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STUDY OF XBPM DIAGNOSTIC PARAMETERS IN THE TPS FRONTEND*

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Abstract

The XBPM installed in the TPS frontend determines the center position of the photon beam using four CVD diamond blades. The combination of XBPM and upstream/downstream EBPM readings of the insertion device enables verification of the photon beam's alignment along the correct trajectory. Significant changes in the beam position or profile, as well as prolonged periods without recalibration, may cause the XBPM measurement data to lose its reliability. Therefore, evaluating the reliability of the XBPM measurement data is of critical importance. By analyzing the deviation between the theoretical and measured blade intensities and calculating the standard deviation of the similarity percentage among the four blades, a reliability indicator is established. The variation of this indicator is analyzed under different conditions and compared with the corresponding Q values.

INTRODUCTION

The X-ray Beam Position Monitor (XBPM) is mounted within the frontend vacuum chamber of the accelerator and serves to monitor the spatial position of the transmitted synchrotron radiation beam, thereby enabling accurate beamline alignment and diagnostics. In the frontend of the Taiwan Photon Source (TPS), a blade-type XBPM is employed. The main structure of the XBPM is based on the design developed by the Advanced Photon Source (APS) in the United States [1, 2]. Four gold-coated chemical vapor deposition (CVD) diamond blades are mounted on an oxygen-free copper base equipped with internal cooling water channels. The distances between the blade tips are 5 mm in the horizontal direction and 3 mm in the vertical direction. Schematic diagrams showing the side and front views of the XBPM are presented in Fig. 1.

Signal acquisition and processing are performed using a LIBERA PHOTON, which captures the micro-current generated by CVD diamond blades and calculates the center position of photon beam in real time. Most of XBPM1 units installed in the TPS insertion device frontend have completed calibration procedures. These units now provide real-time measurements of the synchrotron radiation beam center position at the frontend, serving as a reference for the control room and beamlines.

XBPM Diagnostic Parameters

The XBPM center position is computed using dedicated calibration parameters. Nevertheless, its positional accuracy is subject to fluctuations arising from multiple factors, including variations in electron beam current, insertion device gap widths, and the dynamic properties of the synchrotron radiation source. Therefore, diagnostic parameters are required to determine whether the position values provided by the XBPM still maintain the same level of accuracy as achieved during the initial calibration.

The Q-value in a four-signal position detector is commonly employed as an indicator of signal stability, particularly in electron position monitor. It is defined by comparing the diagonal signal pairs of the detector. Specifically, the signals from two opposite blades are summed, and the difference between the two diagonal sums is calculated. This difference is then normalized by the total signal amplitude and scaled by a calibration constant K, where A, B, C and D denote the signal intensities collected by the four blades. The corresponding expression is given by Eq. (1):

$$Q = K\,\frac{(A+C)-(B+D)}{(A+B+C+D)}. \tag{1}$$

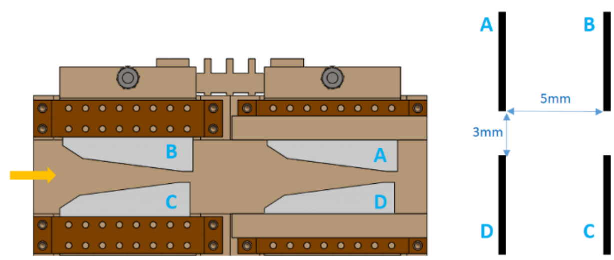

Figure 1: Schematic diagrams of the side and front views of the XBPM in TPS.

The principle of XBPM calibration is based on the correlation between the beam position and the signal intensities collected by four diamond blades. As the synchrotron radiation source shifts position, the photocurrents induced on each blade exhibit corresponding changes in intensity. Within a range of several hundred micrometers, these variations demonstrate an approximately linear relationship, defining what is referred to as the effective linear region. Within this linear region, a stable and reproducible correspondence exists between the beam center position and the blade signal values. Consequently, the beam center can be reliably calculated using a predefined formula [3]. Accordingly, the theoretical blade signal values corresponding to a given beam center position can be calculated using a proportional formula. By comparing these theoretical values with the actual measured blade signals, one can assess whether the current beam position remains accurate relative to the original calibration.

The proportional formula used to compute the theoretical blade signal values is given below. As an example, the calculation for Blade A is shown; the same principle is applied to Blades B, C, and D accordingly. The parameters involved in calculating are defined as Eq. (2):

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$$A_i = A_0 + H_A\left(\frac{X}{10}\right) + V_A\left(\frac{Y}{10}\right). \quad (2)$$

- Let the theoretical signal value for Blade A be denoted as A_i, which corresponds to the beam center located at position (X, Y).
- A_0: The calibrated signal value of Blade A when the beam center is located at the origin (0, 0).
- H_A: The average change in Blade A's signal per 10 μm horizontal displacement of the stage.
- V_A: The average change in Blade A's signal per 10 μm vertical displacement of the stage.
- X: The current measured horizontal position of the beam center (in μm)
- Y: The current measured vertical position of the beam center (in μm).

After obtaining the theoretical signal values for the four blades—denoted as A_i, B_i, C_i and D_i—each is individually compared to its corresponding measured signal value by computing the ratio of measured to theoretical value, multiplied by 100 %. This yields the similarity percentage for each blade, which quantifies how closely the current signal matches the calibrated reference. A similarity percentage closer to 100 % indicates that the blade's response under current operating conditions remains consistent with that observed during calibration.

However, this percentage can fluctuate due to variations in accelerator parameters, such as changes in insertion device (ID) gap or beam current. To simplify monitoring and facilitate rapid assessment, the four individual similarity percentages are further consolidated into a single metric. This is achieved by calculating the standard deviation among the four similarity percentages, which is then defined as the diagnostic parameter of the XBPM. This standard deviation is referred to as the STD value, with its minimum possible value being zero. A higher STD value reflects a greater deviation from the calibrated condition, whereas a lower value indicates stable and uniform blade behavior, thereby serving as a useful indicator of the system's calibration integrity.

RESULTS AND DISCUSSION

After completing the calibration of the frontend XBPM and applying the corresponding calibration parameters, the XBPM stage was translated by ±200 μm along the horizontal and vertical axes, respectively, with a step size of 5 μm. At each position, the intensities of the four blades were recorded, and the corresponding STD and Q values were subsequently calculated, as illustrated in Figs. 2 and 3. The horizontal axis represents the stage displacement, with Fig. 2 corresponding to the horizontal scan and Fig. 3 to the vertical scan. The left vertical axis shows the STD value, while the right vertical axis indicates the Q value.

As shown in Fig. 2, the STD value gradually increases with displacement from the origin, reaching a maximum of approximately 0.3 within the ±200 μm range. By combining calibration data from XBPM in other frontend stations, it is observed that the STD value remains below 0.5 within the effective linear region. Therefore, when the calculated STD value is less than 0.5, the position readout of the XBPM can be considered consistent with the effective linear region established during calibration, ensuring reliable accuracy. Conversely, when the STD value exceeds 0.5, the accuracy of the XBPM position measurement begins to gradually decrease. The Q value varies between 24 and 33 as a function of displacement, indicating that it changes with the photon beam position. This suggests that the Q value is less reliable for assessing whether the XBPM position readout remains accurate.

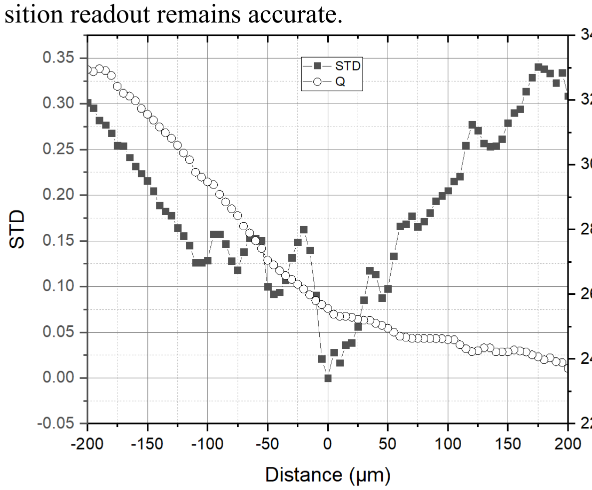

Figure 2: Variation of Q and STD values during horizontal translation of the XBPM stage within a range of ±200 μm.

Figure 3 presents the results of the vertical displacement scan, which exhibit a trend similar to that observed in the horizontal direction. However, the variation in the STD value is less regular, although it remains below 0.3 within the ±200 μm range. During vertical translation, the Q value increases from 3 to 50, exhibiting a variation significantly larger than that observed in the horizontal scan. This indicates that the Q value cannot be used as a fixed threshold to reliably assess the accuracy of the XBPM position readout.

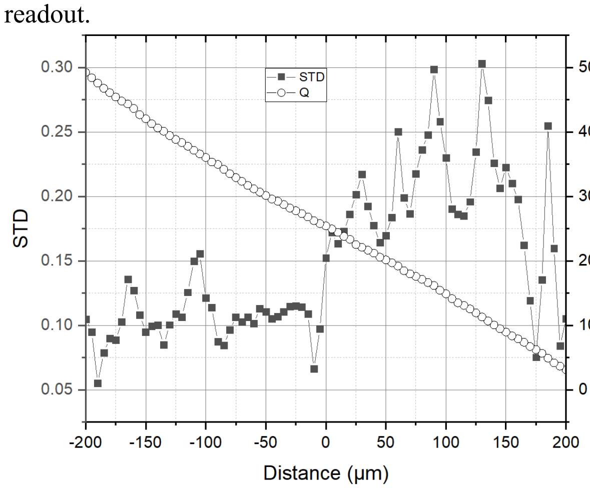

Figure 3: Variation of Q and STD values during vertical translation of the XBPM stage within a range of ±200 μm.

The accuracy of XBPM measurements may gradually deteriorate over time due to variations in photon beam conditions or the degradation of blade signal intensities.

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Table 1 summarizes the photon beam positions measured by XBPM1 at TPS FE09 at different time points, expressed as horizontal (X) and vertical (Y) displacements, together with the corresponding Q and STD values. The gap of the insertion device was identical across all datasets. Following the initial calibration in October 2021, both X and Y values were close to the origin and the STD value was 0.4. However, as time progressed, the X and Y positions gradually deviated from the origin, accompanied by a steady increase in STD, which reached 2.3 in July 2024. This result indicates a significant deterioration in the accuracy of XBPM measurements. Consequently, a recalibration was performed in October 2024, after which the X and Y values returned close to the origin and the STD value decreased to 0.4. By April 2025, although the X and Y positions had slightly shifted from the origin, the STD remained at 0.6, demonstrating that the XBPM continued to provide reliable position measurements.

In addition to serving as an indicator of XBPM accuracy, the STD value can also be used to determine whether recalibration is required. When the STD value becomes significantly greater than 1, recalibration should be performed. Although the Q value of the XBPM also varies with time and photon beam position, its fluctuations are comparatively irregular, making it less suitable for directly assessing the current measurement accuracy of the XBPM or the necessity of recalibration.

Table 1: Beam Positions Measured by FE09 XBPM1 and Associated Q and STD Variations, 2021-2025

Date	**X [µm]**	**Y [µm]**	**Q [µm]**	**STD**
2021-10	-17	-9	-253	0.4
2022-04	310	262	-210	1.2
2022-10	255	283	-212	1.4
2023-03	152	348	-216	1.5
2023-11	209	532	-200	1.4
2024-07	-130	467	-241	2.3
2024-10	-20	8	406	0.4
2025-04	-124	128	410	0.6

When the photon beam undergoes a substantial shift it moves outside the effective linear region. This simultaneously causes pronounced variations in both the STD and Q values, indicating that the XBPM measurement of the photon beam position is no longer reliable. Table 2 summarizes the variations in beam position, STD and Q values at TPS FE09 during beam shifts. In December 2024, the photon beam was located at -164 µm in the horizontal direction and 275 µm in the vertical direction, while the corresponding STD and Q values were 0.6 and 435, respectively. After a long shutdown, in February 2025 the photon beam position shifted significantly to -992 µm horizontally and -980 µm vertically. The STD value increased markedly to 68.3, while the Q value changed to 376. These results indicate a substantial displacement of the photon beam and demonstrate that the position data measured by the XBPM had lost its accuracy. After the electron beam orbit was adjusted, the beam position returned to -145 µm horizontally and 142 µm vertically, and the STD value decreased to the nominal level of 0.4.

In addition, when the signal from one of the XBPM blades becomes abnormal, the anomaly can be diagnosed through the pronounced variations in the STD and Q values. Under such conditions, the photon beam position data provided by the XBPM are no longer reliable, and maintenance is required.

Table 2: Beam Positions Measured by FE09 XBPM1 and Associated Q and STD Variations During Beam Shifts

Date	**X [µm]**	**Y [µm]**	**Q [µm]**	**STD**
2024-12	-164	275	435	0.6
2025-02	-992	-980	376	68.3
2025-03	-145	142	414	0.4

CONCLUSION

By using the diagnostic parameters of the XBPM, the reliability of the photon beam position data can be evaluated. Compared with the Q value, the STD value provides a more straightforward indicator for rapid assessment. After calibration, the STD value is typically less than 0.5, whereas an STD value substantially greater than 1 indicates a decline in measurement accuracy and the necessity for recalibration. Moreover, sudden large variations in both STD and Q values may signal either a significant displacement of the photon beam or an abnormal signal from one of the XBPM blades.

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