DESIGN AND TESTING OF A FAST BEAM POSITION MONITOR*

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Abstract

The University of Maryland Electron Ring (UMER) group is currently exploring the physics of space-charge dominated beams. Seventeen Beam Position Monitors (BPMs) will be used to determine the beam centroid for steering correction purposes to within 0.5 mm. Since the pulse length is relatively long (100 ns), the BPMs can also be used for temporal beam profiling. These features are extremely useful for perturbation and longitudinal dynamics studies. For these uses the BPM needs a temporal resolution better than 2 ns. We report on the final design and testing as well as other unique features of this device.

INTRODUCTION

The University of Maryland Electron Ring (UMER) is designed as a low-energy recirculator ring for studying the physics of space-charged dominated beams [1], [2]. Since the parameters of UMER can be scaled to those of higher energy machines, it will act as a benchmark for future designs. Although UMER is compact (11.52m circumference), it is an unusually complex device. This complexity coupled with its operation in the space-charge dominated regime requires UMER to make use of multiple diagnostics and controls [3], [4], [5]. This paper will report on the final design of capacitive beam position monitors (BPMs) and the experimental results obtained using them in the areas of steering, beam profile, current and loss monitoring. For these applications, the BPM needs spatial resolution better than 0.5 mm and temporal resolution better than 2 ns.

ENGINEERING AND DESIGN

Both mechanical and electrical aspects of the BPM have been upgraded for simplification of assembly and improved data collection. Currently, UMER is utilizing ten BPMs, one in the injector and one in each of the nine ring chambers of the UMER assembly. The final UMER assembly will contain a total of seventeen BPMs. Due to space constraints; we will only discuss the changes in design since the last publication [6].

Mechanical Design

The mechanical design has been simplified. The number of individual pieces that make up the housing has been greatly reduced. This cuts the construction time in half and results in a simple and robust frame for the BPM. Signals are collected via four striplines that are separated by grounded planes and separated from the housing by means of a ceramic encasing ring. This ring provides a consistent distance between the collecting plates and the grounded housing, ensuring that each channel of the BPM has the same capacitance. Each stripline forms an arc of 77°, an important feature held over from the old design. It can be shown that at this angle, beam displacement in the X and Y dimensions are decoupled [7].

Unlike most machines, the UMER BPMs are not a fixed part of the beam line. They can be raised out of the beam line, via a mechanical actuator, to allow an attached phosphor screen flag to intercept the beam. This enables a visual inspection of position and internal structure of the beam. When the BPM is lowered into the beam line a good electrical contact is maintained between the housing and beam line via a beryllium copper RF shielding mesh.

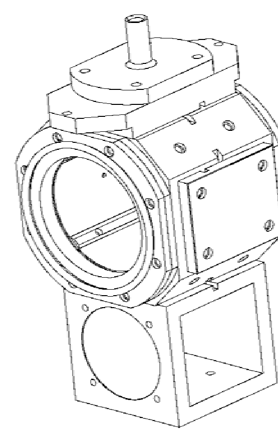

Figure 1: BPM / Phosphor Screen combination. BPM inner diameter is 2 inches.

Electrical signals from the BPMs are brought by 50Ω kapton encased transmission line to a vacuum feed through and to the electronics.

Electrical Design

The BPM buffering circuit has been redesigned with a high enough bandwidth to faithfully reproduce the beam rise and fall times. The buffer amp selected has a –3db small signal bandwidth of 750Mhz, and high AC input impedance (C_{in} = 1.0pF and R_{in} = 700kΩ). This input impedance is used, along with the capacitance of the collecting plate, to create the necessary time constant to accurately reproduce the beam profile. This resistance also serves to bleed off any excess charge between the 60 Hz beam pulses.

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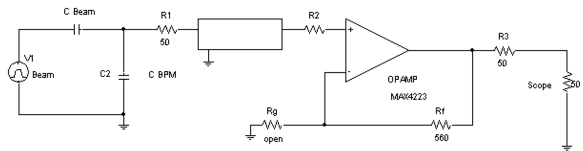


Figure 2: The BPM circuit.

Figure 2 shows the circuit where C_{Beam} is the capacitance between the beam and collecting plate. C_{BPM} is the capacitance between the collecting plate and the grounded housing. R_1 and R_2 are dampening resistance. R_1 is placed on the housing inside the vacuum chamber; R_2 is a coaxial resistor outside vacuum and can be varied as necessary. R_2 is not necessary for lower current beams. R_3 is used to match the signal input to the oscilloscope a 50 Ω impedance. The downside is that R_3 also acts as a voltage divider, lowering the signal magnitude into the oscilloscope. It is preferential to have the matched signal than a larger magnitude. R_f and R_g set the gain of the circuit. Currently $R_g = 0$, resulting in a unity gain.

For calibration a 100 mA, 100 ns pulse was sent through each BPM via a metal rod to simulate the beam. The rod was moved incrementally and signals were taken from each collecting plate. Calibration was achieved by taking the data from any two coplanar channels (i.e. horizontal or vertical) and plotting the difference over the sum of the signals, figure 3 shows a calibration plot.

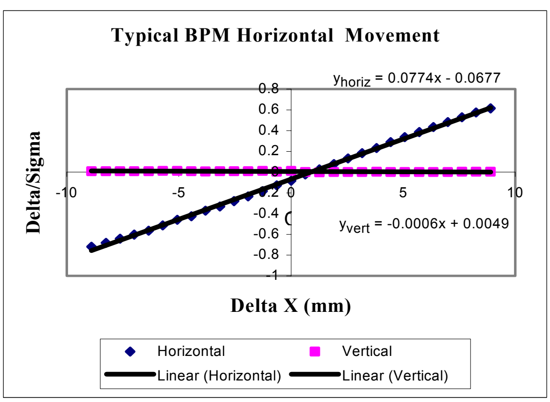


Figure 3: This graph shows the sensitivity, linearity and offset of a typical UMER BPM. Also, note that the horizontal and vertical signals are decoupled within this range.

On average the BPMs that have been calibrated using the delta over sigma method have resolution < 0.1mm. Results using the BPMs with actual beam confirm predicted values for linearity and resolution.

The ability to acquire an accurate beam profile is a unique feature of the UMER BPMs. In beam tests we have found the frequency response to be much better than anticipated. The experiment was conducted comparing it to a well-established diagnostic, the Bergoz current transformer model number FCT-082-20:1, in order to ascertain the relative frequency response of the BPM. Both diagnostics are located in the injector line. Two opposing channels of the BPM were summed to get total current. The Bergoz coil is approximately 60 cm from the electron gun and the BPM is 19 cm downstream from the Bergoz coil. Hence, it is expected that the beam would have spread longitudinally and the rise and fall times would be greater at the BPM. However, as figure 4 shows, the rise time of the Bergoz coil was measured to be 2.8 ns while the rise time of the BPM was 1.7 ns for the 25 mA beam. The test was repeated with a current of 85 mA, a dampening resistance $R_2 = 200\Omega$ (see figure 2) is added to control oscillations. Even then, the BPMs' frequency response is as fast as that of the Bergoz coil.

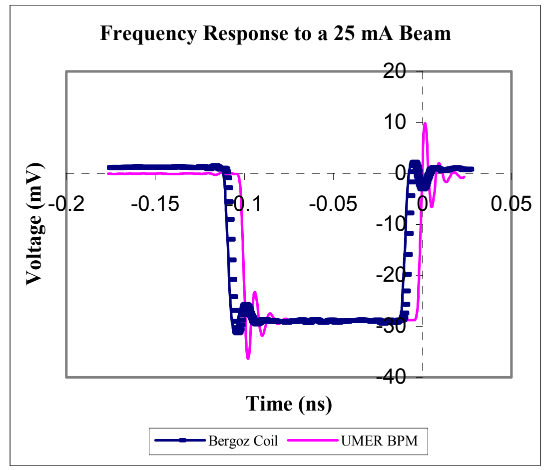


Figure 4: Frequency response of the BPM compared to the Bergoz Coil.

APPLICATIONS

The UMER BPMs have evolved into a versatile diagnostic capable of beam profiling, position and current monitoring with good resolution and high bandwidth.

Beam Position Monitoring

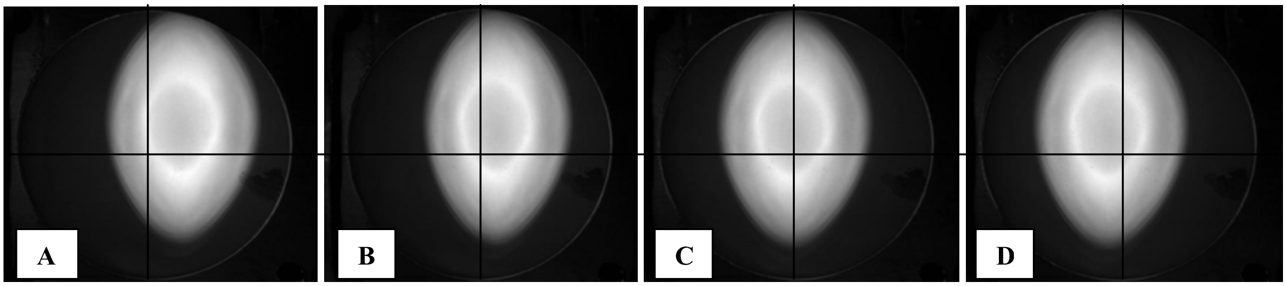
The UMER BPM is first and foremost used to determine the location of the beam centroid as a function of time. Beam position in the horizontal plane is determined by dividing the difference of the two horizontal (right and left) signals by their sum and applying the offset and resolution factors determined in calibration. Since X and Y are decoupled, repeating the process with the vertical (top and bottom) signals creates an XY pair at which the beam centroid lies. The equations are

$$X = \frac{(V_R - V_L)}{R(V_R + V_L)} - \frac{B}{R} \quad (1)$$

$$Y = \frac{(V_T - V_B)}{R(V_T + V_B)} - \frac{B}{R}, \quad (2)$$

where V_X is the signal from the corresponding signal plate, R (slope) is the resolution number and B (X-intercept) is the offset number as in figure 3.

Tests were conducted with beam to confirm the accuracy of the BPMs. Varying the current on an upstream steering dipole to move the beam, position data and beam images were taken at the same location using the BPM / phosphor screen combination. The center of



Measured
A to B: X = 1.12526 mm, Y = 0.06307 mm
B to C: X = 2.33359 mm, Y = 0.18921 mm
C to D: X = 1.13526 mm, Y = 0.06307 mm

BPM Calculation:
A to B: X = 1.03819 mm, Y = 0.03904 mm
B to C: X = 2.59375 mm, Y = 0.19337 mm
C to D: X = 1.15206 mm, Y = 0.04006 mm

Figure 5: Phosphor screen images of the beam with relative center measured directly and calculated by the BPM. The crosshairs show the center of the phosphor screen.

the beam image was determined by direct measurement and converted from pixels to mm. Since the exact location of the phosphor screen is not known only a relative comparison is possible. Figure 5 shows the close agreement between direct measurement and the BPM calculations.

A user interface has been developed and is in the process of being debugged. When finished it will allow the user to select desired BPM and see a graphical representation of beam position. This is accomplished by means of a Labview BPM control program for unit selection via a mulitplexer. The desired signals are fed into an oscilloscope and then into the computer. The same BPM control program then computes the beam position and displays it graphically for the user to set the proper steering to center the beam. Future upgrades will automatically control the steering magnets.

Beam Current and Loss Monitoring

Since the BPM measures charge as a function of time it may be used as a current monitor. This is achieved using a conversion factor determined from the following equation [8]

$$\frac{V_{L+R}(t)}{I_B(t)} = \frac{\phi \ell}{4\pi C_{tot} \beta_c} \quad , \tag{3}$$

where V_{L+R} is the total voltage of two opposing plates, I_B is the beam current, ϕ is the collecting plate angle, ℓ is the plate length, C_{tot} is the total capacitance in the circuit and β_c is the relativistic factor of the beam. Solving this equation gives a conversion factor of 1.25 V/A. This number agrees with experimental observations and comparisons to the Bergoz current transformer. UMER employs a BPM every 0.64 m; therefore, the location of beam loss can be determined.

The UMER BPM has such a good frequency response that the longitudinal spread due to Coulomb forces at the head and tail of the beam can be accurately profiled. Since the UMER beam is 100 ns long and the time it will take to make its journey once around the ring is approximately 200 ns this profiling ability is of great importance. If unchecked, the longitudinal spread will cause the head and tail of the beam to meet. UMER will employ three induction gaps to keep the beam compressed. A study of the longitudinal dynamics of the beam is currently underway to establish the specifications of the induction gaps [9]. The BPMs have become an important diagnostic for this study. Using the BPMs' ability to accurately measure the length, as well as rise and fall times, of the beam will give a better understanding of the longitudinal dynamics of space-charge dominated beams.

CONCLUSION

The UMER group has completed design and implemented a capacitive BPM for aiding the study of space-charge dominated electron beams. A spatial resolution of 0.1 mm (100 mA, 0.4 mm for 25 mA) and temporal resolution of 1.7 ns have been achieved, which exceed the design specifications. In addition to locating the centroid of the beam, the UMER BPMs are capable of high resolution beam profiling, current and loss monitoring. Ten BPMs have been constructed and are in use with the UMER beam, with seven more on the way. A user interface is being developed that will control data collection and aid in beam steering.

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