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Abstract

The four electrodes in the stripline beam position monitor (BPM) for Hefei Light Source (HLS II) storage ring are of axially symmetric type. We have derived a new calibration method of electrode gains for this type stripline BPM. The gain fit error of different data grids was analyzed, and the $±$5 mm by $±$5 mm grid is the best. The electrode gains of two stripline BPMs (HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2) were obtained based on offline calibrated data. The results show that data after fitting gains are improved, with the electrode gains being between 0.94 and 1.15.

Full Text

Preamble

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Calibration method for electrode gains in an axially symmetric stripline BPM

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The four electrodes in the stripline beam position monitor (BPM) for the Hefei Light Source (HLS II) storage ring are of axially symmetric type. We have

derived a new calibration method for the electrode gains of this type of stripline BPM. The gain fit error for different data grids was analyzed, and the $±$5 mm by $±$5 mm grid was found to be optimal.

The electrode gains of two stripline BPMs (HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2) were obtained based on offline calibrated data. The results show that the data are improved after fitting the gains, with the electrode gains ranging between 0.94 and 1.15.

Keywords: Stripline beam position monitor, Electrode gain, Axially symmetric, Calibration

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Introduction

The Hefei Light Source (HLS) is being upgraded to HLS II. Three stripline BPMs are designed to measure the beam position, emittance, and momentum dispersion in the storage ring. To decrease the beam emittance, the circular vacuum chamber of the storage ring will be changed to an octagonal type. A cross-section of the stripline BPM is shown in Fig. 1 [Figure 1: see original paper] (dimensions in mm).

Due to mechanical errors in the stripline BPM, the four axially symmetric electrodes, labeled #R, #L, #T, and #B to denote the horizontal (right and left) and vertical (top and bottom) electrodes, do not have identical relative gains. These differences in electrode gain couple the measured horizontal position with the vertical position, resulting in measurement errors [**?**]. To measure beam parameters correctly, the electrode gains of a stripline BPM must be determined.

Electrode gains for button BPMs were measured by Rubin et al. [**?**]. This method requires mirror-symmetric geometry of the four BPM electrodes. BPM electrode geometries can be either mirror-symmetric or axially symmetric. The measurement method for electrode gains in mirror-symmetric type stripline BPMs is the same as that for button BPMs. However, the BPM electrodes in the HLS II storage ring have axially symmetric geometry, and we have developed an offline measurement method to determine the electrode gains, which uses three electrode gains and a correction factor.

Methods

The quadrupole component with the difference/sum method for the stripline BPM can be expressed as Eq. (1):

$$Q_{\Delta/\Sigma} = \frac{V_R + V_L - V_T - V_B}{V_R + V_L + V_T + V_B}$$

where V_R, V_L, V_T, and V_B are the electrode signals for the four electrodes.

Assuming that the #R, #L, #T, and #B electrodes lie on the X and Y axes as shown in Fig. 1, and ignoring higher-order components, the quadrupole component for an axially symmetric stripline BPM in a circular vacuum chamber [?, ?] can be calculated by Eq. (2):

$$Q_{\Delta/\Sigma} = S_Q \left(x_0^2 - y_0^2 + \sigma_x^2 - \sigma_y^2\right)$$

where (x_0, y_0) is the beam position in the BPM, (σ_x, σ_y) is the beam transverse size, and S_Q is the quadrupole component sensitivity, which depends on the azimuthal opening angle of the electrodes and the distance from the electrode to the BPM center.

For an axially symmetric stripline BPM on an octagonal vacuum chamber, the boundary element method [?] and Gaussian weighted method of 2D-grid structure [?] are used to simulate beam motion in the BPM. A model for the stripline BPMs in the HLS II storage ring was established based on the boundary element method using Matlab.

The quadrupole component $Q_{\Delta/\Sigma}$ for the stripline BPM in the HLS II storage ring can be calculated as:

$$Q_{\Delta/\Sigma} = Q_0 + S_Q \left(x_0^2 - y_0^2 + \sigma_x^2 - \sigma_y^2\right)$$

Because the distance between horizontal electrodes differs from that between vertical electrodes, there exists a non-zero component Q_0, compared to the stripline BPM on a circular vacuum chamber.

Ignoring higher-order components, the electrical position (P_x, P_y) can be obtained using the difference/sum method:

$$P_x = \frac{V_R - V_L}{V_R + V_L} = S_x x_0, \quad P_y = \frac{V_T - V_B}{V_T + V_B} = S_y y_0$$

Combining Eqs. (3) and (4) to eliminate x_0 and y_0, we obtain an expression relating the electrode signals and beam transverse size:

$$Q_{\Delta/\Sigma} - Q_0 = S_Q \left[\left(\frac{P_x}{S_x}\right)^2 - \left(\frac{P_y}{S_y}\right)^2 + \sigma_x^2 - \sigma_y^2\right]$$

By using a point charge to substitute for the Gaussian beam, (σ_x, σ_y) becomes $(0, 0)$, and Eq. (5) simplifies to:

$$Q_{\Delta/\Sigma} - Q_0 = S_Q \left[\left(\frac{P_x}{S_x}\right)^2 - \left(\frac{P_y}{S_y}\right)^2\right]$$

Since HLS is being upgraded, the electrode gains can be measured offline rather than online. Two stripline BPMs (HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2) were calibrated [?] using the antenna method with a 0.2-mm tungsten filament. This situation can be regarded as the beam passing through the stripline BPM with (σ_x, σ_y) equal to $(0.2 \text{ mm}, 0.2 \text{ mm})$ and $\sigma_x^2 - \sigma_y^2 = 0$, so the electrode gains can be calculated using Eq. (6).

Before measuring the electrode gains, the parameters (S_x, S_y, Q_0, S_Q) must be determined. The boundary element method [?] was used to simulate a point charge moving in a grid of $±$5 mm by $±$5 mm with a 0.5 mm step. The four electrode signals V_R, V_L, V_T, and V_B were obtained to calculate the beam positions (Fig. 2) using Eq. (4). The position sensitivities (S_x and S_y) can be obtained by fitting the simulation data. As shown in Fig. 2, $S_x = 0.0773 \text{ mm}^{-1}$ and $S_y = 0.0764 \text{ mm}^{-1}$. The quadrupole component $(Q_{\Delta/\Sigma})$ calculated using Eq. (1) at point charge positions (x_0, y_0) from $(0, 0)$ to $(5, 5)$ only (due to symmetry) is shown in Fig. 3. By plotting and fitting the data of $(Q_{\Delta/\Sigma} - Q_0)$ versus $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$ for $Q_{\Delta/\Sigma}$ at (x, y) from $(-5, -5)$ to $(5, 5)$, the parameters Q_0 and S_Q can be obtained using Eq. (6). Since electrode gains would be measured offline based on Eq. (6), to directly obtain constraints on the four electrode signals and reduce calculation error, $(x_0^2 - y_0^2)$ should be replaced by $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$.

As shown in Fig. 4, $(Q_{\Delta/\Sigma} - Q_0)$ varies linearly with $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$, and the fitting yields $Q_0 = -0.7832$ and $S_Q = 0.0012 \text{ mm}^{-2}$.

Gain Error of the BPM Electrodes

In practice, due to mechanical errors in the stripline BPM, the four electrodes do not have identical gain, which breaks the relationship defined by Eq. (6). The effect of gain errors was simulated by introducing an 8% reduction in the signal on electrode #R. Fig. 5(a) shows $(Q_{\Delta/\Sigma} - Q_0)$ versus $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$ under this condition for simulated data on a $±$5 mm by $±$5 mm grid. The relationship between $(Q_{\Delta/\Sigma} - Q_0)$ and $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$ is no longer linear, deviating from zero (marked by the + sign). The BPM (HLS II SR-BD-STLB1) was calibrated offline [?], and the results are shown in Fig. 5(b). The situation is similar to Fig. 5(a), confirming that the four electrodes of this BPM have different gains.

Due to the gain errors of the four BPM electrodes, Eq. (6) is no longer applicable. Therefore, a nonlinear least-squares fitting method was used to determine the electrode gains (g_R, g_L, g_T, and g_B). The merit function is:

$$\chi^2 = \sum_i \left\{ \frac{g_R V_R^i + g_L V_L^i - g_T V_T^i - g_B V_B^i}{g_R V_R^i + g_L V_L^i + g_T V_T^i + g_B V_B^i} - c \cdot S_Q \cdot \left[\left(\frac{1}{S_x} \frac{g_R V_R^i - g_L V_L^i}{g_R V_R^i + g_L V_L^i} \right)^2 - \left(\frac{1}{S_y} \frac{g_T V_T^i - g_B V_B^i}{g_T V_T^i + g_B V_B^i} \right)^2 \right] \right\}^2$$

where c is a coefficient to correct S_Q.

The best-fit gains (g_R, g_L, g_T, and g_B) and c are obtained by minimizing χ^2. This method was used by Rubin et al. [**?**], who obtained desirable results by constraining one electrode gain to equal 1 each time for each of the #R, #L, #T, and #B electrodes and averaging the data from the fitting measurements. They also found that different grid data affected the gain fitting algorithm, so gain fit error was analyzed for various grids.

Fig. 6 [Figure 6: see original paper] shows the gain fit error for three different grids with 1%–12% reduction in electrode signal. For each fit, the relative difference between the fitted gains and the real gains was calculated as $\Delta g = (|g_{\text{fitted}} - g_{\text{real}}|/g_{\text{real}}) \times 100\%$. The results demonstrate that the data grid size affects the gain fitting algorithm. The $±$3 mm by $±$3 mm grid is too small, resulting in the largest gain fit errors, while the $±$8 mm by $±$8 mm grid is too large, causing higher-order components to be non-negligible and violating the assumptions underlying Eqs. (3) and (4), which are valid only within a certain range of the stripline BPM. We found that among all data grids, the $±$5 mm by $±$5 mm grid yields the smallest gain fit error, so it was chosen for measuring electrode gains.

Results of Calibration

Two BPMs, HLS II SR-BD-STLB1 and HLS II SR-BD-STLB2, were calibrated offline [**?**]. The beam was simulated using a 0.2-mm tungsten filament. The filament was moved relative to the BPM by a stepper motor in a $±$5 mm by $±$5 mm grid, and data were acquired using Libera Brilliance [**?**]. The fitting results for HLS II SR-BD-STLB1 are shown in Fig. 7 [Figure 7: see original paper], which demonstrates that the data points after gain fitting are linear and pass through zero (0, 0). The fitted gains for the two BPMs are shown in Fig. 8 [Figure 8: see original paper], where the electrode gains range between 0.94 and 1.15.

Conclusion

We have derived an offline measurement method for electrode gains in axially symmetric stripline BPMs. Simulation results show that the fitted electrode gain error is minimized in a $±$5 mm by $±$5 mm grid, and the $(Q_{\Delta/\Sigma} - Q_0)$ versus $\left[(P_x/S_x)^2 - (P_y/S_y)^2\right]$ curve after gain fitting is linear and passes through zero. In the future, online measurement of the electrode gains will be performed and the results will be compared with the offline results.

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References

[1] Rubin D L, Billing M, Meller R, et al. Phys Rev Spec Top-AC, Venice, Italy, 2007. 2010, 13: 092802.

[2] Miller R H, Clendenin J E, James M B, et al. Nonintercepting Emittance Monitor, SLAC-PUB-3186, 1983.

[3] Fang J, Sun B G, Lu P, et al. Atom Energ Sci Technol, 2011, 44: 511–516. (in Chinese)

[4] Olmos A, Pérez F, Rehm G. Matlab Code for BPM Button Geometry Computation. Proceedings of DIPAC 2007, 186–188.

[5] Russell J S, Gilpatrick D J, Power J F, et al. Characterization of beam position monitor for measurement of second moment. Proceedings of PAC 1995, 2580–2582. Dallas, USA, 1995.

[6] Wu F F, Zhou Z R, Sun B G, et al. High Power Laser Part Beam, 2011, 23: 2971–2975. (in Chinese)

[7] Ma T J, Yang Y L, Sun B G, et al. Nucl Sci Tech, 2012, 23:

Note: Figure translations are in progress. See original paper for figures.