Results from Orbit and Optics Improvement by Evaluating the Nonlinear Beam Position Monitor Response in CESR*

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Abstract

In the Cornell Electron Storage Ring, pretzel orbits (with large horizontal oscillations) are used to keep electron and positron beams out of collision except at the interaction point. Because the previous system of evaluating signals from beam position monitors (BPMs) was accurate only for bunches near the center of the beam pipe, orbit and phase measurements were not possible under colliding beam conditions. We present results from a new algorithm that greatly improves the accuracy of both measurements.

BACKGROUND

CESR measures beam position and betatron phase with approximately one hundred beam position monitors (BPMs) distributed around the storage ring. At many accelerators, the button signals' nonlinear dependence on the beam position is linearized for simplicity. Before the improvements described here, this approach was also used in CESR.

Our efforts to improve the beam position measurements by including the nonlinear BPM response is motivated by CESR's pretzel orbits, where electron and positron beams avoid parasitic collisions by following separate paths with large displacements from the central axis of the beam pipe. The linearized methods are not reliable for such large amplitudes, and have made accurate beam position and betatron phase measurements at CESR impossible under colliding beam conditions.

Figure 1 shows a regular grid of horizontal and vertical beam displacements. The distorted set of points illustrates the positions which a CESR arc BPM would determine if it was evaluated after linearizing the button's dependence on the beam position. Our nonlinear evaluation of BPM signals is an effort to eliminate the displayed distortion.

Our new system, described in [1] eliminates this limitation. The results that follow demonstrate several examples of the improvement.

VERIFICATION OF THE BPM MODEL

Testing the new system presents a challenge in that we can only produce controlled large amplitude orbits with the electrostatic separators which produce the pretzel orbits. Since the separators are calibrated from BPM measurements, they do not provide an independent check on our ability to measure large amplitudes accurately. Our strategy, therefore, must be to use other measurements to check the accuracy at small amplitudes, and then con£rm

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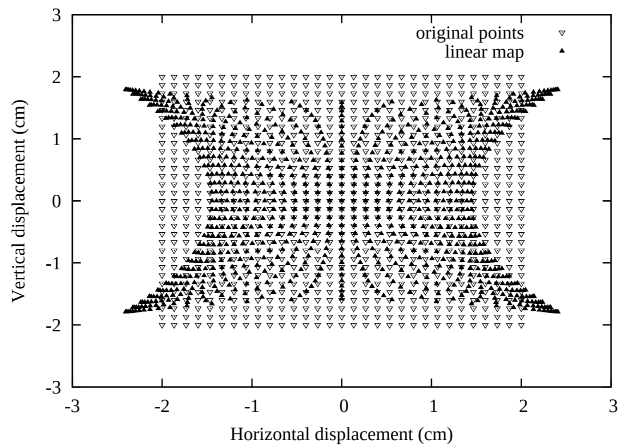

Figure 1: Distortion in CESR arc BPMs with approximately elliptical cross-section when linearization is used.

the expected linear relation between the separator strength and the beam position at large amplitudes.

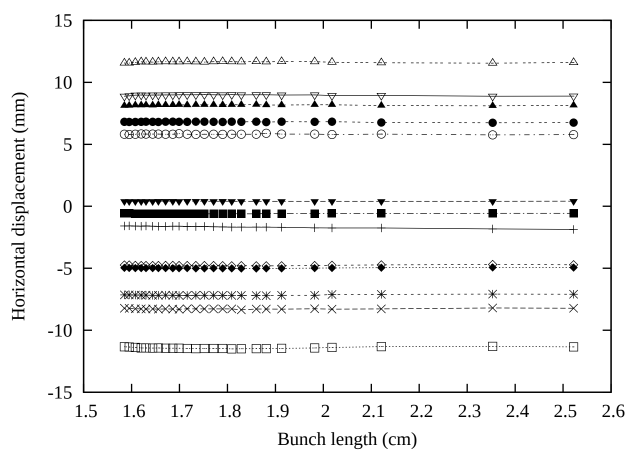

Figure 2: Beam position at various detectors showing little or no bunch length dependence.

For our new algorithm, the button signals nonlinear dependence on the beam position has been computed under the simplifying assumption of very long beams. To verify that assumption, we have looked experimentally for a bunch length dependence in large amplitude orbits. With the pretzel at its nominal value of about 1.5 cm closed orbit deviation, the bunch length was calculated from the measured synchrotron tune, which we adjust by changing the RF accelerating voltage. As Fig. 2 illustrates, the beam position shows little or no dependence over the range of bunch lengths we expect in CESR.

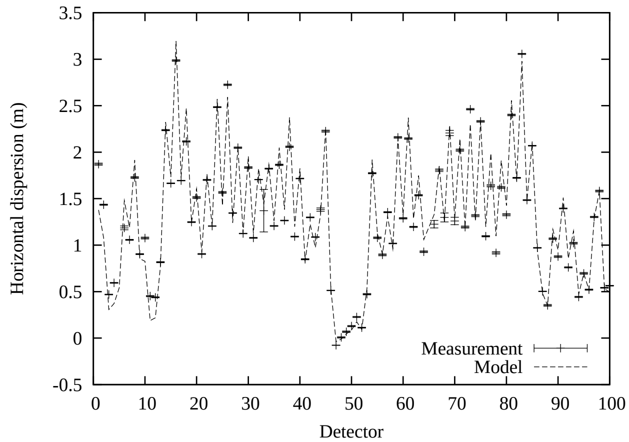

Figure 3: Measured and calculated dispersion.

Changing the RF frequency in CESR changes the beam energy, and in dispersive regions, changes the beam position by up to a few millimeters. Measuring the beam position at many different energies allows us to measure the dispersion, which we compare to the theoretical value from the lattice in Fig. 3. This agreement veri£es the small amplitude, or linear part of our nonlinear models.

IMPROVED MEASUREMENTS

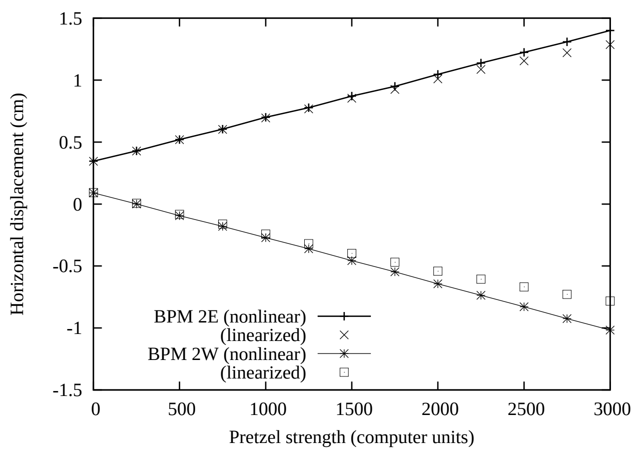

Figure 4: Beam position at two detectors calculated with the nonlinear and linearized methods.

To observe the large amplitude accuracy of the new system, we rely on the electrostatic separators to change the orbit amplitude linearly. By increasing the horizontal separator strength, we observe in Fig. 4 that the orbit calculated with the nonlinear method does show the correct behavior, while the orbit calculated with the linearized formula shows the expected deviation.

To demonstrate improvement in two dimensions, the voltages on individual horizontal and vertical separators were scanned over a regular grid. The measured beam positions should also lie on a regular grid, which is shown in

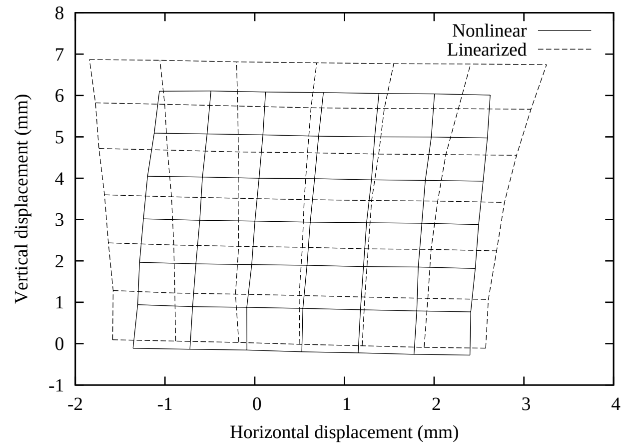

Figure 5: Separator scan. Orbits at detector 9W calculated using linearized (dashed) and nonlinear (solid) methods.

Fig. 5. Some sheering is evident in the plot, which may be due to coupling of the vertical and horizontal motion between the separator and the BPM, or to a rotation of the BPM. The pincushion effect is notably reduced with the new calculation.

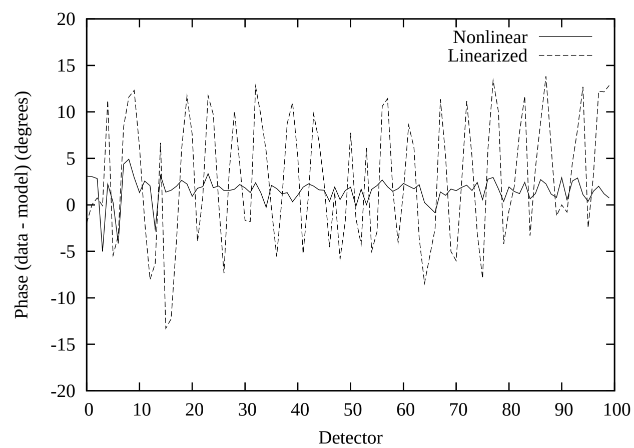

Figure 6: Difference in horizontal betatron phase advance between data and model with large closed orbit distortion after using a phase correction algorithm based on the linear (dashed) and nonlinear (solid) BPM evaluation.

We use betatron phase measurements to correct the difference between the physical optics and the values in our model lattice. Without the nonlinear correction, large closed orbit distortions hindered this process since the data we sought to £t did not correspond to the actual phase. Figure 6 shows the drastically improved agreement we can achieve between the model phase and the data when the new BPM calibration is used.

BPM CALIBRATION

The response of a particular BPM may differ from that of the computational model (linear or nonlinear) for a variety of reasons. The leading candidate for this effect is the variation in insertion depth of the individual buttons (i.e., the distance from the button surface to the surface of its cylindrical housing). This manifests itself as different gains for the signals from different buttons.

Following the method of [2, 3], we determine the gain for each button from the capacitive coupling between each pair of buttons. If the ideal coupling between two buttons is given by U_{ij}, then the measured coupling will be $\tilde{U}_{ij} = b_i b_j U_{ij}$ where b_i, b_j are the effective gains of the input and output button, respectively. Symmetric pairs of buttons have equal ideal coupling, so $U_{12} = U_{34}$, $U_{13} = U_{24}$, and $U_{14} = U_{23}$.

Using this symmetry for the six measurements $\tilde{U}_{ij}$ $(i = 1, \ldots, 3,\ j = i+1, \ldots, 4)$ we can calculate the four b_i up to an multiplicative factor. These gain coef£cients are used to correct the button signals before calculating the beam position.

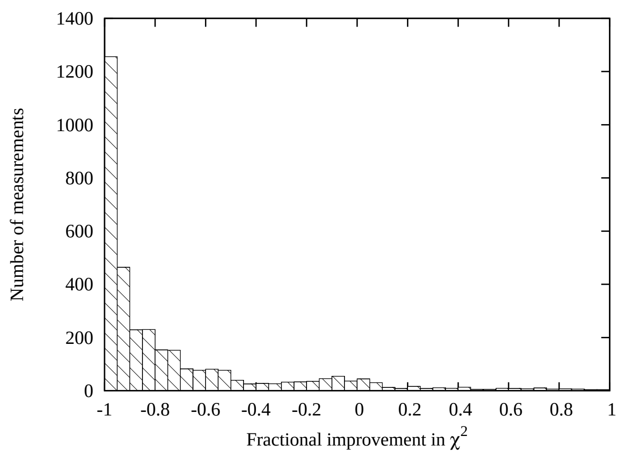

Figure 7: Fractional improvement in the χ^2 of the beam position £t due to the calibration coef£cients ($-1 = 100\%$ improvement).

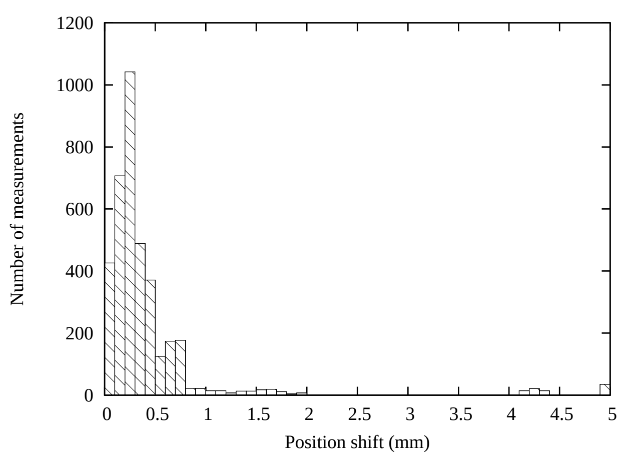

Figure 8: Correction in the calculated position due to the calibration coef£cients.

With data drawn from approximately 3700 individual beam position measurements, Fig. 7 shows that when these coef£cients are employed, the χ^2 of the £t between the measured signals and the modeled signals is signi£cantly reduced. The resulting correction to the calculated position is shown in Fig. 8 to be approximately 0.5 mm.

CONCLUSION

Two-dimensional, electrostatic models of BPM pickup response have been used with great success at CESR to measure beam position and betatron phase advance for large closed orbit distortions. We have tested our new system in a variety of ways, each of which demonstrates signi£cant improvement over our historical, linearized approach.

In addition, calibration of our BPMs has reduced measurement errors due to button misalignments.

ACKNOWLEDGMENTS

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REFERENCES

[1] Results from Orbit and Optics Improvement by Evaluating the Nonlinear Beam Position Monitor Response in CESR *Proc. EPAC04*, Lucerne/CH (2004)

[2] G.L. Lambertson. Calibration of position electrodes using external measurements. *LSAP Note-5* (1987)

[3] J. Keil. *Messung, Korrektur und Analyse der Gleichgewichtsbahn an der Elektronen-Stretcher-Anlage ELSA*. PhD thesis, Universität Bonn (2000)