A FAST BEAM POSITION MONITOR FOR UMER*

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Abstract

Construction has recently begun on the University of Maryland Electron Ring (UMER) [1]. This system will be used to investigate the physics of space-charge-dominated electron beams. Beam centroid drift and beam current will be investigated on a sub-bunch timescale (< 50 ns). A capacitive beam position monitor (BPM) with good temporal (< 5 ns) and spatial resolution (< 0.5 mm) is being constructed for these measurements. Seventeen of these BPMs will ultimately be installed in the ring and will also be used for computer-assisted steering of the beam. In this paper we report the successful construction and testing of the second-generation prototype BPM.

1 BACKGROUND

The University of Maryland Electron Ring (UMER) is a compact ring for studying the physics of space-charge dominated electron beams [1], [2]. Although physically small, UMER is an unusually complex device. This complexity and the operation of UMER in the largely unexplored space-charge regime make the use of sophisticated diagnostics and controls critical [3]. Among the diagnostics that will be used with UMER are capacitive beam position monitors (BPMs). Our work has concentrated on the development of a robust, reproducible design with good spatial and temporal resolution. This paper will give background on capacitive BPMs and our recent results.

2 BPM PHYSICS PROTOTYPE

The capacitive BPMs being built for UMER need to fulfill several requirements. First, they need to be able to locate the centroid of the beam for use with beam steering controls (good spatial resolution). Second, they need to be able to resolve information about beam pulse structure (good temporal resolution). Because the beam rise time is expected to be about 5 ns, the temporal resolution of the BPM must be smaller than this.

The capacitive BPM design used at UMER consists of four striplines placed just inside the beam pipe but separated from the beam pipe by insulating standoffs (See Figure 1). A beam passing by the striplines induces an image charge on the stripline plates. These plates form capacitors with the grounded BPM housing, so the induced charges cause a voltage to exist across this capacitor. If the beam is closer to a given plate, there will be a higher surface charge density on that plate, causing the voltage on the plate to increase. By comparing the voltages on each pair of plates, the beam centroid position can be detected.

For each pair -- one pair for each transverse dimension -- the left and right plate voltages depend on the beam displacement (x), the beam pipe radius (b), and the angle subtended by the plates (Φ):

$$20\log\left(\frac{V_R}{V_L}\right) = F_1(\Phi)\frac{\mathrm{x}}{\mathrm{b}} + F_2(\Phi)\frac{x^3}{b^3} + F_3(\Phi)\frac{xy^2}{b^3} + \ldots \tag{1}$$

The functions F_1, F_2, and F_3 depend only on the angle Φ. The BPM sensitivity to a displacement of the beam centroid is given by F_1, while F_2 is a measure of the BPM's nonlinearity, and F_3 gives the strength of coupling between the two dimensions.

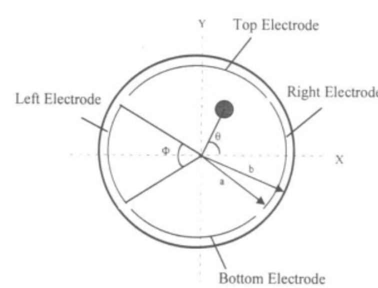

Figure 1: BPM Schematic Drawing, showing four stripline plates inside the beam pipe [4].

It can be shown that $F_3(\Phi) = 0$ if $\Phi = 76.99°$ [4]. At this angle, the x and y dimensions are decoupled. The angle subtended by the plates in our initial physics prototype was larger than this, but 77° was used in our engineering prototype.

The function F_1 is given by

$$F_1(\Phi) = \frac{160}{\ln 10}\frac{\sin\left[\frac{\Phi}{2}\right]}{\Phi} \tag{2}$$

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If the F_1 term were the only term in Eq. (1), the plot of $\log(V_R/V_L)$ vs. x would be a straight line. However, since $F_2(\Phi) \neq 0$, there will be some nonlinearity in the output for large beam displacement. Therefore in general, a calibration must be used to take this into account.

The physics prototype BPM was thoroughly tested and found to be satisfactory [5].

3 BPM ENGINEERING PROTOTYPE

With the capacitive BPM physics prototype tested successfully, work proceeded with the design, construction, and testing of an engineering prototype. Unlike the physics prototype, which was a proof of principle for our basic BPM design, the engineering prototype was intended to be essentially identical to the actual BPMs, which will be used for UMER.

3.1 Electrical Design

In order for the BPM to remain sensitive, the induced charge must be drained from each plate between beam pulses. To accomplish this, a bleeder resistor (R_p) is placed in parallel with each stripline (Fig. 2). In fact, the parallel resistor is not connected directly to the BPM plates, but is connected via a transmission line. The BPM plates and the transmission line form an LC circuit. In order to dampen the ringing of this LC circuit, 250 Ω of resistance was added to the transmission line. This resistance was split into a 50 Ω resistor and a 200 Ω resistor, which were placed on either end of the transmission line to reduce reflections. There is a tradeoff between time constant (temporal resolution) and sensitivity (spatial resolution). Reducing R_p would reduce the charging or discharging time, increasing temporal resolution. However, this would cause more voltage to be dropped across the transmission line and matching resistors, reducing the spatial resolution of the BPM. Since one of the goals is to be able to sense 0.5 mm displacements, R_p was chosen empirically to be 2.5 kΩ.

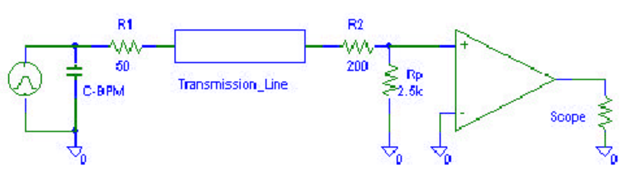

Figure 2: Circuit for BPM and associated systems. The source represents the beam when the BPM is in actual operation, or the pulser and rod during bench testing.

3.2 Mechanical Design

The UMER ring will ultimately consist of 18 bend sections. One of these sections will be dedicated to injection, one will be dedicated to extraction, and three will be used for induction gaps. Each of the remaining 13 sections includes a diagnostic port, which will contain one capacitive BPM and one phosphor screen. In addition, two BPMs will be located in the injection line, and two will be located in the extraction line. The screen and the BPM will both be mounted in a moving support frame that is actuated pneumatically. This will allow either the BPM (noninvasive) or the phosphor screen (invasive) to be used at any given time. Because of this pneumatic system, the BPM has been designed to be compact, rugged, and reliable.

The BPM stripline plates are mounted within a compact metal housing, and are insulated from the housing by small ceramic beads. The housing itself forms part of the path for the return wall current. In order to ensure that this current is disturbed as little as possible, beryllium copper RF shielding mesh is used to create a good electrical connection when the housing is lowered into position in the beam pipe (Fig. 3).

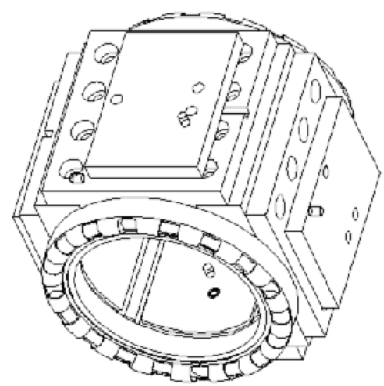

Figure 3: Assembled BPM and BPM housing. BPM inner diameter is 2 inches.

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

3.3 Bench Testing

The BPM engineering prototype has been extensively tested. Initial testing was conducted separately from the UMER beamline. For these bench tests, the engineering prototype was fixed inside a diagnostics port. A metal rod was inserted through the BPM, and a 100 mA, 50-100 ns pulse was sent through the rod to simulate the beam. A buffer amplifier was used for impedance matching between the BPM circuitry and the 50Ω oscilloscope input. Initially, ringing was a serious problem. The addition of the matching resistors (R1 and R2) greatly improved device performance. Typical BPM input and output pulses recorded during bench testing are shown in Fig. 4.

Nonlinearity of BPM signals can require calibration. To determine if this is necessary, the rod used to simulate the beam was translated horizontally and vertically, and the resulting signals were recorded. It was found that nonlinearity was only seen for very large beam displacements. Such large displacements would not be expected in normal operation, and would be indicative of other more serious problems upstream of the BPM. Calibration of the BPMs is therefore not critical at this time.

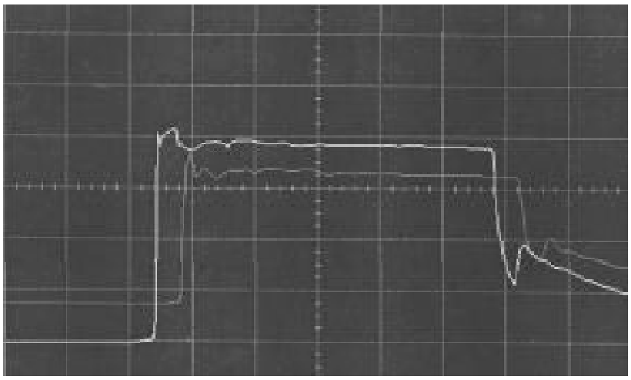

Figure 4: Typical bench test signal (white) and BPM measured signal (gray). Vertical scale is 500 mV/division, and horizontal scale is 20 ns/division.

In bench testing, the BPM sensitivity and spatial resolution were found to be functions of simulated beam current. For currents of 100 mA -- which will be used in the actual UMER beam -- sensitivity was 6.5 mV/mm, and resolution was 0.17 mm/mV. The resolution was much better than the 0.50 mm design criterion.

One of the goals of UMER is to examine structure *within* the beam bunch. Initial bench testing used a square wave signal to simulate the beam bunch. This square wave had a rise time of about 2 ns, and included some low-level noise due to the limitations of the pulser used. The BPM was able to reproduce both the rise time and the signal noise. Note that this rise time is less than half that of the actual UMER beam (5 ns). In order to simulate large-scale modulation of the UMER beam bunch, the pulser circuit impedance was deliberately mismatched to that of the BPM/rod system. This mismatch caused a significant distortion of the simulated beam pulse, which was reproduced almost exactly by the BPM. These results suggest that the BPMs will be able to detect any modulation or distortion of the actual UMER beam bunches, whether deliberately induced or naturally occurring.

Some ringing is still present in the BPM output. This ringing has a characteristic frequency of 155 MHz, and is damped out within a few periods. The simulated beam pulses had a fundamental of about 7 MHz, meaning that any output or signal processing circuitry used with the BPM must be fairly wide band.

3.4 Beam Test

Testing of the BPM with the actual UMER electron beam has begun. The BPM was inserted into a diagnostics port in the injector line, and beam was successfully run through the injector. A short steering dipole 16 cm upstream from the BPM was used to deflect the beam, and this deflection was measured with the BPM and with a phosphor screen. The BPM response vs. beam displacement is shown in Fig. 5.

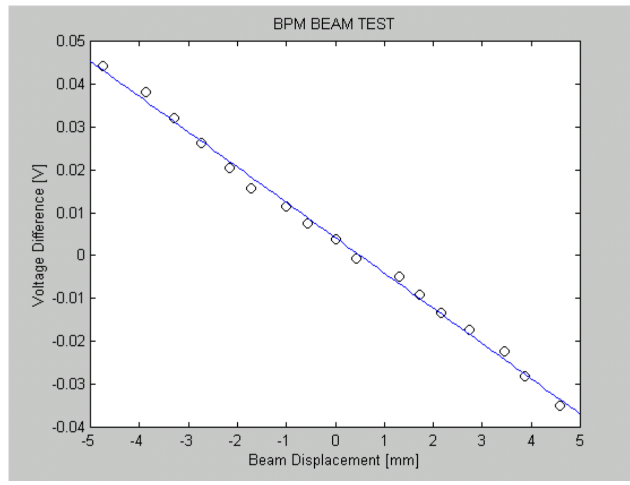

Figure 5: Voltage difference between plates as a function of beam displacement. The signal is very linear.

4 CONCLUSION

The UMER research group has developed a capacitive BPM for aiding the study of space-charge dominated electron beams. The BPM spatial and temporal resolutions are better than expected (0.17 mm/mV, 2ns), and will allow investigation of structure within a single beam bunch. Initial testing of the engineering prototype with the actual UMER beam has begun, and additional beam testing will help to further refine the BPM. Once beam testing is complete, construction on the remaining BPMs will begin.

5 REFERENCES

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