DEVELOPMENT OF A RESISTIVE BEAM POSITION/CURRENT MONITOR FOR THE UMD ELECTRON RING*

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Abstract

A prototype resistive beam position/current monitor has been developed for the proposed small electron ring at the University of Maryland. It consists of 32 low-inductance resistors which are uniformly distributed around a ceramic gap between two conducting pipes. The resistors are divided into four quadrants and each quadrant has a total resistance of 0.625 Ω. The beam image currents are measured in the four quadrants and the measurement leads to the information about beam position and total beam current. A bench test has been done for the prototype beam position/current monitor. The result shows that the beam position/current monitor gives an accurate total beam current with an error of 2% and satisfactory position information in both radial and azimuthal directions. The rise time of the monitor is measured as about 1 ns.

1 INTRODUCTION

A small electron ring is being developed at the University of Maryland[1, 2]. In this machine, space-charge dominated electron beams with an energy of 10 keV and a current of 100 mA are designed to recirculate in the ring with a circumference of 11.5 m. The beams easily tend to be off-centered in this ring because of misalignment, earth magnetic field, etc. Therefore, it is necessary to detect the beam position and to restore the beams to the axis. Furthermore, one needs to measure the total beam current. For these purposes, a prototype resistive beam position/current monitor was designed and built[3]. In this paper, the design and the bench test results of the prototype beam position/current monitor are presented.

2 BASIC PRINCIPLE

The basic principle of a resistive beam position/current monitor is quite simple. When a charged particle beam propagates in a conducting tube, an image current is induced on the inner surface of the tube. If the current is a little off-centered from the geometrical axis, the image current is induced nonuniformly in the azimuthal direction. The azimuthal current distribution is determined by the position of the beam. Therefore, the position can be determined by measurement of the azimuthal current distribution. Figure 1 shows a schematic diagram to explain the basic principle. As shown in the figure, the conducting tube is divided into four quadrants. Suppose that a thin current flow is at the position of (r, ϕ) in the polar coordinate system, as shown in the figure. In this case, the current distribution $J(\theta)$ on the conducting tube is given by[4]

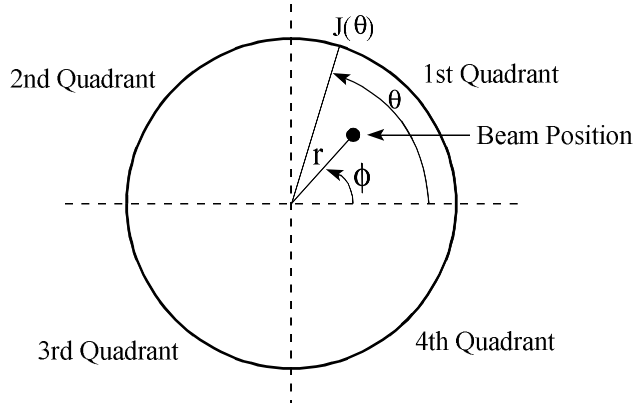

Figure 1: Schematic diagram of an off-centered beam in a conducting tube. As shown in this figure, the nonuniform image current $J(\theta)$ is induced when the thin beam is positioned at (r, ϕ).

$$J(\theta) \;=\; \frac{I_t}{2\pi R}\frac{1-(r/R)^2}{1+(r/R)^2-2(r/R)\cos(\theta-\phi)}, \quad (1)$$

where R is the diameter of a conducting tube and I_t is the total current. Hence, I_t is a sum of the currents in the four quadrants, i.e., $I_t = I_1 + I_2 + I_3 + I_4$, where I_1 through I_4 are the currents flowing in the four quadrants, respectively. Instead of measuring an exact current distribution as a function of θ, the beam position (r, ϕ) can be determined by measurement of I_1 through I_4, based on the following two equations:

$$\frac{2(r/R)\cos(\phi)}{1-(r/R)^2} \;=\; \tan\left[\frac{\pi}{2}\left(\frac{I_1+I_4-I_2-I_3}{I_1+I_2+I_3+I_4}\right)\right], \quad (2)$$

$$\frac{2(r/R)\sin(\phi)}{1-(r/R)^2} \;=\; \tan\left[\frac{\pi}{2}\left(\frac{I_1+I_2-I_3-I_4}{I_1+I_2+I_3+I_4}\right)\right]. \quad (3)$$

To measure the current in each quadrant, there are two ways, i.e., a capacitive method[5] and a resistive method. For faster response, the resistive method is employed in our case. In other words, the conducting tube is split into two pieces and resistors are uniformly distributed around the gap between the two conducting tubes. Resistors in each quadrant are electrically connected in parallel, and the current in each quadrant is measured to determine the position

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and total current. In the next section, the detailed design parameters and the bench test results of a prototype are presented.

3 DESIGN AND BENCH TEST OF A PROTOTYPE POSITION/CURRENT MONITOR

3.1 Design

A prototype resistive position/current monitor was designed and built, based on the principle given in Section 2. It consists of two stainless-steel tubes with an inner diameter of 30.5 mm and a ceramic insulator of 6.4 mm in width. The two conducting tubes are brazed with the ceramic insulator for high vacuum sealing. The total length of the monitor is 6.1 cm, including two flanges at both ends. 32 low-inductance carbon resistors are uniformly distributed around the ceramic insulator and 8 resistors in each quadrant are connected to a common BNC cable. Each resistor has 20 Ω, so each quadrant has 2.5 Ω. With these parameters, a voltage drop from each quadrant is expected to be 62.5 mV if the beam current is 100 mA. The expected voltage 62.5 mV is large enough to measure with high accuracy.

3.2 Bench Test Results

Figure 2 shows the experimental setup to test the prototype beam position/current monitor. As shown in the figure, the position/current monitor is connected with two additional conducting tubes at both ends, and a current in a conducting rod is used to simulate a beam current. The conducting rod has a diameter of 12.7 mm so that the coaxial structure has an approximate transmission impedance of 50 Ω. A square pulse with a voltage of 5 V and a duration of 50 ns is sent to the setup for test of the monitor. In this case, the current in the conducting rod is 100 mA. To avoid a reflection from the end of the system, a 50 Ω terminator is connected at the end, as shown in the figure.

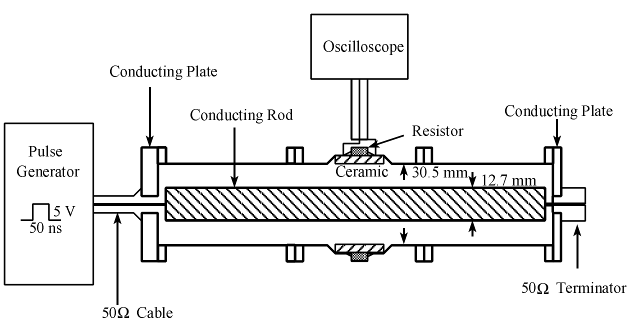

Figure 2: Bench-test setup of the resistive position/current monitor.

If the conducting rod is exactly on the axis, signals from the four quadrants yield almost the same square pulses. However, if the conducting rod is a little off-centered towards the first quadrant, for example, the signals from the four quadrants are different. The signal from the first quadrant will be larger than signals from other quadrants, according to Eq. (1). Figure 3 shows the measured signals from the first quadrant when the conducting rod is at r = 0 mm, r = 1.43 mm, r = 2.63 mm, and r = 4.75 mm, respectively, with a constant angle of ϕ = 45°. As expected, the top trace is almost flat, but other traces show larger overshoots as the rod is moved away from the axis in the first quadrant. The large overshoots decay to flat signals after about 15 ns. The reason for this is that the resistors with a finite resistance are distributed around the conducting pipes so that an initial nonuniform potential around the circumference of the conducting tube becomes uniform after some time. Therefore, the four signals in Figure 3 have almost the same amplitude of about 63.5 mV after about 15 ns, which is close to the expected value of 62.5 mV. If these voltages are converted into currents, the current in the conducting rod is calculated as 101.6 mA, which is very close to the setup current 100 mA. Hence, this device gives an accurate total current.

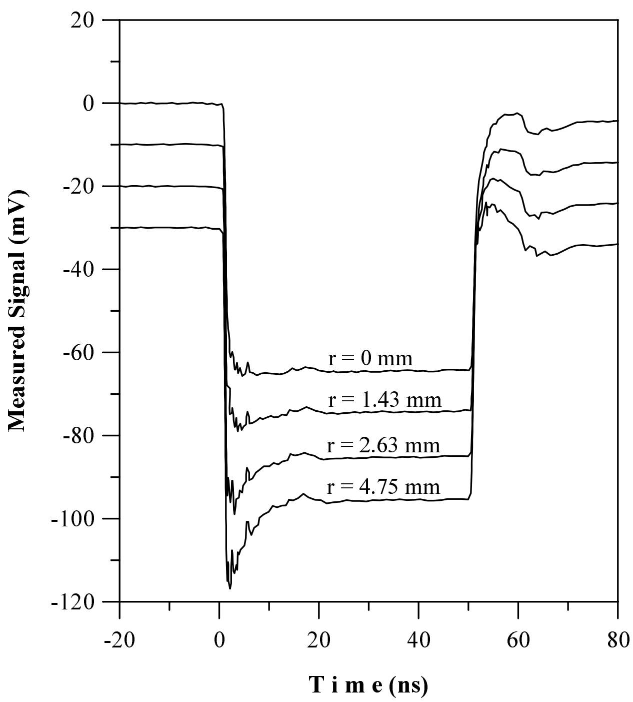

Figure 3: Signals from the first quadrant when the conducting rod is positioned at r = 0, 1.43, 2.63, 4.75 mm, respectively for a fixed azimuthal angle ϕ = 45°.

The signals obtained from the four quadrants are analyzed to yield the information about the conducting rod position. Figure 4 shows the measurement result for a fixed ϕ = 45°. In this case, the conducting rod is positioned at r = 0 mm, 1.43 mm, 2.63 mm, and 4.75 mm, respectively. Figure 4(a) shows a comparison between the setup radii and the measured radii. Deviation from the straight dotted line implies the difference between setup and measurement. According to the graph, their difference is equal to or less than 0.46 mm. Figure 4(b) shows a comparison between the setup azimuthal angle ϕ = 45° and the measured angles.

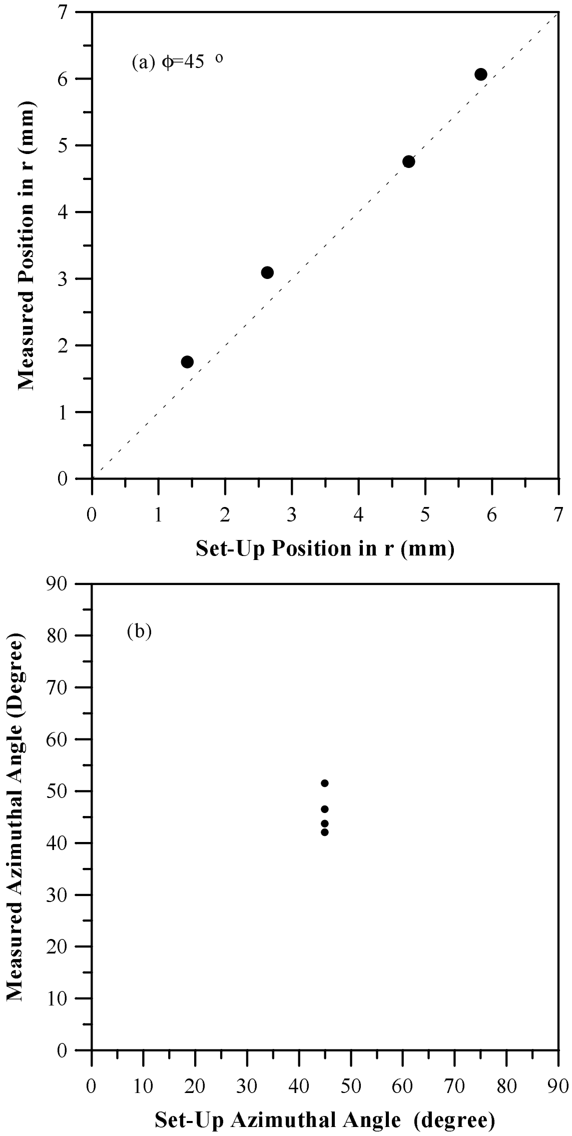

Figure 4: (a) Comparison of measured radii with setup radii for fixed ϕ = 45°. (b) Comparison of azimuthal angle measurement with a setup angle for different radii in Fig. 4(a).

Similar comparisons are done for different angles. The case for ϕ = 90° is shown in Figure 5. Figure 5(a) shows that all data points are distributed close to the straight dotted line within 0.35 mm in radial direction. An angular comparison is shown in Figure 5(b), where the data points are distributed from 85° to 90°.

4 CONCLUSIONS

The small scale prototype of a resistive beam position/current monitor was designed and tested. The bench test shows that it yields satisfactory results in position, total current, and response time. Thus, a full-size beam position/current monitor will be built and tested for the electron ring.

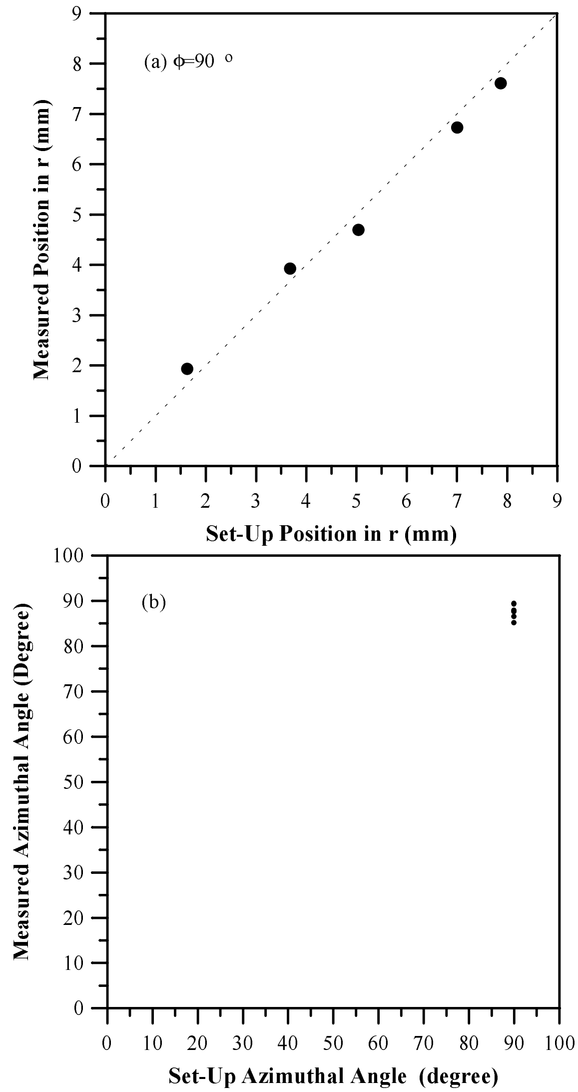

Figure 5: (a) Comparison of measured radii with setup radii for fixed ϕ = 90°. (b) Comparison of azimuthal angle measurement with a setup angle for different radii in Fig. 5(a).

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