# Characterization of Beam Position Monitors for Measurement of Second Moment

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A dual-axis beam position monitor (BPM) consists of four electrodes placed at 90$^o$ intervals around the probe aperture. The response signals of these lobes can be expressed as a sum of moments. The first order moment gives the centroid of the beam. The second order moment contains information about the rms size of the beam. It has been shown previously that the second order moment can be used to determine beam emittance [1]. To make this measurement, we must characterize the BPM appropriately. Our approach to this problem is to use a pulsed wire test fixture. By using the principle of superposition, we can build up a diffuse beam by taking the signals from different wire positions and summing them. This is done two ways: first by physically moving a wire about the aperture and building individual distributions, and, second, by taking a two dimensional grid of wire positions versus signal and using a computer to interpolate between the grid points to get arbitrary wire positions and, therefore, distributions. We present the current results of this effort.

## I. INTRODUCTION

Here at Los Alamos, we have two photoinjector driven electron linacs. The first is an 8 MeV machine originally built to drive the APEX free electron laser. It has since been moved from its original location and is currently being employed in experiments investigating sub-picosecond bunching of an electron beam. The second is the 20 MeV accelerator for the Advanced Free Electron Laser experiment and has been operating since the summer of 1992.

Photoinjector driven electron accelerators are at the forefront of electron beam technology. They produce beams of unparalleled quality. However, measuring second moment properties of these beams, such as the rms emittance, is very difficult [2]. This is due to their generally non-Gaussian beam distributions. In order to measure the rms emittance, we need an approach that does not require prior knowledge of the beam distribution. Beam position monitors (BPMs) offer such a technique [3].

For us to be able to use BPMs for emittance measurements, we need a method of calibration for measuring the second moment of the BPM signal. Our approach is presented here.

## II. CALIBRATION THEORY

The BPMs that we will be using for this measurement were originally built for the AFEL beamline [4]. These are capacitive, or button-style, probes that differentiate the beam bunch charge distribution that is induced on the probe electrodes.

### *A. BPM Signal*

For the square electrodes, or lobes, of our BPMs, the signal induced by a relativistic beam on the lobe at angular position $\phi$ is proportional to

$$\begin{aligned}\{ &2\alpha + 4\frac{\sin\alpha}{a}(\bar{x}\cos\phi + \bar{y}\sin\phi) \\ &+ 2\frac{\sin 2\alpha}{a^2}\{ [ (\sigma_x^2 - \sigma_y^2) + (\bar{x}^2 - \bar{y}^2) ] \cos 2\phi \\ &+ 2\langle xy\rangle \sin 2\phi \} + O(\frac{1}{a^3}) \}\end{aligned} \tag{1}$$

The radius of the BPM apeture is a, the angle subtended by the BPM lobe is $\alpha$, $\bar{x}$ and $\bar{y}$ give the centroid position of the beam and the angled brackets indicate an rms average over the beam distribution. The term $\sigma_x^2 - \sigma_y^2$ is what we are trying to measure. $\sigma_x^2$ is equal to the rms average $\langle x^2\rangle$ in the coordinate system centered on the beam distribution, and similarly for $\sigma_y^2$.

### *B. Calibration equation*

We are interested in extracting the quantity

$$(\sigma_x^2 - \sigma_y^2) + (\bar{x}^2 - \bar{y}^2)$$

from our BPM signals. For a perfect BPM, with four identical lobes at 0, 90, 180 and 270 degrees around the apeture, this term is given by

$$(\sigma_x^2 - \sigma_y^2) + (\bar{x}^2 - \bar{y}^2) = k\frac{S_R + S_L - S_T - S_B}{S_R + S_L + S_T + S_B} \tag{2}$$

where $S_R$, $S_L$, $S_T$ and $S_B$ are the signals from the right, left, top and bottom BPM lobes respectively (see Fig. 1) and k is a constant to be determined. However, the lobes of a real BPM will not be identical in general. Each will have a unique subtended angle, $\alpha$, and a unique apeture radius a. Therefore, equation (2) must be modified to

$$\begin{aligned}&(\sigma_x^2 - \sigma_y^2) + (\bar{x}^2 - \bar{y}^2) \\ &\qquad = \frac{c_1 + c_2 S + c_3\bar{x}(1 - S) + c_4\bar{y}(1 + S)}{1 + c_5 S}\end{aligned} \tag{3}$$

where S is defined by

$$S \equiv \frac{S_R + S_L - S_T - S_B}{S_R + S_L + S_T + S_B} \tag{4}$$

and the $c_i$s are constants that need to be determined. This is the goal of our calibration procedure.

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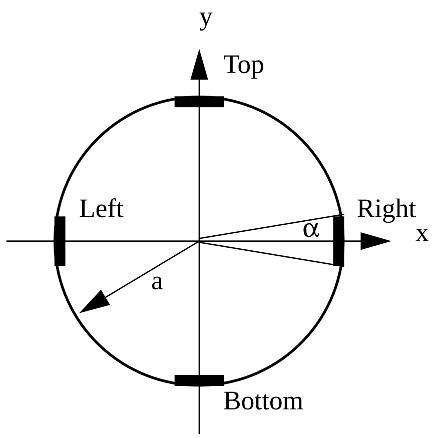
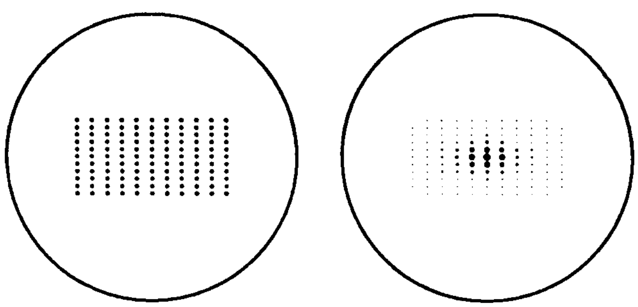



Figure 1: Schematic of BPM.

## III. SIMULATING A DIFFUSE BEAM

In order to calibrate a BPM to measure the second moment, we need the ability to input a known beam and look at the lobe response. To do this, we use the pulsed wire setup that calibrates the BPM for centroid measurements [5]. This apparatus uses a thin wire running through the BPM apeture to simulate a $\beta = 1$ beam. A signal is generated on the wire and the responses of the BPM lobes are measured vs. wire location.



a b

Figure 2: a) Rectangular grid of 121 points within BPM apeture. b) Same grid as in a, but with Gaussian distribution overlaid. The size of the dot indicates the weighting factor.

### *A. Principle of superposition*

A thin wire simulates a beam with zero width. To simulate a diffuse beam we use the principle of superposition. We define a rectangular grid such as that in Fig. 2a. Each grid point represents a wire position for which we can determine the lobe responses. On top of this grid we can superimpose a distribution function, such as a Gaussian (Fig. 2b). By summing the lobe signals, multiplied by their appropriate weighting factor as determined by the distribution function, we can get the response of each of the lobes for the total beam. The total beam is the beam that is created by the “beamlets” of Fig. 2b.

### *B. Method*

To simulate a diffuse beam, we need to determine the lobe response for a given grid point. The obvious way to do this is to move the wire to the desired position and measure its response with the test fixture. However, the signal to noise ratio for a given beam gets better the more wires it contains. With our test stand, we have found that it is generally necessary to use at least 100 wires per simulated beam. As a result, complete calibration of a BPM can take several weeks.

Another way to determine lobe response is to create a map of the BPM such as that in Fig. 3. Using this map, we can interpolate the response for any wire position. This allows us to duplicate the calibration procedure described above with a computer. Instead of weeks, the computer does a complete calibration in a day. Part of our goal is to show that the two methods are effectively the same.

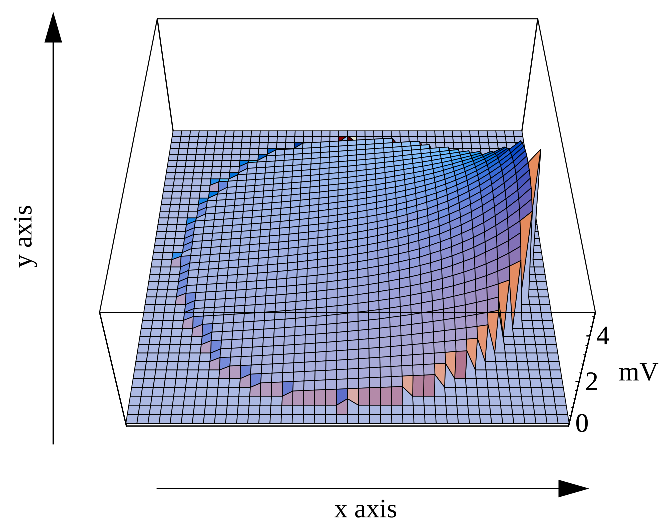



Figure 3: Typical two dimensional map of a BPM lobe response. Center is at x = 0, y = 0 and grid squares are 0.5 mm on a side. The z axis is the lobe signal for a given wire position in mV.

## IV. EXPERIMENTAL RESULTS

To carry out the actual BPM calibration, a number of simulated beams were generated with different $\sigma_x$s and $\sigma_y$s and known x and y centroid positions.

### *A. Beam centroid equal to zero*

According to the theory, we have five constants to determine to fully characterize the BPM for second moment measurements. The first step is to generate a data set with $\bar{x}$ and $\bar{y}$ equal to zero. Then, we fit the data to the equation

$$\sigma_x^2 - \sigma_y^2 = \frac{c_1 + c_2 S}{1 + c_5 S} \quad (5)$$

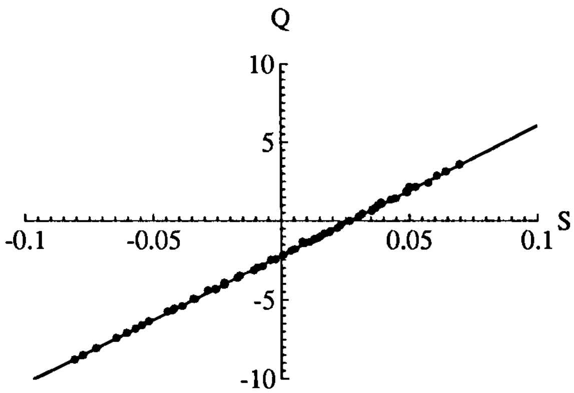
where S is the same as defined in (4). Fig. 4 shows the results for data generated using the test stand and for data generated using the computer model.

The fit to the two sets of data give the following results:

$c_1 = -2.2$, $c_2 = 82.2$ and $c_5 = -0.19$ (test stand)

$c_1 = -2.2$, $c_2 = 81.9$ and $c_5 = -0.11$ (computer).

These results, for all practical purposes, are the same. (The $c_5$ term is so small that it could be dropped.)

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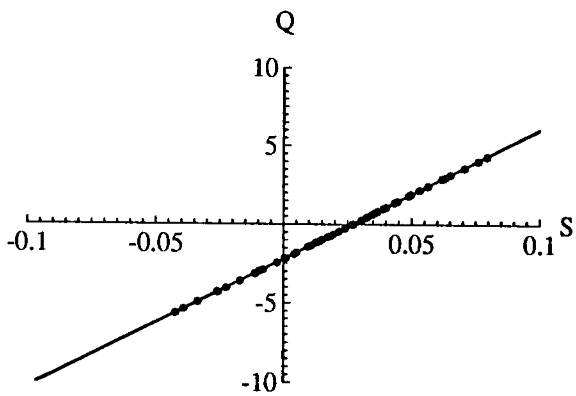



b

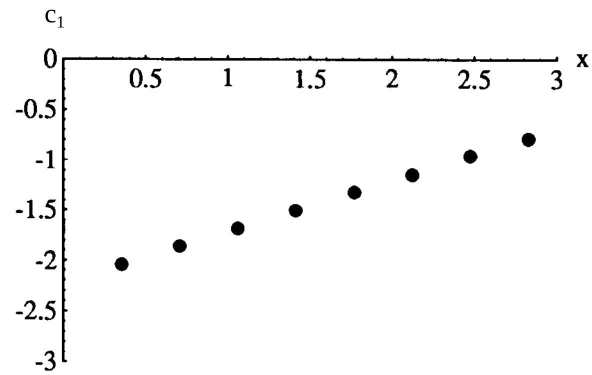
Figure 4: a) Q vs. S generated by test stand where $Q \equiv \sigma_x^2 - \sigma_y^2$ in mm² and S is defined by (4). b) Q vs. S generated by computer using interpolation of BPM map. 225 wires were used and a Gaussian distribution was overlaid on the grid for both plots. The solid lines are the fits to the data using (5).

*B. Beam centroids nonzero*

To determine the remaining two constants, we vary $\bar{x}$ and $\bar{y}$, generating data sets as in Fig. 4 for each centroid position. Fitting these data sets with (5), we get plots of how $c_1$ changes with $\bar{x}$ and $\bar{y}$ (Fig. 5). From these, we get

$c_3 = 0.505$ and
$c_4 = 0.054$.

As of this publication, we have not finished taking data on the test stand for $c_3$ and $c_4$, so comparisons with the computer generated data of Fig. 5 are not available.

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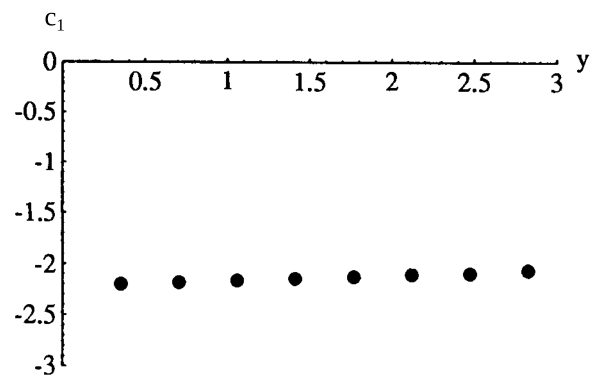


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Figure 5: a) $c_1$ vs. x (in mm) and b) $c_1$ vs. y (in mm).

## V. CONCLUSION

The calibration of our BPMs for second moment measurements is going well. So far, our data fits our model very well and is well understood. In addition, early results indicate that the computer interpolation method is a legitimate approach to speeding up the process.

## VI. REFERENCES


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