SIMULATING A UMER BEAM POSITION MONITOR*

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Abstract

We have investigated numerically and experimentally a beam position monitor (BPM), using the WARP code [1] to study image charge effects for an off-axis beam. In order to apply the theory of image charge, we calibrated the BPM response for the University of Maryland Electron Ring [2]. We studied the BPM linearity using several WARP simulations with different transverse offsets. The simulations were also compared with offsets measured employing a phosphor screen. In this paper we report the methodology used and results of this work.

INTRODUCTION

The University of Maryland Electron Ring (UMER) [3] is a compact low energy ring for studying, on a scaled basis, the fundamental physics of space-charge-dominated electron beams. We primarily employ two main diagnostics: phosphor screen and capacitive beam position monitor (BPM), to measure the transverse position of the beam centroid for steering the beam. The phosphor screen is an intercepting but precise device which allows a visual inspection, and the BPM is a noninvasive way to measure the location of the beam centroid with good spatial and temporal resolution. The goal of this work is to improve understanding and measurements of UMER beams.

As the beam passes inside the capacitive BPM, which consists of four striplines, it induces an image charge on the stripline plates. Because the plates form a capacitor with the grounded BPM housing, induced charges cause a voltage on the plates. When the beam is closer to a given plate, there will be a higher surface charge density on that plate, causing the voltage on it to increase. By comparing voltages on each opposite pair of plates, the beam centroid position can be measured. There is some nonlinearity in the voltage induced on each transverse pair for large beam displacement, therefore a calibration must be established to take this into account [2]. The angle subtended by the plates is 77°, because it can be shown that for this geometry there is no coupling between the x and y axes [4]. This is incorporated in the BPM design and simulations.

WARP SIMULATION

We simulated a beam passing through a nondestructive beam position monitor, along a 32 cm section of the UMER ring, with 13.5 cm of drift, then a 5 cm long BPM, followed by an additional 13.5 cm of drift. In order to keep beam radius constant a uniform focusing field was applied. The code was run using:

- Initial semi-Gaussian beam distribution.
- Circular boundary pipe, with radius $r_{wall} = 2.45 \times 10^{-2}$m, removing particles when they hit the pipe.
- Kinetic energy of 10 keV.
- Unnormalized 4 × RMS emittance $\epsilon = \epsilon_x = \epsilon_y$.
- $N = 40,000$ macro particles, using a grid with 256 × 256 cells.

Simulations were performed using the beam parameters shown in Table 1. For each beam current, we performed simulations varying beam radius from 1 mm to 10 mm. For each radius we varied the centroid displacement from −10 mm to 10 mm, in 1 mm steps. In each simulation, we saved the values of induced charge measured for all the BPM plates.

Table 1: Typical UMER beam parameters.

Current	**Radius**	**Emittance**
100 mA	10 mm	60 μm
23.5 mA	5 mm	35 μm
7.0 mA	3 mm	20 μm
0.7 mA	1.5 mm	6 μm

The $X_{calibration}$ value is obtained from the known centroid position $\langle x \rangle$ measured at the midplane of the BPM as the beam moves in the horizontal direction, divided by $\frac{L-R}{L+R}$, where L and R are the sum of image charge accumulated on two coplanar horizontal channels. Thus the calibration factor will be given by:

$$X_{calibration} = \frac{\langle x \rangle}{\frac{L-R}{L+R}}. \quad (1)$$

Because WARP is x-y symmetric, we would have same values for $Y_{calibration}$ if the centroid displacements were in the y direction. In the next section we will also show the vertical signals in order to demonstrate the absence of coupling between x and y dimensions.

Calibration Plots

We performed simulations for round and elliptical beams at different currents as the beam centroid moves horizontally. Signals at all four plates are obtained as the position of the beam centroid is varied up to 10 mm from the symmetry axis of the pipe. Note that the Figs. 1- 3 are the calibration plots from WARP simulation, where the y-axis

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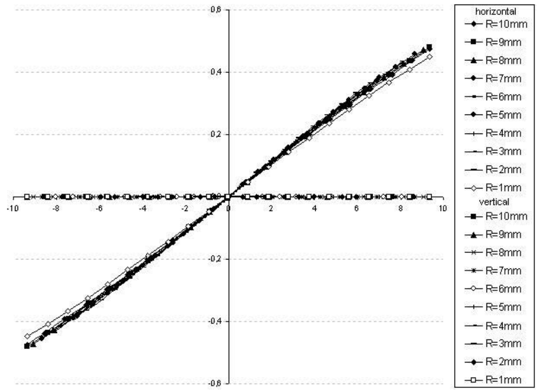

Figure 1: Calibration of the BPM response using simulations that vary the beam radius from 1 mm to 10 mm, for an elliptical beam with constant current I=100 mA. A little radial dependence was observed, but no x-y coupling.

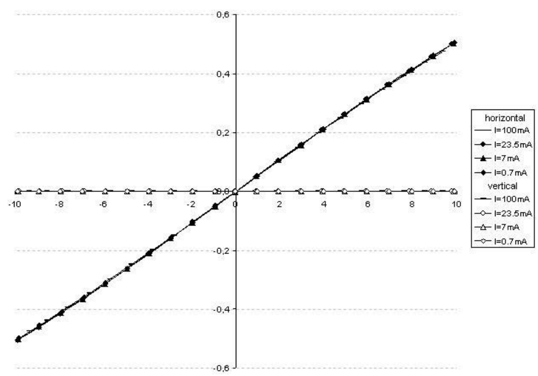

Figure 2: Elliptical beam with 10 mm radius, for different currents. No current dependence or x-y coupling were observed.

signal is $\frac{L-R}{L+R}$ for horizontal plates and $\frac{T-B}{T+B}$ for vertical plates.

The elliptical beams have eccentricities equal to $e = 0.94281$, which means that the ratio of the beam semimajor to semiminor axes is 3:1. It was necessary to recalculate the focusing fields in each direction in order to maintain constant beam size and shape along the ring.

EXPERIMENTAL MEASUREMENTS

Knowledge of the beam centroid location is important to the operation of the ring. We performed an experiment on UMER to benchmark the WARP simulations. We used the phosphor screen to measure beam position, in order to examine any difference between experiment and simulations.

The phosphor screen measurements were performed in the injection line of UMER. Measurements were made using the 7 and 23 mA beams, for steering dipole current varying from -5 to +5 A. The phosphor screen images were taken by a Panasonic 8-bit CCD camera, and analyzed using a custom software.

It can be seen from Fig. 4 that the beam is off-axis at

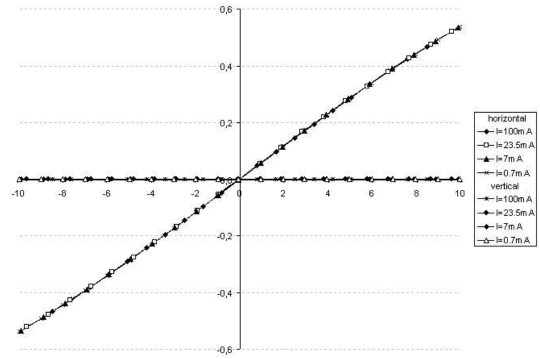

Figure 3: Round beam with 10 mm radius, for different currents. No current dependence or x-y coupling was observed as well.

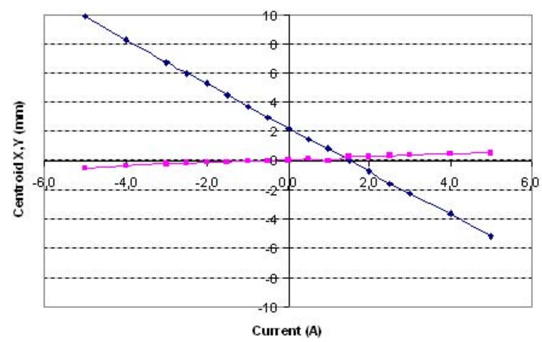

Figure 4: Data from phosphor screen, for a 23 mA beam. As the dipole current is varied, the beam centroid moves horizontally. Only a small x-y coupling was observed.

the zero dipole current. This is believed to result from the perturbation to the 10 KeV beam orbit by the Earth's ambient magnetic field. It also can be seen that there is a slight x-y coupling. It should be noted that there is a quadrupole magnet between the dipole used to deflect the beam and the screen. The coupling could therefore result from either a slight skew of the quadrupole axis or the dipole axis relative to the measurement axes.

CONCLUSION

WARP modeling of the UMER BPMs has been performed. The BPM was found to be insensitive to the beam current since the relation between current and voltage is linear. It also has good linearity for different geometry, i.e., for different beam radius. No coupling among vertical and horizontal components was detected in simulations.

Work is in progress to refine both the simulation and the experiment. In the simulation we plan to examine, in detail, the consequences of the beam centroid movement during traversal of the simulated region. In the experiment a more systematic parameter study is planned, including a study of the consequences of beam alignment for BPM calibration.

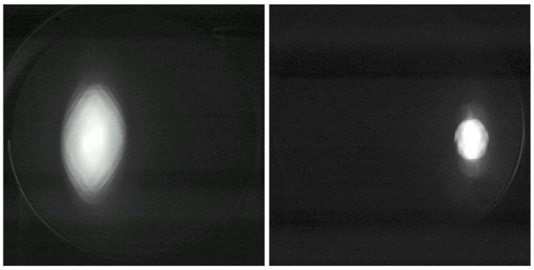

Figure 5: Image of actual UMER beam, measured by phosphor screen. Figure at left is a 23 mA beam for dipole current I=-5 A, where centroid coordinates measured in a software are x=9.889464 mm and y=-0.49764 mm. At right side is the 7 mA beam for dipole current I=+5 A, which centroid coordinates are x=-5.92644 mm and y=2.696304 mm.

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