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FEASIBILITY OF USING THE EXISTING RHIC STRIPLINE BPMs FOR THE EIC*

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Abstract

The design of the Electron-Ion Collider (EIC) at Brookhaven National Laboratory (BNL) will utilize portions of the existing Relativistic Heavy Ion Collider (RHIC) for the EIC hadron ring. The EIC design calls for up to 10-times shorter ion bunches compared to the present RHIC operation. Higher single bunch peak currents will result in higher voltages to the output ports of the BPMs consequently producing more heating of the cryogenic signal cables connected to these output ports. Therefore, the existing stripline BPMs should be either upgraded or replaced with new ones. In this paper, we explore the potentially cost-effective approach by incorporating an RF-shielding piece into the existing BPMs as opposed to replacing them completely. Starting with the power delivered to the output ports, we present the proposed BPM modification with the RF-shielding piece. Then we discuss in detail the RF-shielding piece geometry including the dimension of RF slot and RF-fingers configuration. Finally, we present the optimization of the shielding piece and the mechanical tolerances required for its fabrication.

INTRODUCTION

For the proposed EIC [1,2], the current RHIC rings will serve as a hadron ring with some modification, which will have up to 10 times shorter bunches in comparison to the present RHIC, refer to Table 1. These shorter and intense bunches induce larger voltage on the existing RHIC stripline Beam Position Monitor (BPM) electrodes, which consequently deposit higher power to the output ports of the BPM. This increased power generates excessive heating of the BPM signal cables [3]. Therefore, the existing RHIC stripline BPMs must be either upgraded or be replaced with new ones to mitigates the heating effect caused by the EIC shorter bunches. A parallel research on the design of a new button-BPM for the EIC hadron ring is ongoing. Here, we focus our discussion on the feasibility of using the existing RHIC BPMs by incorporating an RF-shielding piece.

A stripline BPM together with beam pipe housing acts as the same as a transmission line whose characteristic impedance is mostly same as that of its signal pickup ports. The power deposited to a BPM can be expressed as [4]

$$P = f \times \int \frac{V^2(t)}{Z_c} , \tag{1}$$

where f is the bunch frequency, V_t is the amplitude of the output port voltage for one bunch, and Z_c is the characteristic impedance of the output port. The signal amplitude $V(t)$ scales linearly with the instantaneous bunch current and this bunch current scales inversely with the bunch duration. Therefore, for the same bunch charge, P scales linearly with f and inversely with the bunch length. In other words, with ~ 10 times more bunches in EIC as compared to RHIC and bunch lengths that are ~ 10 times shorter, P is ~ 100 times larger.

Table 1: Hadron Beam Parameters Comparison between the RHIC and EIC

Parameters	EIC Design	RHIC Demonstrated	Unit
Energy	275	255	GeV/A
RMS bunch length	6	55	cm
Charge/bunch	32	36	nC
Max. number of bunches	1160	110	NA

In terms of the beam coupling impedance, the same expression, Eq. (1), can be written as

$$P(\omega) = \frac{1}{2}|I_0|^2\, \Re[Z_\parallel(\omega)] , \tag{2}$$

where $\Re[Z_\parallel(\omega)]$ is the real part of the longitudinal impedance.

Equation (1) implies that small increment on the port voltage increases the power quadratically and hence has larger impact in heating of feedthroughs and cryogenic signal cables. Therefore we explore the potentially cost-effective approach to reduce this port voltage by incorporating an RF-shielding piece, which we discuss in details in the following section.

GEOMETRY AND THE PERFORMANCE OF RF-SHIELDING PIECE

The cut view of a single plane type-2 RHIC stripine BPM (dual plane BPMs with four electrodes also exist) is shown in Fig. 1. The inner diameter (ID) between stripline electrodes is of 69.11 mm (same as nominal ID of the RHIC beam pipe), while the their housing has an ID of 97.23 mm.

To reduce beam induced heating due to EIC shorter bunches without affecting the signal to noise ratio of the output signal, we insert a cylindrical shielding piece, Fig. 2(b) (yellow colored geometry), having an internal diameter of 63.5 mm and thickness of 1.27 mm. The length of this shielding piece is sufficient to shield all stripline electrodes. The shielding piece has four RF-slots, just underneath the output

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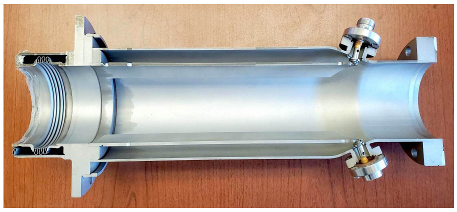
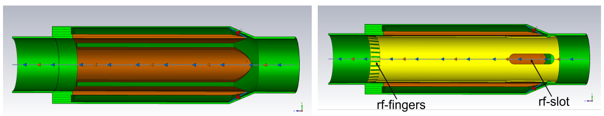


Figure 1: Cut view of a prototype a single plane RHIC stripline BPM.

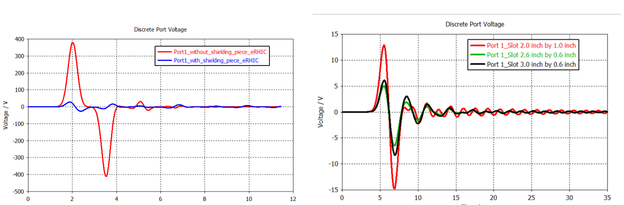


(a) (b)

Figure 2: Cut view of a simplified CAD design for the RHIC BPM having four-striplines (reddish color) (a) without RF-shielding, and (b) with RF-shielding piece (yellow color).

ports of each stripline electrode, see Fig. 2(b), which allow to propagate electromagnetic signals via the output ports. To maintain an RF-contact of the shielding piece with beam pipe we plan to weld it at the upstream and use RF-fingers at the downstream.

We evaluated shielding piece performance by comparing the output port voltages with and without inserting it into the BPM with the EIC hadron beam parameters listed in Table 1. Figure 3(a) shows this comparison, where the dark blue curve and the red curve represent the port voltages with and without inserting the RF-shielding piece respectively. CST [5] simulation, shows that shielding piece reduces the amplitude of the output port voltage (recorded by the discrete port of 50 Ω in the CST simulation) by a factor of ~ 15. In addition, simulation shows that the shielding piece reduces the real part of the impedance by a factor of ~ 18. The performance of the shielding piece is quite good to lower the output port voltage and the real part of the impedance, however the bunch by bunch measurement seems challenging. We optimize the geometry of this shielding piece, which we present in the following section.



(a) (b)

Figure 3: Comparison of output port voltages (a) with (dark blue curve) and without shielding piece (red curve), and (b) with different RF-slot dimensions, where the red, black and green curves represent RF-slot dimension of 2.0 inch × 1.0 inch, 3.0 inch × 0.6 inch, and 2.6 inch × 0.6 inch, respectively.

SHIELDING PIECE OPTIMIZATION

We optimised the shielding piece to determine the dimension of RF-slots, configuration of RF-finger, and and mechanical tolerances associated with it. For the optimization of former two parameters we used beam with slightly longer bunch (20 cm) to save our computational resources while to determine mechanical tolerances we used EIC proton bunch of 6.0 cm.

Dimension of RF-Slots

We determined the appropriate dimension of RF-slots without compromising the signal strength by comparing output signals propagated via three different dimension of RF-slots: 2.0 inch × 1.0 inch, 3.0 inch × 0.6 inch, and 2.6 inch × 0.6 inch, respectively. Figure 3(b), shows this comparison which indicates that the larger slot-width produces the higher amplitude of the output voltage. The geometry of 2.6 inch × 0.6 inch slot with rounded corners was chosen to lower the the power deposition without compromising the sensitivity.

RF-Fingers Configuration

We have optimized the configuration of RF-fingers by performing a parametric study of the azimuthal gap between each finger. Simulation shows no distortion in the output signals up to the gap of 5.0 mm if all the fingers are present. In addition, we separately studied the effect of missing RF-fingers to estimate the possible impact for the worst-case scenario for the two different configurations; keeping the total number of RF-fingers equal to 16 and 32, respectively. Simulation showed that 32-fingers configuration results less perturbed output signal than that of 16-fingers for the similar or larger azimuthal gap between the fingers. Therefore, we kept 32-fingers configuration with much smaller azimuthal gap of 1 mm for the shielding piece design.

Estimation of Mechanical Tolerances

Our final optimization task was to evaluate the mechanical tolerances associated with the shielding piece, which are crucial for its fabrication and during the installation inside the BPM. Estimation of these tolerances directly related to the bunch length and hence we used the actual EIC bunch length of 6.0 cm for these calculations. In addition, we assume the entire geometry made up of perfect electric conductor to save simulation time

To determine the tolerance, we first evaluated the sensitivity factor, also called k-factor, whose value remains the same in the linear region (region around the central beam axis) of BPM. To find the value of k-factor, we displaced a particle beam slightly off (Δx) from the beam axis and record the signals using two opposite ports. The port near to the displaced beam produces larger amplitude while the port away from the beam produces lower amplitude. A typical plot for the k-factor calculation using a particle beam (48 nC and 20 cm) transversely displaced (vertically upwards) by 5.0 mm from the beam axis is shown in Fig. 4. If V_1 and

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V_2 are the amplitude of the voltage signal recorded by two opposite ports, then the the small transverse displacement Δx of a beam relates to the k-factor by $\Delta x = k\left(\frac{V_1 - V_2}{V_1 + V_2}\right)$. The value of k using the peak voltages in the Fig. 4 is found to be 18.58 mm. Similarly using the EIC beam parameters (32.9 nC and 6 cm) with the beam's transverse displacement of 1 mm, the value of k-factor was found to be 16.68 mm.

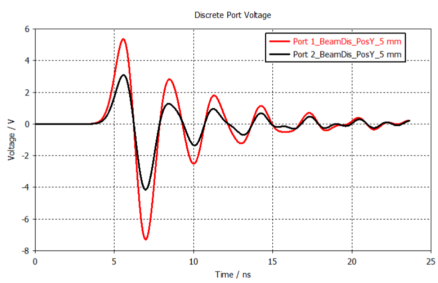


Figure 4: Output signals while displacing a beam 5.0 mm off in the vertical axis. The red curve and black curve represent voltage signals recorded by the opposite ports.

After evaluation of of k-factor we used the following steps to determine the tolerance associated with the shielding piece;

i Change the geometry of the shielding piece slightly (for example change the width of an RF-slot) that creates asymmetric geometry with respect to opposite o ports.

ii Re-run the simulation with the centered beam which generates two different amplitude of port voltages, similar to Fig. 4, because of the asymmetric geometry.

iii Evaluate the beam position error corresponds to the difference between the amplitude of port voltages using the calculated value of k.

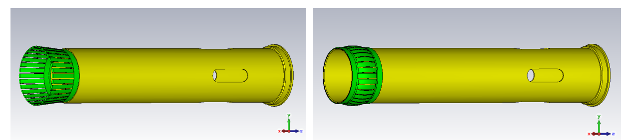
Using the value of $k = 16.68$ mm, we evaluated the mechanical tolerances of the shielding piece for three different parameters: the width of RF-slot, the radial gap between the shielding piece and stripline electrodes, and rotating the shielding piece with respect to beam axis. All these values of mechanical tolerances are listed in Table 2. These large value of tolerances will ease the fabrication process of the desired shielding piece. As the rotation of the shielding piece does not create asymmetric geometry, we used a transversely displaced beam of 1.0 mm to record opposite port voltages, and finally subtract this 1.0 mm from the evaluated beam position error.

CURRENT STATUS

Currently we have two slightly different (in terms of RF-fingers) CAD designs of the RF-shielding piece. In the he first design, Fig. 5(a), the RF-fingers are welded along the shielding piece cross-section and are slightly curved inwards to ensure a good RF-contact with the beam pipe, while the second design, Fig. 5(b), the fingers stay outside the shielding piece and it seems more practical in terms of risk associated during its insertion and replacement. The length of these shielding pieces are slightly longer than shown in the Fig. 2(b) to ease for bench testing.

Table 2: Tolerances Associated with the Shielding Piece

Parameters	**Change by**	**Beam Position Error (µm)**
Width of RF-slot	25 µm	54
	50 µm	57
Radial gap	50 µm	240
Axial rotation	3°	28



(a) (b)

Figure 5: CAD design of two slightly different shielding pieces with RF-fingers (a) along the shielding piece cross-section, and (b) outside the shielding piece cross-section.

SUMMARY AND FUTURE WORKS

We explored the feasibility of reusing the RHIC stripline BPMs for the EIC hadron ring by inserting an RF-shielding piece. CST simulations showed a significant reduction in both the discrete port voltage (by a factor of ~ 15) and the real part of the wake impedance (by a factor of ~ 18) while putting a shielding piece into the stripline BPM. The dimension of RF-slots for this shielding piece are chosen to be 2.6 inch × 0.6 inch to lower the heating effect without compromising the strength of output signals. In addition, simulation showed practically attainable results for the mechanical tolerances: 25 microns for the width of RF-slot, 50 microns for the radial gap, and 3-degrees for its axial rotation. Currently, two prototype designs for the shielding piece are ready for the fabrication. Finally, we are planning a bench set up to cross check and to validate simulation results.

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