EVALUATION AND CORRECTION OF THE NON-LINEAR DISTORTION OF CEBAF BEAM POSITION MONITORS*

M. Spata[#], T Allison, K. Cole, J. Musson, J. Yan

Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA.

Abstract

The beam position monitors at the Continuous Electron Beam Accelerator Facility (CEBAF) have four antenna style pickups that are used to measure the location of the beam. There is a strong nonlinear response when the beam is far from the electrical center of the device. In order to conduct beam experiments at large orbit excitation we need to correct for the nonlinearity. The correction algorithm is presented and compared to measurements from our stretched wire BPM test stand.

INTRODUCTION

Jefferson Lab's CEBAF accelerator is a 1497 MHz CW 6 GeV polarized electron machine that has been providing high quality beam to users since 1995. The machine is presently being upgraded to 12 GeV with the installation of 10 new 100 MeV cryomodules and the addition of a fourth user facility. The accelerator beamlines are instrumented with ~600 ¼ wave antenna-style Beam Position Monitors (Fig. 1).
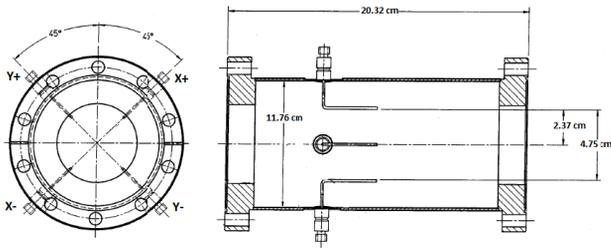

Figure 1: The M20 ¼ wave antenna-style BPM.

The antennas are rotated 45º to the lab frame to shield the electrodes from synchrotron radiation in the racetrack-shaped beamlines. Throughout the operation of CEBAF a linear relationship has been assumed for these devices with the X and Y positions calculated in the rotated frame according to

$$X_{rot} = k_x \frac{\left(X^+ - X_{off}^+\right) - \alpha_x \left(X^- - X_{off}^-\right)}{\left(X^+ - X_{off}^+\right) + \alpha_x \left(X^- - X_{off}^-\right)} \quad (1)$$

$$Y_{rot} = k_y \frac{\left(Y^+ - Y_{off}^+\right) - \alpha_y \left(Y^- - Y_{off}^-\right)}{\left(Y^+ - Y_{off}^+\right) + \alpha_y \left(Y^- - Y_{off}^-\right)} \quad (2)$$

where k_x and k_y are geometric scale factors that depend on the geometry of the BPM, α_x and α_y are calibration constants to account for any difference in gain between a

pair of antennas, $X^+ X^- Y^+ Y^-$ refer to the raw signal strength from each antenna and $X_{off}^+ X_{off}^- Y_{off}^+ Y_{off}^-$ are antenna signals with the beam and calibration signals off. The position of the beam in the lab frame is then calculated by a 45º rotation

$$X = \frac{1}{\sqrt{2}}\left(X_{rot} - Y_{rot}\right) \quad (3)$$

$$Y = \frac{1}{\sqrt{2}}\left(X_{rot} + Y_{rot}\right). \quad (4)$$

BPM NONLINEARITY

The difference/sum method of determining beam position (see Eq. 1 and 2) is only accurate when the beam displacement from the center of the device is small compared to the radial position of the antennae. The extent of the nonlinearity has been measured (Fig. 2) on a BPM test stand and also simulated using Poisson [1].
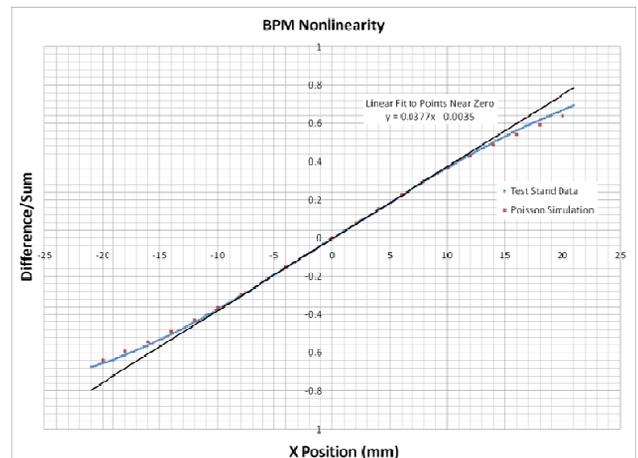

Figure 2: Plot of the nonlinearity of a BPM in the rotated X mid-plane. Linearity holds to about 8 mm from center.

BPM Test Stand

A surface wave transmission system has been developed [2] along with a precision X-Y stage to perform in-air tests on CEBAF BPMs (Fig. 3).

It was demonstrated by Sommerfeld that certain dielectric boundary conditions allow for the existence of a travelling wave on the surface of a coaxial cylinder with finite conductivity [3]. Georg Goubau first proposed a method for launching and capturing these waves as a substitute for low-loss coaxial microwave transmission systems [4]. The Goubau Line (G-Line) system consists of a single thin conductor coated in a dielectric material. The wire is connected to conical launchers that excite the proper fields for SW formation and provide impedance

06 Beam Instrumentation and Feedback

T03 Beam Diagnostics and Instrumentation

the cones at either end of the test stand. One end is terminated to a 50 Ω load while the other end is connected to an RF source.

The stepper stand is capable of moving the BPM in the horizontal or vertical plane in 10 micron steps and across the full aperture of the BPM. The Test Stand was used to take data on an M20 style BPM across the rotated X mid-plane with 200 micron step size to ±21 mm (Fig. 2). The raw wire data was processed using the difference/sum method and shows that the system behaves linearly to about ±8 mm.

Poisson Model

A two-dimensional electrostatic model was developed using Poisson [5]. A potential of 1 Volt was placed on a single electrode with the outside of the can grounded. The potential map was calculated across the interior of the BPM (Fig. 5). Using Green's reciprocity theorem [6] we can infer that the simulated voltage at any point within the BPM is simply the voltage that would be induced on the antenna. Potential maps for the other three antennae are generated through rotations using the inherent symmetry of the BPM.

Figure 5: Two-dimensional potential map of the BPM.

A series of points across the X mid-plane were simulated using the potential maps and the difference/sum method. The results are shown in Fig. 2 and compare well with the Stretched Wire Test Stand data. Poisson also predicts that the BPM is linear to about ±8 mm. At large amplitude the nonlinearity of the system is also observed.

CORRECTION OF BPM NONLINEARITY

The Poisson model was applied across the full aperture of the BPM to simulate the nonlinearity within a square grid of points (Fig. 6) between the antennae. For each point within the grid a spline interpolation was performed to calculate the potential on each wire based on the Poisson model. The difference/sum method was then applied using the geometrical constants from the Stretched Wire Test Stand data to create a 2-dimensional map of what would be measured with the linear method.

Figure 3: BPM test stand showing X-Y stage at right with a mounted BPM. The 160 micron wire stretched between the RF cones at both ends of the system simulates a beam.

matching from the 50 Ω transmission line to the nominal 200 Ω of the single conductor (Fig. 4).

The electron beam is simulated with a #34 AWG enamelled magnet wire which has a diameter of 160 microns and is comparable to typical beam sizes in CEBAF. The wire is soldered to the center conductor of
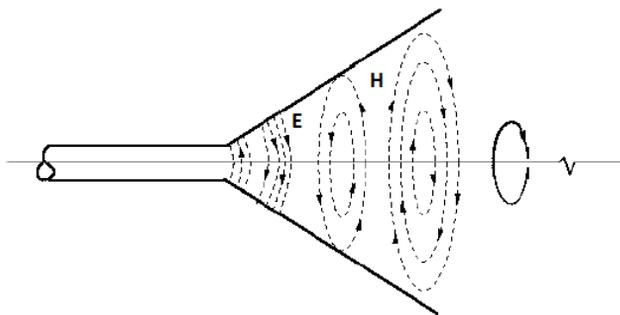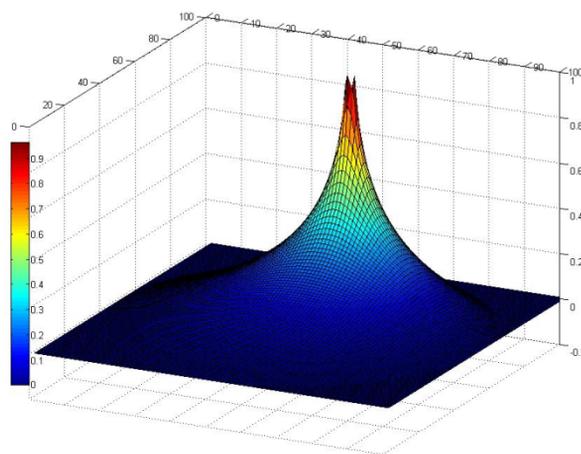
Figure 4: Conical coaxial launcher for generating a surface travelling wave to simulate an electron beam.
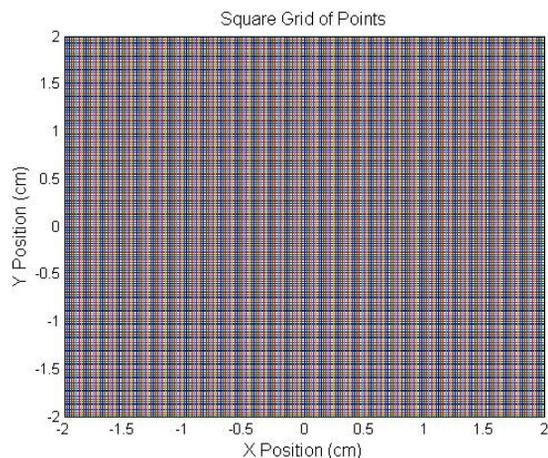
Figure 6: A 2x2 cm square grid of points for seeding the Poisson simulation.

The simulations were done in the rotated frame which places the antennae at the top, bottom, left and right of the grid. Significant pin cushioning of the linear map is observed (Fig. 7).
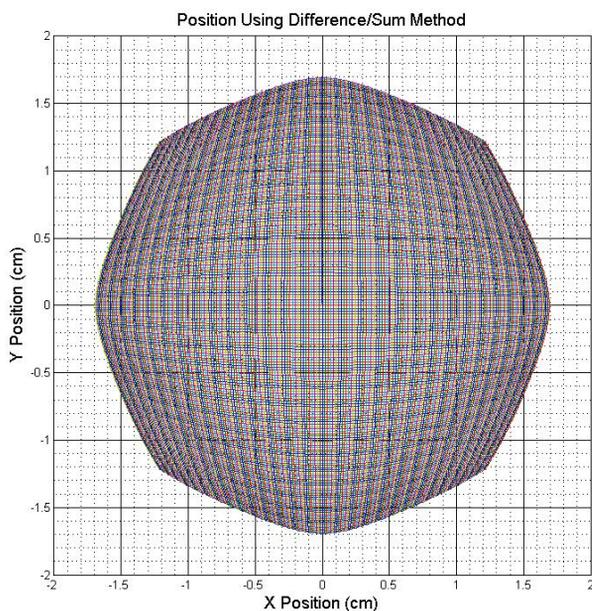

Figure 7: Beam position of square grid of points after the difference/sum method is used to calculate the position.

A correction of the distortion is made by generating a pair of two-dimensional polynomials. The square grid of points and the values from the linear method are used to calculate the coefficients in a least squares sense and then applied to the distorted position map. The corrected grid of points is shown in Fig. 8. The precision of the correction is gauged by plotting the absolute value of the difference between the square grid of points and the corrected grid of points (Fig. 9). The method recovers the original grid to better than 100 microns across the entire grid of points.
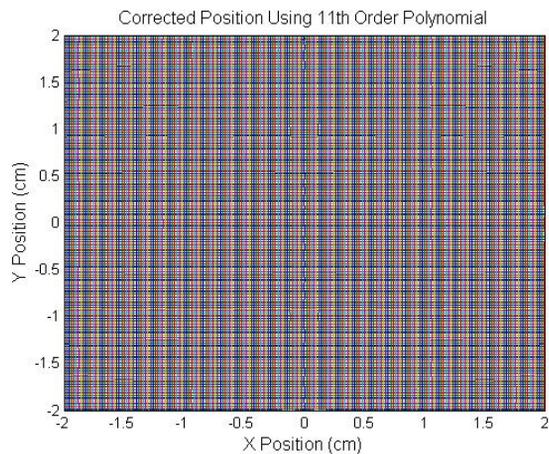
Figure 8: Corrected grid of points after applying a two-dimensional 11th order polynomial to the linear data.
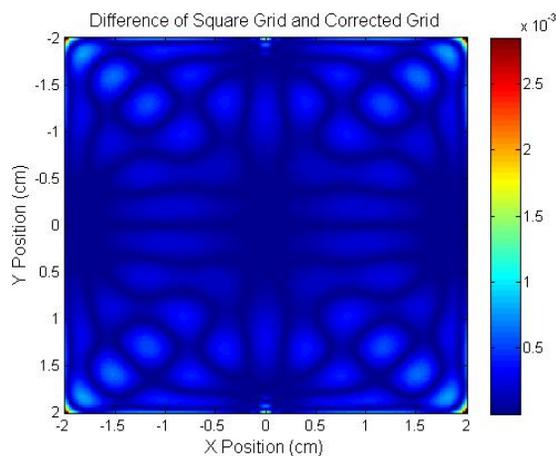

Figure 9: Colour map showing the precision of the polynomial correction for the X-plane. The Y-plane has similar results.

CONCLUSION

The nonlinearity of ¼ wave antenna-style BPMs has been modelled and measured with good agreement between simulation and test stand data. An algorithm was applied to correct for the instrumental nonlinearity with better than 100 micron precision over a 2x2 cm grid of points.

REFERENCES

[1] K. Halbach and R. F. Holsinger, PAC 7 (1976) 213-222.
[2] J. Musson, K. Cole and S. Rubin, PAC09 (2005) 4060-4062.
[3] A. Sommerfeld, Ann. Phys. u. Chemie (Neue Folge) 67-1, 233, December, 1899.
[4] G. Goubau, Proc. *IRE* 39 (1951), 619–624
[5] P. Piot, "Evaluation and correction of nonlinear effects in FNPL beam position monitors", Internal FNAL note, 2005.
[6] R. Helms and G. Hoffstaetter, PRSTAB 8 062802, 2005.