BEAM DIAGNOSTICS EXPERIMENTS: BPM CALIBRATION & SR INTERFEROMETER

G. Kim*, Div. of Advanced Nuclear Engineering (DANE), POSTECH, Pohang, Republic of Korea

Abstract

We present two complementary beam diagnostics methods for modern accelerators: (1) calibration of button Beam Position Monitors (BPMs) using a stredthed-wire test bench, and (2) non-invasive measurement of transverse beam size via a Synchrotron Radiation (SR) two-slit interferometer. Key emphasis is placed on the underlying theory, experimental setup, and understanding of experimental procedure. The BPM calibration establishes the linearity and sensitivity of the system, while the SR interferometer enables precise determination of the horizontal beam size, σ_x, through visibility analysis of interference fringes. These experiments provide insights into fundamental beam diagnostic techniques, improving our understanding of accelerator instrumentation principles and their practical implementation.

1. INTRODUCTION

Accurate beam characterization is essential for stable operation and optimization of modern accelerators. Beam diagnostics provide critical information about beam parameters, enabling optimal experimental conditions. Among these, Beam Position Monitors (BPMs) track beam centroid position for micron-scale orbit corrections, while beam size measurements relate directly to emittance.

BPM calibration converts relative position signals to absolute coordinates through calibration constants, preventing systematic errors that cause orbit distortions. We implemented a wire-based calibration method using a strected-wire carrying RF signals to simulate the beam. By moving the wire to known positions and recording normalized difference-over-sum signals, we determined sensitivity constants k_x and k_y with high precision.

For non-invasive beam size determination, we employed a Synchrotron Radiation (SR) interferometer exploiting spatial coherence properties. Using two-slit configurations (15 μm width, 18-40 μm separations), we monitored interference pattern visibility to determine the horizontal beam size (σ_x) with high precision, enabling continuous beam quality monitoring during operations.

2. THEORY

This section presents the theoretical foundations and methodological approaches for two beam diagnostic techniques: button BPM calibration and SR interferometry.

2-1 Beam Position Monitor calibration

Button-type BPMs operate on the principle that a charged particle beam induces electromagnetic signals on electrodes

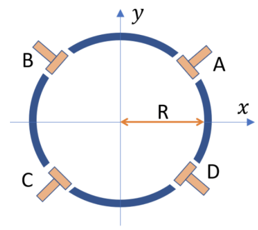

Figure 1: Cross-sectional view of the button BPM showing the four-electrode configuration [1]. The electrodes are symmetrically arranged around the beam pipe to detect the electromagnetic signals induced by the passing beam.

positioned around the beam pipe. In a typical four-electrode configuration (see Fig. 1), the relative signal strengths depend on the beam's proximity to each electrode. The horizontal (x) and vertical (y) positions are calculated using the difference-over-sum (Δ/Σ) method:

$$\begin{aligned} x &= k_x \frac{(A+D)-(B+C)}{A+B+C+D} \equiv k_x \frac{\Delta_x}{\Sigma_{\text{electrode}}}, \\ y &= k_y \frac{(A+B)-(C+D)}{A+B+C+D} \equiv k_y \frac{\Delta_y}{\Sigma_{\text{electrode}}}. \end{aligned} \tag{1}$$

where A, B, C, and D represent the signal amplitudes from the respective electrodes, and k_x, k_y are calibration constants with units of length per normalized signal. These constants convert the dimensionless normalized signals to actual beam positions in millimeters.

2-2. SR Young's Interferometer

SR interferometry exploits the wave nature of light to determine the transverse size of an electron beam. When SR passes through two narrow slits, the resulting diffraction pattern contains information about the spatial coherence of the source, which is directly related to its size (see Fig. 2).

For a two-slit (Young's) interferometer with slit width a and separation D, the intensity distribution at a distance L from the slits is given by:

$$I(x) = I_0 \cdot \left[\frac{\sin(u)}{u}\right] \cdot \left[1 + \frac{|2J_1(v)|}{|v|}\cos(\delta)\right] \tag{2}$$

where λ is the wavelength of light, x is the transverse position on the observation screen, and V is the fringe visibility [2]. By using multiple slit pairs (15x18 μm, 15x22 μm, 15x35 μm), we can verify the consistency of the extracted beam size. The method is useful as it provides a non-invasive measurement of the beam size with resolution up to the micrometer scale.

* Student number: 20242438
E-mail: geunwoo@postech.ac.kr

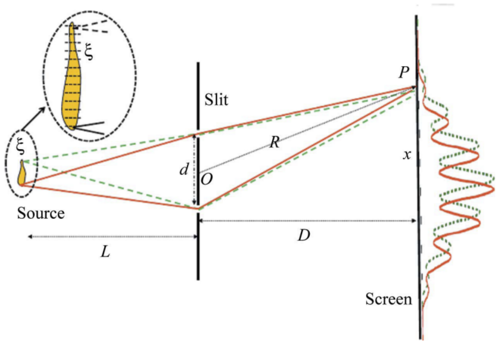

Figure 2: Schematic diagram of the SR Young's interferometer principle [2]. The synchrotron radiation from the electron beam passes through a double-slit mask, creating an interference pattern that is detected at distance L. The visibility of the interference fringes is related to the horizontal beam size σ_x.

3. EXPERIMENTAL SETUP

3-1. BPM Calibration Setup

The calibration of the button BPM was performed using a dedicated wire test bench (see Fig. 3). The setup consists of a precision-aligned mechanical system with the following key components:

- A strecthed-wire to imitate particle beam
- Two-axis servo-motor stages
- Signal generator (R&S SMB100A) providing 500 MHz RF signal
- Button BPM
- Motor controller system for precise positioning of the wire relative to the BPM
- Data acquisition system connected to the main PC for signal processing

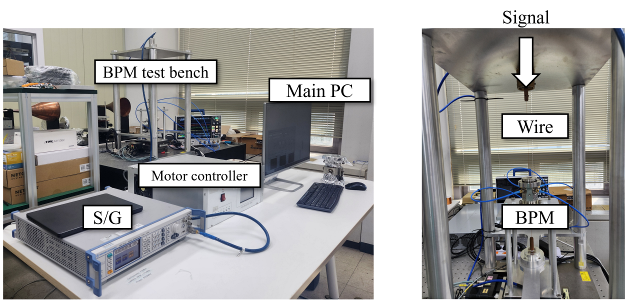

Figure 3: Schematic of BPM wire test bench. (Left) The complete experimental setup including the signal generator (S/G), motor controller, and main PC for data acquisition. (Right) A close-up view of the BPM with the wire passing through it and the signal path indicated.

During the calibration procedure, the wire was systematically displaced within a range of ± 5 mm in both horizontal and vertical directions, with incremental steps of 1 mm. At each position, the four electrode signals (A, B, C, D) were measured simultaneously. The signal generator was set to deliver a 500 MHz continuous wave within dynamic range of BPM electronics.

The calibration constants k_x and k_y were determined by fitting the normalized Δ/Σ signals versus the known wire positions via polynomial fitting method. The linearity of the BPM response was evaluated throughout the measurement range. While better linearity was observed near the central region, slight non-linear behavior was indicated as the wire approached the extremes of the displacement range (± 5 mm).

3-2. Beamline Setup for SR Interferometer

Fig. 4 illustrates the optical layout of SR interferometor test setup, which follows the principles of Young's double-slit interference.

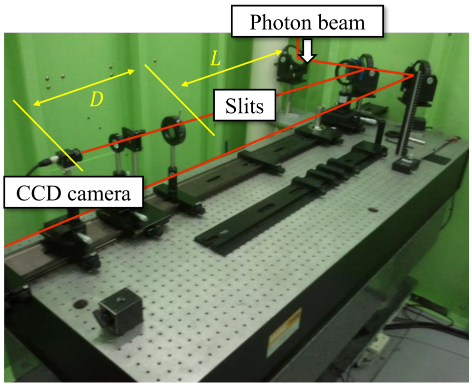

Figure 4: Optical layout of the SR interferometer beamline at PLS-II [2]. The double-slit masks are mounted between the photon beam source and the CCD camera. The complete system is installed on a vibration-isolated optical table to ensure measurement stability during beam size determination.

The optical path should be shielded to minimize ambient light contamination, and the entire system was mounted on vibration-isolated supports to ensure stability during measurements. The red lines in Fig. 4 indicate the trajectory of the SR light from the photon beam through the optical elements to the detector.

By measuring the visibility for different slit separations D (see Figs. 2 and 4), we can verify the consistency of the extracted beam size and identify systematic errors in the measurement system such as ambient light. This approach provides a reliable method for monitoring the beam size during regular accelerator operations without perturbing the electron beam.

4. RESULTS

4-1. Calibration results for button BPM

The calibration of the button BPM was performed by measuring the electrode signals as a function of wire position. Linear regression of the normalized difference-over-sum signals versus the actual wire offset yield the calibration constants. (see Fig. 5).

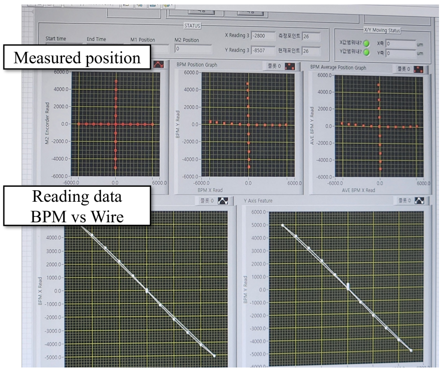

Figure 5: BPM calibration measurement interface showing real-time position data. The upper panels display the calibrated positions in both X and Y coordinates, while the lower panels show the linear relationship between BPM readings and actual wire positions.

The on-axis measurements were extended to cover a range of ± 5 mm in both horizontal and vertical planes. The results demonstrate linearity throughout this range, with only minimal deviations observed near the extremes.

This calibration procedure ensures that the BPM system can accurately determine the beam position within the central region of the beam pipe, where most operational beam trajectories are maintained.

4-2. Beam size measurements via SR Interferometry

Fig. 6 displays the key results from our SR interferometer measurements, with panels showing distinctive interference patterns. Panel (a) reveals the 15x18 mm configuration results. The sharp contrast between maxima and minima indicates suitable spatial coherence at this separation.

Various slit configurations were employed to systematically observe changes in diffraction patterns. Panel (a) shows results obtained using the 15x18 μm configuration, while panel (b) presents measurements from the 15x22 μm arrangement, and panel (c) displays the diffraction pattern from the 15x35 μm slit configuration.

Panel (d) presents a control experiment specifically designed to simulate the effects of ambient light interference in measurement conditions. For this purpose, a smartphone flash was deliberately used to illuminate the setup without slits, creating a reference image that demonstrates how external light sources can affect measurement quality. This control condition helps distinguish between genuine diffraction patterns in panels (a-c) and potential artifacts caused by environmental light contamination.

SUMMARY

In this work, we explored two essential beam diagnostics methods for accelerator operation. For the BPM calibration, we implemented a wire-based test bench methodology to establish the relationship between electrode signals and beam position. In parallel, we investigated the SR interferometer technique based on Young's double-slit interference principle, which provides non-invasive beam size measurements through analysis of spatial coherence properties. By examining the visibility of interference patterns produced by various slit configurations, we determined the horizontal beam size without disturbing the electron beam. Both diagnostic methods demonstrated performance and complementary capabilities, offering valuable tools for accelerator physics research and facility operation.

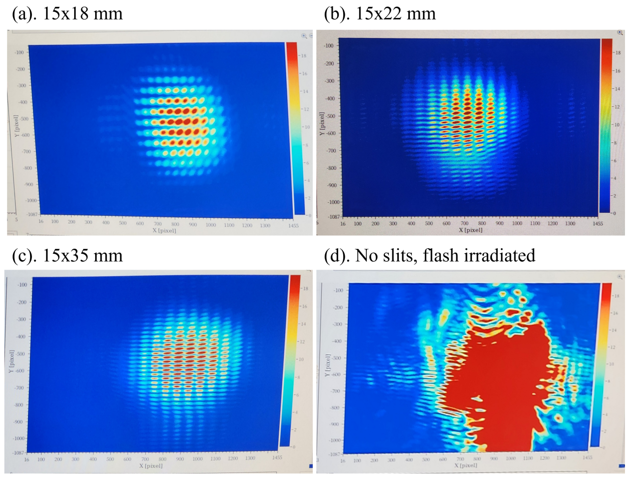

Figure 6: Interference patterns obtained from the SR interferometer under different configurations: (a) 15x18 mm slit configuration, (b) 15x22 mm slit, (c) 15x35 mm slit, and (d) No slits, flash irradiated. The 2D intensity distributions are shown with their corresponding horizontal projections below each panel.

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REFERENCES

[1] S, Eugene, "Propagation speed of Coulomb force. What do experiments say?", Preprint, 2021.

[2] C. Kim, "Streak Camera & SR Interferometer", Lecture Notes, NUCE719P-01, Pohang, Republic of Korea, Apr., 2025.