# BEAM DYIAGNOSTICS USING INTERFEROMETER AND BEAM POSITION MONITOR*

Y. Park†, POSTECH, Pohang, Korea

*Abstract*

This study investigates beam diagnostics using an optical interferometer and a beam position monitor (BPM). The interferometric measurement, conducted at the 1B beamline of PLS-II, determines the transverse beam size by analyzing interference fringes formed by the spatial coherence of synchrotron radiation. The BPM test was performed using a wire test stand to evaluate its response to simulated beam signals. This study explains the basic principles of both diagnostic techniques and presents experimental results from each setup. The combined approach demonstrates the effectiveness of using complementary optical and electronic methods for accurate beam characterization.

## INTRODUCTION

Accurate beam diagnostics are essential for understanding and optimizing accelerator performance. Key parameters such as beam size, position, and orbit stability must be measured with high precision using both optical and electronic techniques.

In this study, we performed two separate experiments to investigate these diagnostic methods. First, we used an optical interferometer to measure the transverse beam size. This technique analyzes interference fringes generated by the spatial coherence of synchrotron radiation emitted from a bending magnet. It allows non-invasive, high-resolution measurement of beam profiles, especially effective in the sub-millimeter range.

Second, we tested a BPM using a wire test stand. By sending current through a thin wire placed along the BPM axis, we simulated the signal induced by a charged particle beam. This setup allowed us to evaluate the BPM's response and understand its signal processing behavior under controlled conditions.

Through these experiments, we aim to understand the fundamental principles behind optical and electronic beam diagnostics and to gain hands-on experience with both systems. The interferometer experiment was conducted at the 1B beamline of PLS-II, while the BPM test was carried out separately using a laboratory wire stand.

In the following sections, we begin by describing the fundamental principles of the interferometer and the BPM, which form the basis of our experimental approach.

* WORK SUPPORTED BY POHANG ACCELERATOR LABORATORY(PAL).

† pym102048@postech.ac.kr

## BASIC THEORY

Both the interferometer and the BPM are used to measure the transverse size of the beam, but they rely on fundamentally different principles.

### *Interferometer*

The optical interferometer determines the transverse size of an electron beam by analyzing the interference pattern of synchrotron radiation emitted from a bending magnet [1]. Synchrotron radiation possesses partial spatial coherence due to the small source size of the electron beam. When this radiation passes through a double-slit system, the degree of coherence is reflected in the visibility of the resulting interference fringes.

In the far-field approximation, the intensity distribution on the observation screen is given by:

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

where the variabls are defined as

$$u = \frac{kax}{R},\ v = \frac{k\xi d}{L},\ \delta = \frac{kdx}{R}. \tag{2}$$

In this expression, $k = \frac{2\pi}{\lambda}$ is the wave number corresponding to the radiation wavelength $\lambda$, $a$ is the aperture size of slit, $x$ is the observation position on the screen, and $R$ is the distance from the slits to the observation point. The variable $d$ denotes the distance between the two slit, $\xi$ is the transverse source size, and $L$ is the distance from the radiation source to the slits. All of these parameters are illustrated in Fig. 1.

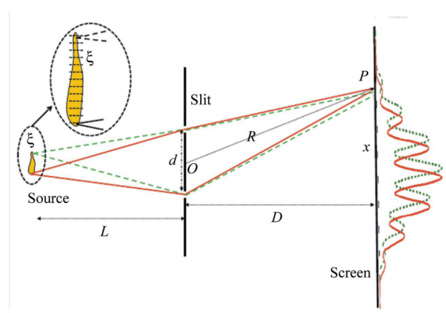


Figure 1: Schematic diagram of the double-slit interferometer setup.

In our setup, a two-dimensional interferometer is used to analyze the transverse beam size in both the horizontal and vertical directions. To enable this, a pair of orthogonal slit grids was installed to independently select the horizontal and vertical components of the radiation, forming a 2D interferometric system. A CCD camera placed at the observation screen captures the full two-dimensional interference pattern, allowing simultaneous measurement of the beam size in both directions.

By fitting the observed interference fringes to the theoretical model, the transverse beam size $\xi_x$ (or $\xi_y$) can be quantitatively extracted. This fitting process typically involves adjusting the beam size parameter in the model until the calculated fringe contrast matches the experimental data.

When using an interferometer, the visibility of the interference fringes is a crucial parameter. It reflects the degree of spatial coherence of the synchrotron radiation, and serves as a direct indicator of the transverse beam size. Higher visibility corresponds to a more coherent source and therefore a smaller beam size, while lower visibility indicates a larger, less coherent source.

The visibility is affected by several factors in the interferometer setup. Increasing the slit separation results in more closely spaced fringes, but also tends to reduce visibility when the source size is large. The slit aperture size influences the diffraction envelope and total light throughput, indirectly affecting the signal-to-noise ratio in visibility measurements. In addition, the distance from the source to the slits, as well as the observation geometry, contribute to the coherence length and thus to the resulting fringe contrast. Accurate fitting of the fringe pattern therefore requires careful consideration of these geometric and optical parameters.

### *BPM*

A BPM is a non-destructive diagnostic device used to measure the transverse position of the beam as it passes through the accelerator [2]. It typically consists of a set of electrodes (buttons or striplines) mounted symmetrically around the beam pipe. When the beam passes through, it induces image currents on these electrodes, and the relative signal strength is used to infer the beam's position.

A conceptual diagram of the BPM structure is shown in Fig. 2.

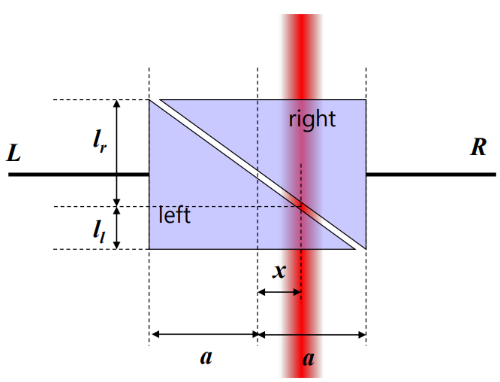


Figure 2: Schematic illustration of a BPM. When the beam passes through, image currents $I_r$ and $I_l$ are induced on the right and left electrodes. As the beam moves off-center, a difference between $I_r$ and $I_l$ arises, from which the beam position $x$ can be determined.

To evaluate the BPM's response without using an actual beam, we used a wire test stand [3]. In this setup, a thin conductive wire is stretched along the central axis of the BPM chamber, and a signal generator drives a current through the wire to simulate the electromagnetic field produced by a relativistic beam.

By moving the wire transversely in small steps using a motorized stage, we scanned its position across the BPM and recorded the signal response from each electrode. This allows us to characterize the linearity, sensitivity, and position resolution of the BPM under controlled conditions. The results from this wire-based calibration can later be used to interpret real beam signals with higher confidence.

## EXPERIMENTAL STUDY OF BEAM DIAGNOSTICS

### *Interferometer Measurement at PLS-II 1B Beamline*

The interferometer experiment was carried out at the 1B beamline of PLS-II. The experimental setup is shown in Fig. 3. In this setup, the horizontal slit separation was fixed at 15 mm, while the vertical slit separation was varied from 15 mm to 40 mm to investigate the effect on the interference pattern.

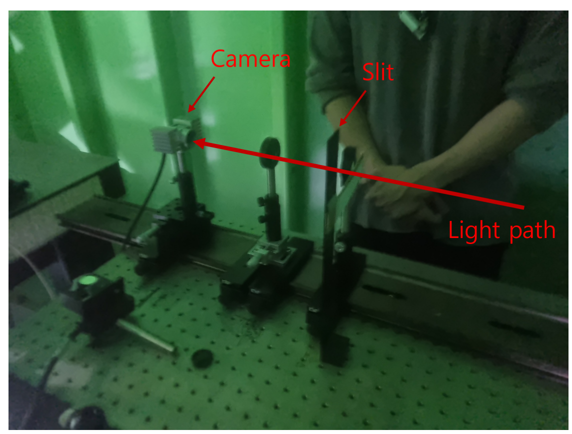


Figure 3: Experimental setup of the interferometer at the PLS-II 1B beamline. The horizontal slit separation is fixed at 15 mm, while the vertical slit separation is adjustable. The resulting interference pattern is recorded on a 2D CCD placed downstream.

The measured interference patterns are presented in Fig. 4. As the vertical slit separation increases, the fringe spacing in the vertical direction becomes noticeably finer. At the same time, the difference between $I_{\max}$ and $I_{\min}$ gradually decreases, resulting in reduced fringe visibility. This observation is consistent with theoretical expectations, where increased slit separation leads to decreased spatial coherence and thus lower fringe contrast.

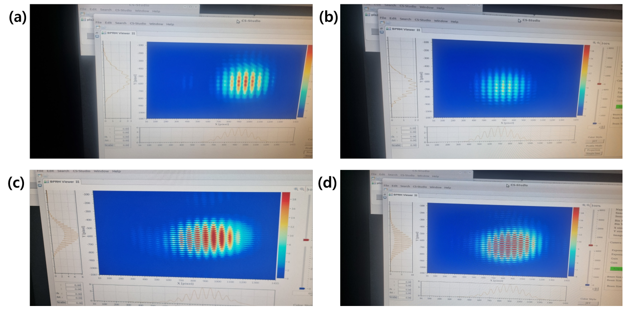


Figure 4: Measured 2D interference patterns for various vertical slit separations: (a) 15 mm, (b) 22 mm, (c) 35 mm, and (d) 40 mm. As the vertical slit distance increases, the fringe spacing in the vertical direction becomes finer, while the fringe visibility decreases due to reduced spatial coherence.

### *BPM measurement*

To evaluate the BPM response under controlled conditions, we used a wire test stand in the laboratory. A thin wire was stretched along the center axis of the BPM chamber, and connected to a signal generator to simulate beam-induced image currents. A motorized stage was used to move the wire transversely, and the position was controlled via software.

Figure 5 shows the experimental setup, including the wire test stand and the motor control interface. The wire was scanned in both horizontal and vertical directions at intervals of 2500 μm, covering a total of nine positions in a $3 \times 3$ grid. At each position, the signals from the BPM electrodes were recorded.

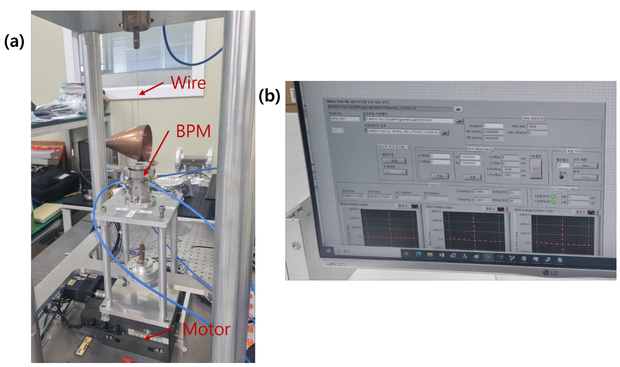


Figure 5: Wire test stand used for BPM calibration. (a) A thin wire is aligned along the BPM axis and excited with a signal generator. (b) The motorized stage used to control the wire position is operated via the software interface shown.

The resulting correlation between the wire position and the BPM signal is shown in Fig. 6. Within this $3 \times 3$ scan region, the BPM response exhibited good linearity with respect to the wire position. This confirms that, under small transverse displacements, the BPM provides reliable position information with a linear signal-to-position relationship.

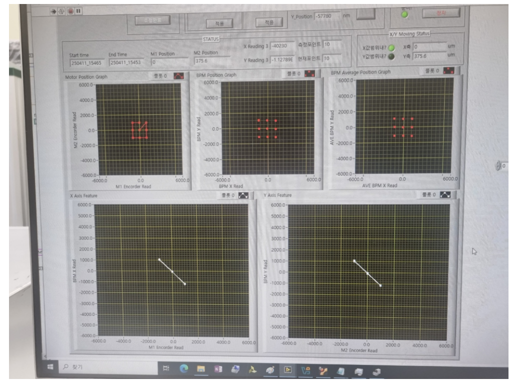

Figure 6: Measured BPM signals as a function of wire position over a $3 \times 3$ scan grid. The wire was moved in steps of 2500 μm in both horizontal and vertical directions.

## CONCLUSION

In this study, we investigated two complementary beam diagnostic methods: an optical interferometer and a BPM. Using a two-dimensional interferometer installed at the PLS-II 1B beamline, we measured the transverse beam size by analyzing interference fringes. The visibility of the fringes was observed to decrease with increasing vertical slit separation, consistent with theoretical expectations based on spatial coherence.

In the BPM measurement, a wire test stand was used to simulate beam-induced signals. By scanning the wire over a $3 \times 3$ grid with 2500 μm spacing, we confirmed a clear correlation between wire position and BPM output. The response within the scanned region showed good linearity, demonstrating the reliability of the BPM in measuring transverse beam displacement.

These results confirm that both interferometric and BPM-based techniques provide consistent and complementary information for characterizing the transverse properties of the beam.

## REFERENCES

[1] T. Mitsuhashi, "Beam profile and size measurement by SR interferometers," in *Joint US-CERN-Japan-Russia School on Particle Accelerators: Beam Measurement*, 1998, pp. 399–427.

[2] P. Forck, "Beam Instrumentation and Diagnostics," in *CAS - CERN Accelerator School 2019: Introduction to Accelerator Physics*, 9 2020.

[3] J. A. Fitzgerald, J. Crisp, E. McCrory, and G. Vogel, "Bpm testing, analysis, and correction," *AIP Conference Proceedings*, vol. 451, no. 1, 12 1998. [Online]. Available: https://www.osti.gov/biblio/21202386