Design study of beam position monitor for heavy-ion beam†

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Owing to their large mass, heavy ion beams may remain at non-relativistic velocities even after acceleration. Slow beams are also susceptible to space-charge effects, which may necessitate beam transport with a large beam diameter to mitigate them. The response of beam position monitors (BPM) to such beams requires special consideration. This is because it cannot allow the use of the approximations that the beam is sufficiently fast ($\beta \sim 1$) or the beam width σ is sufficiently small relative to the distance D between the electrodes ($\sigma \ll D$).

There exist BPMs with high linearity in a wide region between electrodes, such as the diagonal-cut type and the $\cos 2\theta$ type (for second-order moments). However, even these BPMs cannot be measured accurately without corrections for our beam conditions. Figure 1 shows a picture of the Beam Energy Position Monitor (BEPM)[1] used at RIKEN's SRILAC that can determine the quadratic moment and their measurement results. Despite the beam passing through the center, there is a difference in the pulse height, which causes an offset. This offset is attributed to the beam axial structure of the electrode. Therefore, if the beam passing through it is sufficiently longer than this, this effect is considered negligible. Further, the offset is considered to be strongly manifested when the beam length σ_z is sufficiently shorter than the electrode length L ($\sigma_z \ll L$).

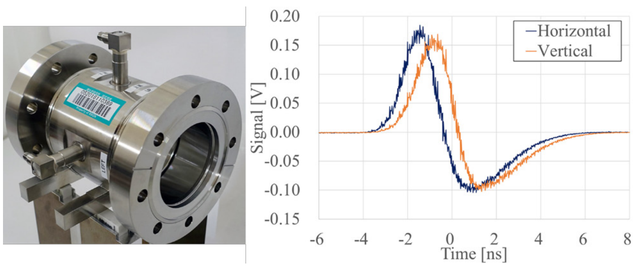

Fig. 1. (Left) Photograph of the BEPM. (Right) Signals from the BEPM.

A spiral-cut electrode could be a countermeasure against the offset. The structure of the spiral-cut electrodes comprises diagonal cut electrodes cut in half, rotated 180°, and connected. In the spiral-cut BPM, offsets occurring in the measurement of the vertical position are canceled out by the right and left halves; consequently, no offset occurs. A further advantage of the spiral-cut is that multiple cuts can be superimposed. In a normal diagonal cut, vertical and horizontal BPMs cannot be placed in the same place; therefore, they must be placed backward and forward. In contrast, with the spiral-cut, three types of cuts—$\cos\theta$, $\sin\theta$, and $\cos 2\theta$—can be superimposed on a single BPM. A spiral-cut BPM with eight-electrodes is shown in Fig. 2 (Left). In this BPM, four types of information can be obtained by combining the readout electrodes: beam intensity, horizontal position, vertical position, and second moment.

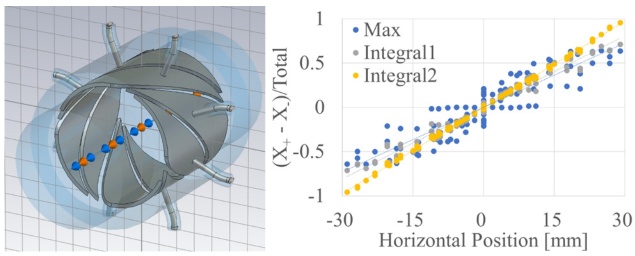

Fig. 2. (Left) Schematic view of the spiral-cut BPM. (Right) Simulated beam position vs. evaluated beam position. Blue, gray, and yellow dots show the results by using pulse height, integrated pulse height, and double integrated pulse height.

The diagonal-cut type typically provides good linearity over a large space. However, non-linearity appears in the case of slow beams. This is also the case for the spiral-cut. Non-linearity in the response with respect to position is problematic when the beam has a width. This is because it produces errors in the calculation of the beam position. This can be avoided by using the double integration of the waveform instead of the pulse height.

The output signal of each electrode is obtained by simulation when a beam of zero width is passed through various positions in an 8-electrodes spiral-cut BPM. A calculated result is shown in Fig. 2 (Right). In the calculations, the double integral retained good linearity. The evaluation of the error in the case of a thick beam showed that if the beam position was within ±2 mm from the center, the error in position was within ±0.1 mm, even if the beam width varied 0–15 mm. The error in the second moment ($x^2 - y^2$) was less than ±0.6 mm^2.

The 8-electrodes spiral-cut BPM is considered to be capable of accurately determining four types of information for slow, thick heavy ion beams: beam intensity, horizontal position, vertical position, and quadratic moment.

Reference

1) T. Watanabe *et al.*, Proc. of IBIC 2019, (2019), p. 526.

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