CONCEPTUAL DESIGN OF A HIGH PRECISION DUAL DIRECTIONAL BEAM POSITION MONITORING SYSTEM FOR BEAM CROSSTALK CANCELLATION AND IMPROVED OUTPUT PULSE SHAPES*

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Abstract

The Relativistic Heavy Ion Collider (RHIC) would benefit from improved beam position measurements near the interaction points that see both beams, especially as the tolerances become tighter when reducing the beam sizes to obtain increased luminosity. Two limitations of the present beam position monitors (BPMs) would be mitigated if the proposed approach is successful. The small but unavoidable cross-talk between signals from bunches traveling in opposite directions when using conventional BPMs will be reduced by adopting directional BPMs. Further improvements will be achieved by cancelling residual cross-talk using pairs of such BPMs. Appropriately delayed addition and integration of the signals will also provide pulses with relatively flat maxima that will be easier to digitize by relaxing the presently very stringent timing requirements.

INTRODUCTION

Accurate beam position monitoring is especially important close to the interaction points (IPs) at colliders such as the Relativistic Heavy Ion Collider (RHIC) [1] where small (tens of μm) colliding beams need to overlap as well as possible to maximize luminosity. The presently used single ended stripline beam position monitors (BPMs) [2] are not accurate enough to achieve this goal, and other means need to be used to optimize the luminosity [3]. It is not clear that even perfect BPMs would suffice, but they could be much more useful if their precision could be improved.

Aside from fabrication and installation alignment issues, the basic problem with single-ended stripline BPMs is that, even when placing them as far as possible from the IPs, the arrival time difference between opposite bunches is not large enough to totally avoid interference. In other words, tails and oscillations following the signal generated by the first bunch to arrive have not decayed sufficiently when the next bunch arrives from the opposite direction.

Directional BPMs [4], i.e., those which have symmetrical striplines (not grounded at one end; see Figure 1) offer the advantage, at least in principle, to separate the signals from bunches traveling in one direction from the signals from bunches traveling in the opposite direction.

Figure 1 illustrates how this works. A positive bunch arriving from the left (upper part of the figure) induces a negative charge -Q on the inside of the stripline that is proportional to the bunch charge and is a function of the bunch position. An equal positive charge Q is generated at the beginning of the stripline on its opposite side as the bunch moves in. This positive charge is being generated at the junction of two 50 Ω transmission lines; the feedthrough leading to the 50 Ω resistor and the stripline forming a 50 Ω transmission line with the grounded inner surface of the beam pipe. Therefore the positive charge is divided equally between these two lines and half of it, Q/2, flows through the resistor and the other half travels to the right in the strip line.

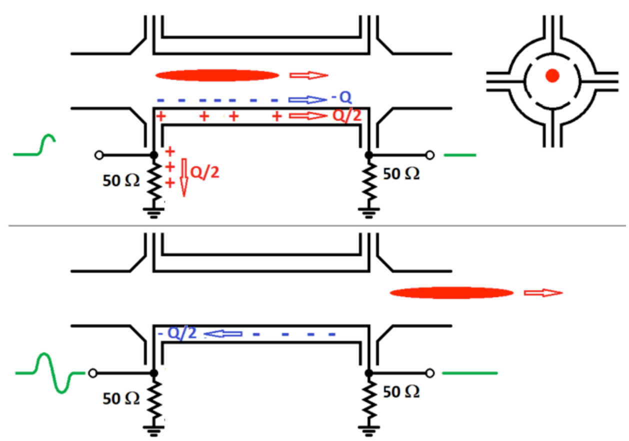

Figure 1: Schematic representation of charges induced by a bunch on one of the striplines of an ideal directional BPM (see text). Only two outputs are shown out of a total of four (for a single plane BPM).

As the bunch exits to the right (lower part of the figure), it releases the induced charge -Q at the junction of the stripline transmission line and the feedthrough line leading to the second 50 Ω resistor. Therefore, half of this charge (-Q/2) travels to the left in the strip line and the other half that would flow through the 50 Ω resistor is neutralized exactly by the +Q/2 charge arriving from the

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left. Therefore there is a bipolar signal generated in the first 50 Ω resistor and no signal at all in the second one. Of course a bunch traveling in the opposite direction will produce a bipolar signal on the resistor to the right and no signal at the left.

This simplified ideal description is however not very realistic. In reality, for reasons given below, one always gets at least a small signal at the outputs that are not supposed to respond. The result is that cross-talk between the opposite direction channels cannot be totally avoided. The reasons for this departure from ideal behavior is that the striplines are not ideal transmission lines and that the BPM is a complex three-dimensional structure where the bunches interact with all the electrodes and the electrodes in turn have some coupling to each other. Also, due to the gaps between the striplines, some charge is induced directly on the beam pipe and impedance mismatches can never be totally avoided. All these effects contribute to the output signals in ways that are not accounted for in the simplified description. We will show realistic PARTICLE STUDIO [5] simulations but first we describe a proposed solution that should, for all practical purposes, compensate this non-ideal behavior by using two BPMs next to each other.

THE PRINCIPLE OF THE DUAL DIRECTIONAL BPM

Using two consecutive BPMs the idea is to take advantage of the difference in the signal time sequence for bunches traveling in opposite directions in such a way that the undesirable parasitic signals cancel while the desirable ones remain.

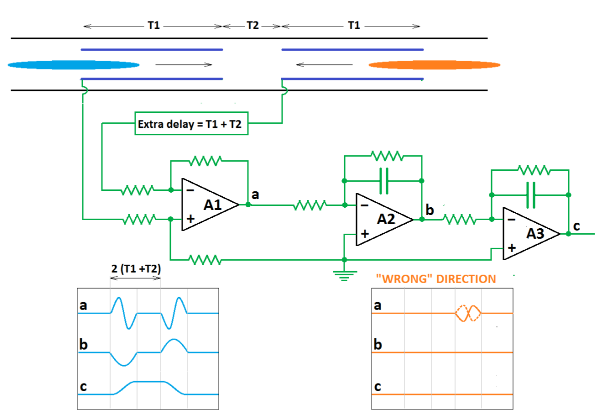

Figure 2: Schematic illustration of the precision dual directional beam position monitoring system. Only one channel out of four is shown. The delays are arranged in such a way that residual signals from "wrong" direction bunches cancel in each of the four (or eight for a two plane BPM) channels. Positions are obtained in the usual way; difference/sum of opposite side signals obtained after two stages of integration shown schematically only (see text). The two "wrong" direction signals labeled "a" cancel each other and are only shown separately for illustration.

The arrangement to implement this approach is shown schematically in Fig. 2 for one out of 4 channels in the case of a single plane system or out of 8 for a two plane BPM. The output labeled "**a**" of the difference amplifier A1 is already compensated and could be digitized and used for the position determination. However two stages of integration are shown schematically.

These stages improve the pulse shape even though the flat topped pulse "c" can in reality only be obtained for very short bunches or relatively large separations between the two BPMs. Real pulse integrators will require baseline stabilization not shown here.

PARTICLE STUDIO MODELLING

The 3D model used for the PARTICLE STUDIO® (PS) [5] simulations is shown in Fig. 3. The design is adapted from existing single-ended two plane RHIC BPMs. For PS simulations the design is simplified by eliminating supports and the coaxial 50 Ω feedthrough connections. Instead of these connections, "discrete ports" (essentially 50 Ω resistors) are connected between all the ends of the striplines and the beam pipe. A Gaussian bunch entering one end or the other (or both) excites the structure, and pulse shapes across all of the discrete ports are obtained as outputs of the simulation.

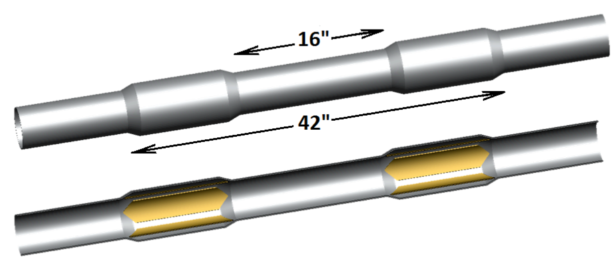

Figure 3: Five-inch-diameter BPM model used for the Particle Studio simulations.

For the results shown below single bunches were used containing 3×10^{11} protons with an RMS width of 20 cm and a vertical offset of 1". First a bunch was injected from the side that generates the desired position signals and then from the opposite side to evaluate the effectiveness in suppressing the parasitic signals. Appropriately delayed simulated outputs were numerically processed in the way indicated in Fig. 2 and are shown below for both cases ("right" and "wrong" direction). We show the outputs of the amplifiers **a** (and its components), **b** and **c**. Gains were selected arbitrarily in these stages to keep voltage values within ± 10 V.

The curves labeled "Component 1" and "Component 2" are the single BPM responses which when combined attenuate the parasitic "wrong direction" signals. We see that before this attenuation takes place the amplitude of the parasitic signals is ~13% of the main signals. It was found that this percentage is strongly dependent on the

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beam position offset. How much this signal contamination would affect the beam position measurement depends on the relative timing of the two bunches and their amplitudes and positions, but the error may be very significant. After the compensation this amplitude is reduced by a factor ~120. After two integrations the amplitude of the spurious signal is only 0.03% of the main signal, i.e., totally negligible.

After the second integration the top of the pulse is fairly flat, which should help with making accurate digitization less sensitive to small timing errors. It should be noted however that this pulse would not be as flat for bunches longer than the 20 cm RMS assumed here and/or for more complex non-Gaussian bunch shapes often observed in RHIC. The cancellation effectiveness of the “wrong direction” signals should be independent of bunch shape.

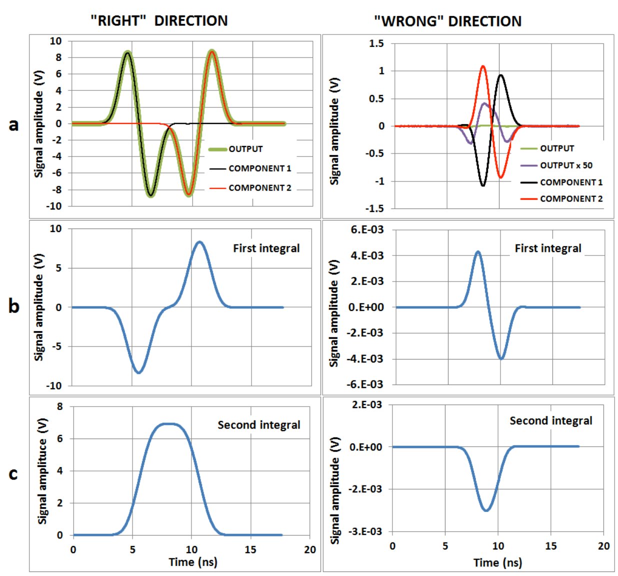

Figure 4: Results from the Particle Studio simulation (see text).

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CONCLUSIONS

The dual BPM system described here may be helpful in establishing collisions in the RHIC IPs, a task that becomes increasingly challenging as the beam sizes are reduced.

The PS simulation shows how large the parasitic signals can be from a single directional BPM and how well they are compensated with the present dual BPM scheme. Careful alignment will be required to obtain the best compensation. The advantages that have been demonstrated with this simulation are the effective suppression of the parasitic signals, the freedom of placing such systems at any distance from the IP, including at the IP itself if desired, and an improved pulse shape easier to digitize accurately.

We now plan to fabricate and test a prototype that will be similar to the model shown in Fig. 3. If these tests are as successful as we expect such systems may be implemented in at least two of the RHIC interaction regions.

ACKNOWLEDGEMENTS

We appreciate the contribution by Karim Hamdi, who generated the 3D solid models used as input to the Particle Studio simulations.

REFERENCES

[1] T. Roser, “RHIC and its Upgrade Programs,” Proceedings of EPAC08, Genoa Italy, Annu. Rev. Nucl. Part. Sci. 2002. 52:435-69

[2] P. R. Cameron, M. C. Grau, W.A. Ryan, T.J. Shea and R.E. Sikora, “RHIC Beam Position Monitor Assemblies,” 1993 Part. Acc. Conf.

[3] Most often the transverse beam position is scanned as in a vernier scan with a small amplitude. Vernier scans are described in A. Drees and T.D’Ottavio, Proceedings of PAC09, Vancouver, BC, Canada, pp. 2480-2482 (2009).

[4] See e.g. J. Borer and R. Jung CERN/LEP – BI/84-14 (CAS, 1984) and references therein.

[5] PARTICLE STUDIO is part of the CST STUDUIO SUITE, Computer Simulation Technology AG, www.cst.com.

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