ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-WEPCO14

SPIRAL BEAM POSITION MONITOR FOR HEAVY ION BEAMS

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Abstract

For slow, short, and thick beams, spiral shaped beam position monitors (BPMs) are expected to provide good linearity and multiple information readouts despite their small size. At the RIKEN Nishina Center, ion beams are accelerated using linacs and cyclotrons. However, some beams are slow enough compared to relativistic speeds, the bunch length is about the same as the electrode size, and the beam diameter may be close to the electrode spacing. For such beams, conventional "diagonal cut" or "cosine two-theta cut" (for quadratic moments) BPMs produce deviations in signal heights. To solve this problem, it is expected that the signal height deviation can be eliminated by cutting the electrode in a spiral shape. Furthermore, by cutting in a spiral shape, multiple cuts can be placed in one BPM, and it is expected that beam intensity, horizontal position, vertical position, and second moment can be read out at a single location. The simulation results show small error within a few percent.

INTRODUCTION

At RIKEN's RI Beam Factory (RIBF) at the Nishina Center, a combination of multiple accelerators is used to accelerate various ions—from hydrogen to uranium—for experimental applications. Ion beams, due to their large mass, often remain non-relativistic even after acceleration. Such slow beams are susceptible to space-charge effects, necessitating beam transport at large diameters to mitigate these effects. Under these conditions, conventional assumptions for BPM responses, such as the beam traveling at near light speed ($\beta \sim 1$) or having a width σ much smaller than electrode gap D ($\sigma << D$), do not hold, requiring special design considerations. For large width beam, high-linearity BPM types, such as diagonal-cut or cosine-two-theta-cut (for second-order moment measurement), exist. However, under our beam conditions, these BPMs yield measurement inaccuracies unless corrected [1].

For instance, a simulation of a diagonal-cut BPM is shown in Fig. 1. It has electrode length of 50 mm, duct inner diameter 40 mm, beam length 0.3 ns, $\beta = 0.1$, and output impedance of 95 Ω reveal differing signal amplitudes between the upper and lower electrodes even when the beam passes through the duct centre. This offset phenomenon can be qualitatively attributed to variations in the axial structure of each electrode.

Notably, this offset becomes negligible when the beam length σ_z is much longer than the electrode length L ($\sigma_z >> \mathrm{L}$).

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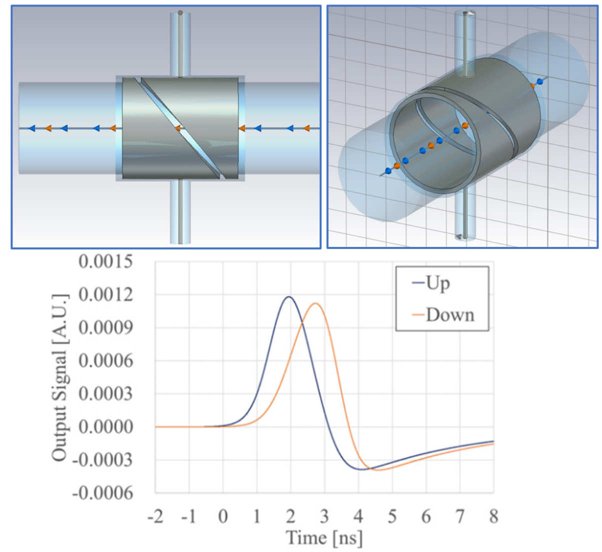

Figure 1: Side view and perspective view of a BPM Model (Top) and simulated signals of the BPM (Bottom).

SPIRAL CUT BPM

A spiral cut type BPM [2] is shown in Fig. 2. It has 8 electrodes. Each electrode is separated by cosine θ, sine θ, or cosine 2θ curve. The spiral BPM is axisymmetric. So, no deviation in signal height occurs.

By selecting electrode combinations, one can extract four kinds of information: beam intensity, horizontal position, vertical position, and quadratic moments.

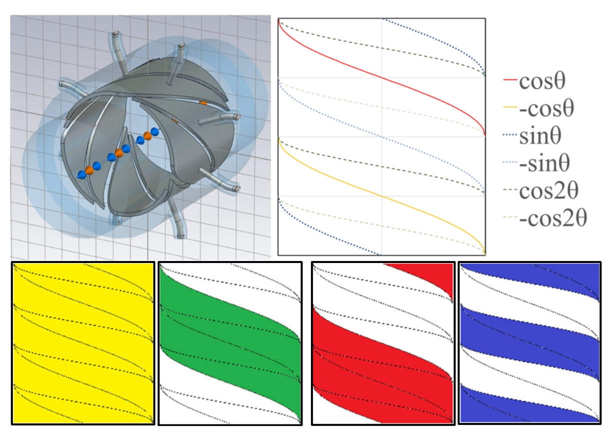

Figure 2: (Top Left) A perspective view of the 8 electrodes spiral BMP model, (Top Right) developed view of electrodes, (Bottom, left to right) the combinations of electrodes to measure intensity, x, y, and x^2-y^2.

DOUBLE INTEGRAL

Even spiral cut type BPM shows non-linearity at non-relativistic velocities. The electric field spreads out along

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the axis direction at non-relativistic velocities, which deforms the signal.

Let $Q(r, \theta, z, r', \theta', z')$ denote the charge induced at a point (r', θ', z') on the electrode by a point charge at position (r, θ, z), $f(r', \theta', z')$ denote the electrode structure and the charge distribution as $\rho(r, \theta, z, t)$, the total induced charge on the electrode is expressed by the following equation

$$Q_s(t) = \int Q(r,\theta,z,r',\theta',z')f(r',\theta',z') \rho(r,\theta,z,t)\, dr\, d\theta\, dz\, dr'\, d\theta'\, dz'. \quad (1)$$

Then, the output voltage $V(t)$ of the BPM at time t is given by the following equation :

$$V(t) = \frac{1}{C}\int_{-\infty}^{t} \frac{\mathrm{d}Q_S(t\prime)}{\mathrm{d}t\prime} e^{-\frac{t-t\prime}{RC}} \mathrm{d}t'. \quad (2)$$

Here, R represents output impedance and C represents capacitance of BPM.

This equation is complicated. But if we integrate signal twice as

$$S = \int_{-\infty}^{\infty}\int_{-\infty}^{t} V(t)\,\mathrm{d}t\,\mathrm{d}t = R\int Q'(r,\theta,r',\theta')f'(r',\theta')\rho'(r,\theta)\, dr\, d\theta\, dr'\, d\theta'. \quad (3)$$

Here, Q', f', and ρ' are the integral of Q, f, and ρ over z direction.

S only depends on radial structure and independent from longitudinal structure like a relativistic beam. So, double integral recovers the linearity.

SIMULATION RESULT

We carried out a simulation of spiral BPM by using CST Studio suite. The condition of the simulation is summarized in Table 1 and the results are shown in Fig. 3 and Fig. 4. It shows good linearity up to the vicinity of the electrode. The error is 6 % on position and 8 % on quadratic moment.

Table 1: Simulation Condition

	Spiral BPM
Electrode length	60 mm
Electrode bore diameter	60 mm
Electrode gap	3 mm
Output impedance	50 Ω
Beam speed (β)	0.15
Beam length	0.37 ns
Beam position	-29 mm - 29 mm

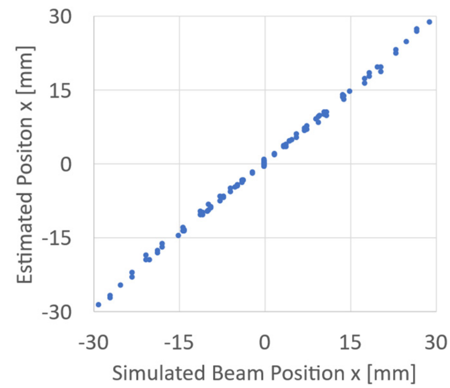

Figure 3: Input beam position in simulation vs. the position estimated from simulated output signal.

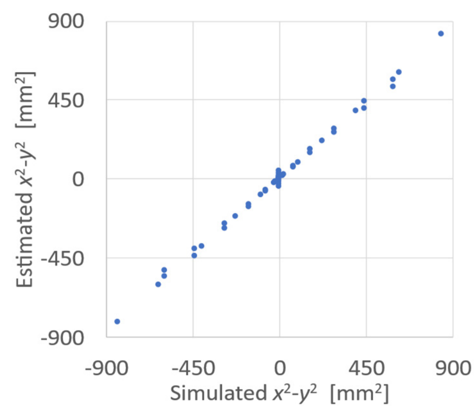

Figure 4: Input beam's quadratic moments (x^2-y^2) vs. that estimated from simulated output signal.

CONCLUSION

The spiral BPM provides good linearity due to its axisymmetric shape. The spiral BPM provides multiple information readouts at single BPM. By applying double integration on output signal, it can recover linearity on non-relativistic velocity. The simulated result shows a 6 % error in position and 8 % error on quadratic moment.

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