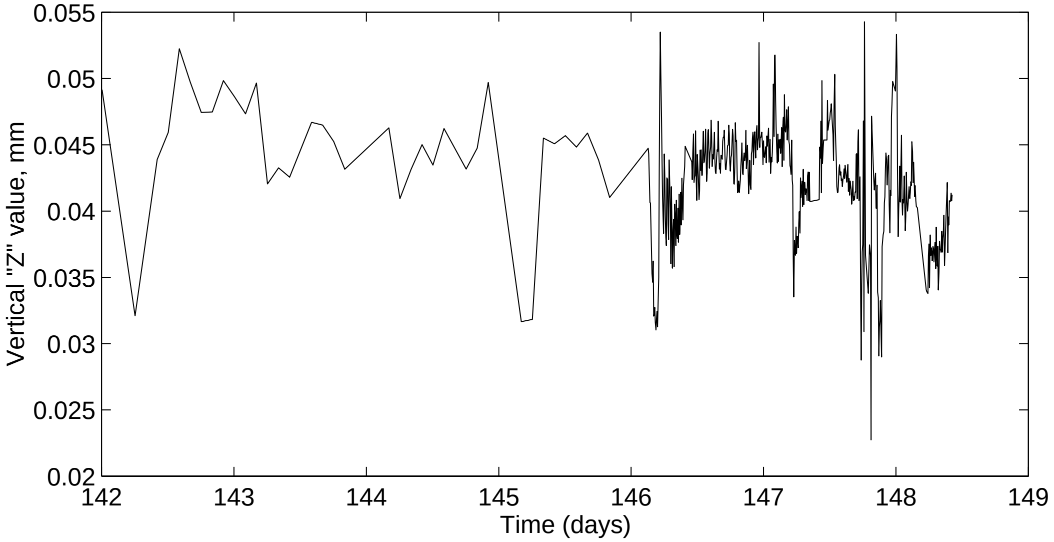

FIGURE 6. Value of Z for vertical plane during May 1997 FFTB run. The rms offset drift per BPM is 4.2 microns.

time periods up to one week can be reasonably achieved with present-day technology at future linear colliders. Higher beam quality may yield some improvements and a system which automatically calibrates the BPM processors continually (rather than the present scheme of calibration-on-demand) seems warranted. The value of temperature stability is also evident.

While the present systems described are not grossly inadequate to meet the NLC specifications, it remains to be demonstrated that reasonable improvements in temperature control of cables, electrical isolation of processors, etc., can reduce the slow offset drifts to the level required for such a future collider.

Future experiments may provide further insight into the various sources of BPM offset drift. These include running both the triplet and the calibration pulser experiment simultaneously and adding bunch charge to the set of variables read out by the triplet data acquisition system in order to measure and suppress any charge-position correlations in the BPM system.

ACKNOWLEDGMENTS

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REFERENCES

1. NLC Design Group, *Next Linear Collider Zeroth-Order Design Report*, Stanford: SLAC, p. 440 (1996).
2. Smith, S., unpublished.
3. Tenenbaum, P., *Expanded Studies of Linear Collider Final Focus Systems at the Final Focus Test Beam*, Stanford: SLAC, 1995, p. 108.
4. Williams, S., unpublished.
5. Hayano, H., et al., *Nucl. Inst. Methods* **A320**, p. 47 (1992).
6. Oide, K., *Proceedings of the 1989 IEEE Particle Accelerator Conference*, Piscataway: IEEE Press, p. 1319 (1989).